ESRI vs BREWER: An Evaluation of Map Use with Alternative Colour Schemes amongst the General Public

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ABSTRACT: This small study evaluates the effectiveness of selected sets of colour schemes used in ESRI's ArcMap and ColorBrewer in communicating information on choropleth maps. Subjects conducted map reading tasks using online questionnaires and their performance was captured. The results did not show significant differences in performance associated with colour scheme - subjects were highly successful in direct acquisition tasks irrespective of the set(s) of scheme used. However, performances were consistently poor for 'distribution' tasks. The results suggest limited spatial capabilities in the sample and highlight the need to test for general spatial ability in such experiments.

KEYWORDS: colour perception, symbology, thematic map, choropleth map, graphicacy

1. Introduction

Colour is an effective way of showing relationships between symbols on a map if used appropriately: "*When colour is used 'appropriately' on the map, the organization of the perceptual dimensions of colours should correspond to the logical organization on the mapped data*" (Brewer, 1994). It allows values, spatial patterns and correlations within data to be clearly visualized. And yet poor use of colour can be destructive, not only will it obscure the map's message, but the map user might be misled or spend a lot of time looking back and forth between the visual variables and the map legend, trying to *make sense* of the display - leaving them unable to perform the intended task effectively (Monmonier, 1996; Mersey, 1990). Monmonier (1996) describes colour as "*a cartographic quagmire*". In ColorBrewer, Harrower and Brewer (2003) propose a series of schemes, but these are not used as defaults in commercial Geographic Information Systems (GIS).

In this study we examine how various sets of colour schemes available in ESRI's ArcMap and through ColorBrewer are used in choropleth maps. To determine which set of schemes are used mostly successfully and whether these findings are consistent, an experiment was designed whereby subjects participated in a number of visual tasks - to locate, compare and consider a distribution in a choropleth display (Mersey, 1990; Brewer & Olson, 1997).

1.1 Map Symbolization and Colour in Cartography

According to Mersey (1990), Robinson's work forms the foundation of colour used in cartography (Robinson, 1952). She quotes Keates (1962), Wood (1968), Makowaski (1967) and Kauffman (1977) - all of whom built upon Robinson's work in representing their own summaries of the perceptual aspects of colour and their implications in cartography. These studies are based on the assumption of a single (communication model) map use. The framework of studying map symbols is based on the behavioural paradigm, where symbols are tested as low-level perceptual visual stimuli. In other words map symbols were studied in isolation without taking into account context – such as the viewer's abilities and limitations. Perhaps the most accessible reference addressing today's user needs and colour use in cartography is '*Designing Better Maps: A Guide for GIS users*' (Brewer 2005). Work preceding this (e.g. Gibson, 1987; Eastman 1986, 1987; Rader, 1989; Mersey, 1990) "*focused on developing syntatic logic for colour attribute*" (MacEachren, 1995) but Brewer's work stands out for several reasons. Firstly she established that carefully selected hues can be used to map ordinal data, - breaking the cartographic norm where hue is generally limited to categorical data. Secondly she designed colour schemes that address issues in visualization: for example diverging schemes that emphasize variation from a particular value. Thirdly, her schemes are additive, providing scope for bi- and tri-variate maps. To summarise, cartography has a long tradition and well established empirically informed colour conventions to depict data (types) from which other sciences may learn (Brewer, 1994). Yet commercial GIS do not use these conventions to address the colour "*quagmire*".

2. Methods

2.1 Colour Schemes Selected

Our colour selection is based on broad guidelines, with hue being used predominantly to map categorical information, and saturation/lightness to map ordinal data (see Robinson, 1952; Mersey, 1990; Brewer, 1994). ColorBrewer has specific colour use guidelines, whereas ESRI's ArcMap colour ramp has no specific usage guidelines. Each set of colours schemes selected spanned three of Brewer's data types and used indicative schemes from ArcMap to reflect potential choices made by a novice user. We include the popular but controversial traffic light colour system - associating red with high and green with low numbers (see ES3 in Figure 1.)

