

Multimodal Trivariate Thematic Maps with Auditory and Haptic Display

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The purpose of this study is to explore the possibility of multimodal trivariate thematic maps by utilizing auditory and haptic displays. With two different modes of display (color only displays and multimodal displays with color, audio, and haptic), the completion time of tasks and the recall (retention) rate were measured in two separate experiments. In terms of the completion time, with minimal learning experience, participants could accomplish the tasks at the same level of speed in both modes. For the recall rate, multimodal displays have much higher recall rates. It is speculated that the natural quantitative hierarchies in auditory and haptic displays provide an advantage in the use of multimodal displays. These findings confirmed the possibility of using auditory and haptic displays in visually dominant geographic information systems (GIS) for multi-variate thematic maps.

Introduction

It is believed that multimedia enhances GIS applications, and among the efforts of multimedia in GIS, sound predominates. Krygier (1994) suggested the abstract sound variables that can be implemented in GIS: location, loudness, pitch, register, timbre, duration, rate of change, order, and attack/decay. Weber (1994) examined the possibility of using musical harmony to represent spatial distance in a map. He used dyads, which were played by two tones at the same time such as "C-D" or "C-F." However, performance

was inconsistent, so further investigation is needed. Jacobson (1998) reported a study with a sound-map, in which audio feedback consisted of verbal instructions, verbal landmarks, and auditory icons while the user moved the mouse across a computer screen. He tested with ten visually impaired and blind people; the results showed that the sound map users performed better, obtaining more information more readily, than a blind control group who explored the same scenes using conventional hard-copy tactile maps. Gluck and his colleagues (Gluck *et al.* 1999; Gluck, 2000) are trying