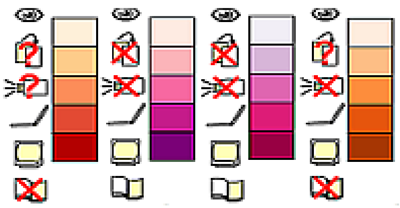
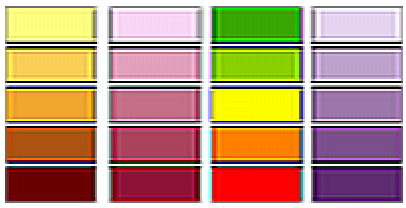
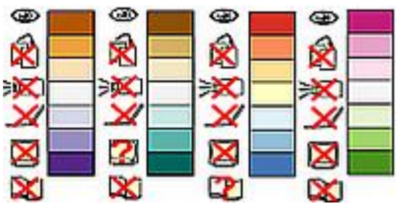
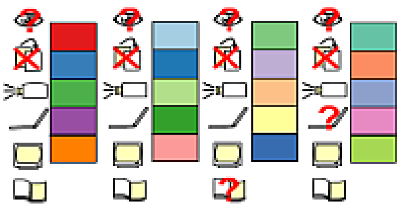
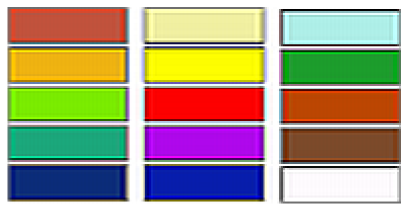
Scheme	ColorBrewer	ESRI
		
Sequential	OrRd RdPu PuRd YlOrRd	ES1 ES2 ES3 ES4
		
Diverging	PuOr BrBG RYB PiYG	EDRYG EDFD EDGB EDRYB
		
Qualitative	Set1 Paired Accent Set2	QE4 QE3 QE1

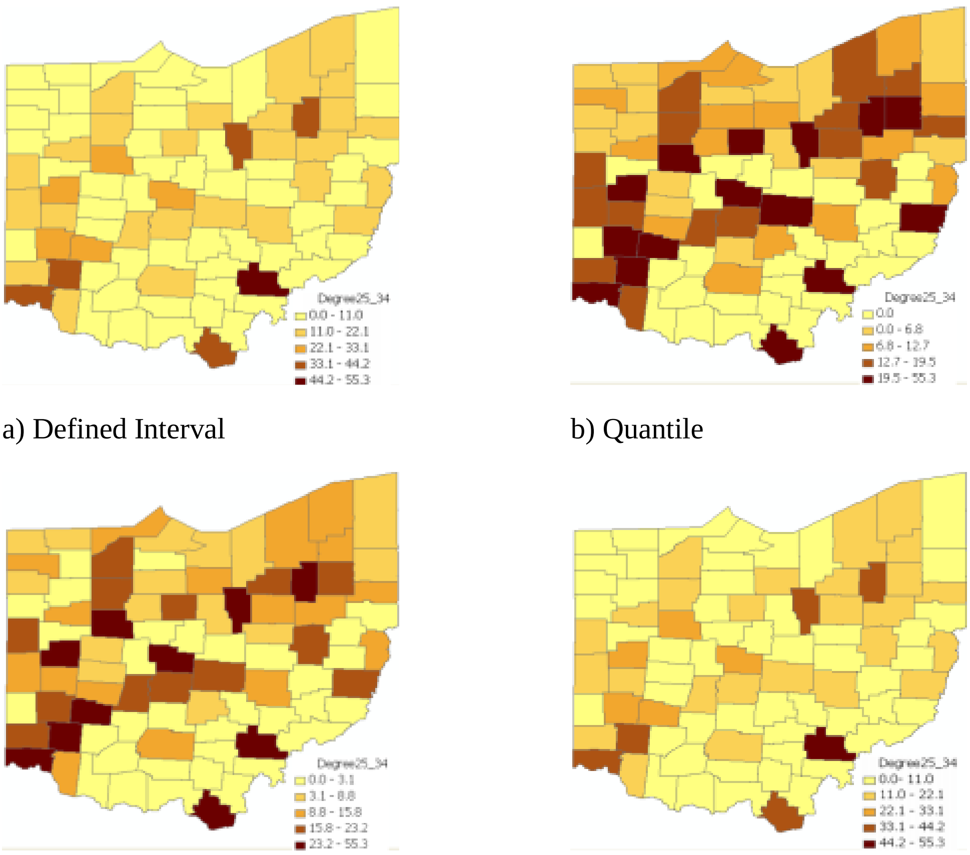
Figure 1. Selected sets of colour schemes from ESRI and BREWER. ColorBrewer colours are named i.e YlOrRd =Yellow Orange Range. ESRI's colours have no formal label thus codes were generated for example ES1= ESRI Sequential Scheme 1, EDRYG =ESRI Diverging Red Yellow Green and QE4= ESRI Qualitative 4.

Four sequential, four diverging and four qualitative schemes were selected for ColorBrewer. Of the forty colour schemes in the ESRI set we select four sequential, and four diverging colour schemes but only three suitable qualitative schemes were available. The ColourBrewer selection was based on recommendations by Harrower and Brewer (2003) - for example suitability for display device and to minimise any potential problems with vision impairment. Not all selected sets of color schemes fulfilled both conditions with frequent compromises - mainly between CRT and LCD display. Combinations of hue and lightness were selected to map ordinal data as advised by ColorBrewer.

2.2 Map Design

When designing the test maps several factors were considered. First, the base map had to have more or less similar sized areas as "*Physically large areas tend to dominate the display. Effectively the visual variable 'size' gives visual predominance to the larger units at the expense of the smaller units*..." (Dykes, 1994; Longley et al., 2005). The counties of Ohio State were selected as our base units.

Secondly, classification: a single data set can produce several different maps according to classification methods used. We used 5 classes along with the Jenks classification method (Jenks, 1977 - cited by Brewer and Pickle, 2002), which MacEachren (1994) recommends due to the minimisation of within-class error.



a) Defined Interval

b) Quantile

c) Natural Breaks Jenks

d) Equal Interval

Figure 2. Example of classification methods. Note with this dataset (*Degree qualification in 25-34yrs age group*), Defined Interval and Equal Interval produced visually similar maps.

2.3 Tasks

An application was developed to randomly generate three locations per map for testing a range of map use a, b and c. Results in which individual locations were clearly within a polygon and multiple locations were in different polygons were accepted as shown in Figure 3. This process was iterated until 60 satisfactory maps were generated (30 ESRI and 30 BREWER).

To determine the effectiveness of each of the colour schemes map reading tasks of varying complexity were designed according to an established typology (Keller and Keller, 1992 - cited in Koua et al., 2006). Subjects were asked to perform tasks of type:

- *locate* – by identifying the population of location (a);
- *compare* – by comparing the population between counties (a) & (b);
- *distribution* **-** by considering the variation in population between counties (a), (b) and (c).

Figure 3. Maps using BREWER's BrGR diverging scheme with 1, 2 or 3 varied locations.

2.4 Participants

Our target population was the general public. The sampling strategy involved email, word of mouth and distributing flyers with a link to the experiment questionnaire at different locations. To engage a wider audience that is "*representative of the larger population which is free of bias*" (Kitchin & Tate,

2000) friends and colleagues posted the questionnaire link on social networking sites. Involving many people in the recruitment process increases the potential of a large and unbiased sample.

2.5 Data Collection

Survey monkey was used for the experiment. As an online tool it is accessible to a wide audience but this advantage comes with a drawback – a lack of condition control. The ColorBrewer selection aimed to address this issue for one of the scheme sets. To keep the questionnaire at a reasonable length, maintain motivation and avoid high dropout rates during the experiments we used a between subjects design in terms of scheme type. The 30 maps for each scheme type were divided into 2 resulting in four online questionnaires to which participants were randomly allocated on clicking the advertised link. Each questionnaire included 15 map displays, 6 sequential, 6 diverging, and 3 qualitative schemes (see Table 1). Multiple choice questions were used to capture quantitative data. Details on subjects' map reading skills, age, gender and any vision impairment were collected. The first three background details are useful in determining characteristics of the sample while the latter was used to exclude subjects with acknowledged vision impairment from the analysis. To keep the experiments consistent (between-subject) the colour schemes were systematically varied, while the maps size, distribution and locations (a, b and c) were held constant.

Table 1. One of the 4 Questionnaires with data themes, tasks (L=Locate, C=Compare & D= distribution) and Colour Schemes

	Data Sets	**Task**	**BREWER**	**ESRI**
Maps 1	*Percentage of population with college degree*	L,D	PuRd	ES4
2	*Percentage of Single Mothers*	L,D	OrRd	ES1
3	*Percentage of Single Mothers*	L,C	PuRd	ES3
4	*Percentage of population over 18 years*	L,C,D	PuRd	ES4
5	*Percentage of population with college degree*	C,D,D	YlOrRd	ES3
6	*Percentage of population over 18 years*	C,D,D	RdPu	ES2
7	*Percentage of population with college degree*	L,D	PuOr	EDRYB
8	*Percentage of population with college degree*	L,D	RYB	EDRYG
9	*The average house Prices*	L,C	BrBG	EDFD
10	*The average house Prices*	L,C	PiYG	EDFD
11	*Population change 2000-2007*	L,C,D	BrBG	EDGB
12	*Population change 2000-2007*	L,D	PiYG	EDRYG
13	*Predominant Occupation*	L,D	Set1	EQ1
14	*Predominant Race*	L,D,D	Set1	EQ2
15	*Predominant Occupation*	L,D,D	Paired	EQ3

3. Results and Findings

A total of 113 subjects attempted the questionnaire. Of these, 36 returned incorrect answers to colour vision questions. This is a large proportion of users to have colour vision impairments and may suggest some problems associated with using online questionnaires that should be explored. These participants were excluded from any analysis along with 19 incomplete responses. The analysis is thus based on 58 completed questionnaires. Most subjects claimed to have '*Good*' or '*Excellent*' map reading skills (Figure 4).

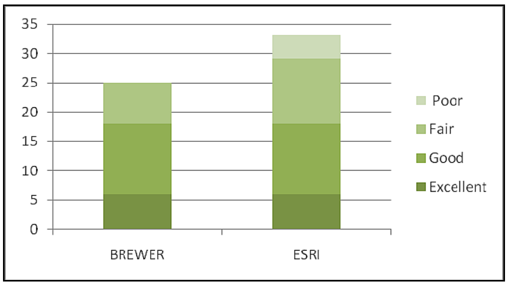


Figure 4. Participants' map reading skills by scheme condition

A summary of responses (accuracy) by scheme set is shown in Figure 5. Success rates were relatively consistent between conditions: around 90% for locating tasks, around 70% for comparing tasks and less than 60% for distribution tasks. A Chi Square test was used to determine the likeihood that any difference in performance by participants between colour schemes was due to chance. The test revealed a number of observations significant at the 0.05 level. Six related to sequential (OrRd vs. ES2, 2* PuRd vs. ES3, 2*YlOrRd vs. ES3, RdPu vs. ES2), four to diverging (BrBG vs. EDFD, PiYG vs. EDFD, BrBG vs. EDGB, PiYG vs. EDRYG) and two to qualitative schemes (Set1 vs. EQ2, Paired vs. EQ3). Of the twelve significant values, four were associated with ES3 – the controversial green-yellow-red scheme (see Figure 1 and Figure 6 c). This provides some evidence that the scheme may be suboptimal – particularly for more complex tasks as these scores were mainly obtained on distribution tasks (Figure 5) whilst Mersey (1990) shows that hue-based schemes work well for simpler tasks as relating class to legend.

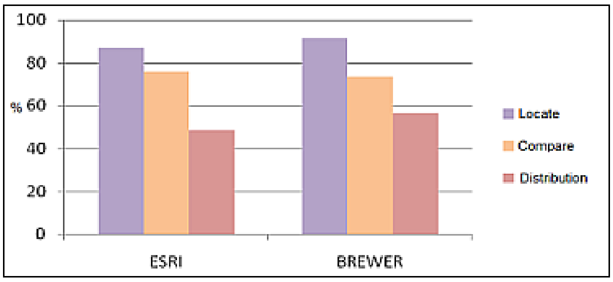
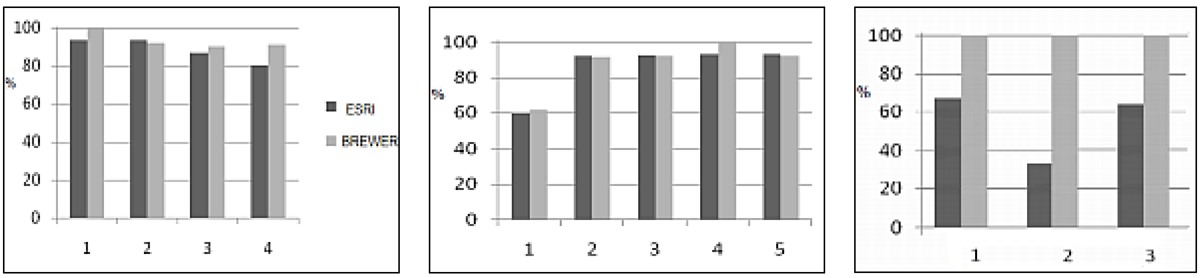


Figure 5. Accuracy: Percentages of correct task responses by scheme set and task type.

Locating Tasks

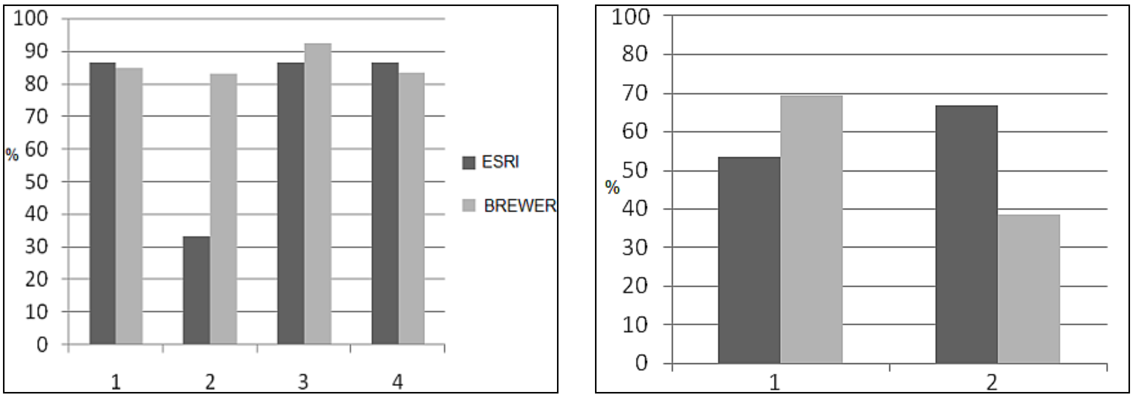


x-axis shows pairs of comparable maps using identical datasets with different schemes (Table 1)

a) Sequential b) Diverging c) Qualitative

Figure 6. Performance levels for both ESRI and BREWER were over 80% for **locating** tasks in the cases of both diverging and sequential schemes with no significant differences between comparable maps. The qualitative schemes resulted in some significant differences with inferior performance achieved through the ESRI schemes.

Comparison Tasks

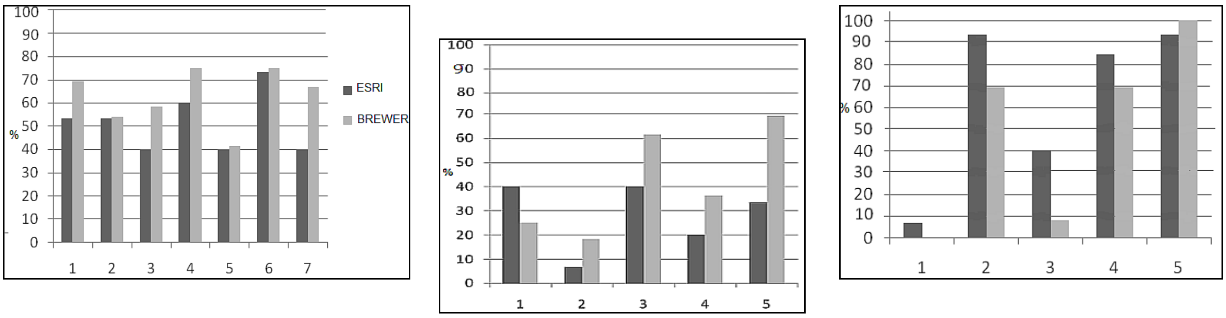


x-axis shows pairs of comparable maps using identical datasets with different schemes (Table 1)

a) Sequential b) Diverging

Figure 7. Responses to **comparison** tasks in the sequential schemes indicate over 80% effective performance for both ESRI and BREWER apart from 34% for an ESRI sequential scheme colour. For diverging schemes no consistent trend is apparent with BREWER performing better in one task and ESRI better in another.

Distribution Tasks



x-axis shows pairs of comparable maps using identical datasets with different schemes (Table 1)

a) Sequential b) Diverging c) Qualitative

Figure 8. Accurate responses to **distribution** tasks indicate that users of BREWER schemes were more successful with diverging and sequential schemes but ESRI performed better in the case of qualitative schemes.

3.4 Differences among the sub groups

A minimun representative sample of 20-30 subjects (Kitchin & Tate, 2000) is required for between or within subjects analysis. The sample in all subgroups (age, gender and map reading skills) was too small to draw any conclusions emphasizing the need for further experiments in which larger samples are acquired to study such differences.

4. Conclusion

In contrast to Mersey's (1990) findings, where hue based schemes performed well for a specific low-level map use task and value base schemes performed well with distribution tasks, here performance was predominantly related to the level of task rather than to the sets of colour symbology. Subjects were highly successful in direct acquisition tasks; however performance was less good for distribution tasks. Where results contrast in this way further research under a controlled environment with a more representative sample of the general public is suggested to overcome some of the limitations of the approach reported here and explore possible differences between group, set and even potentially geography.

The results presented here do draw attention to a concern over the lack of cartographic capability (Cassettari, 2007) among the general public as suggested by low performance in more complex spatial tasks. This seems more significant here that the colour scheme issues studied by Mersey, Brewer and others where participants with spatial ability were tested rather than "*the general public*". There is a need to explore this effect more fully and perhaps to improve spatial capabilities and graphicacy amongst a wider set of map users. The general public may then be able to use and interpret maps for higher-level tasks than did our sample. Informed colour choices when creating and using thematic maps that address the "*cartographic quagmire*" may be a secondary issue.

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6. Biography

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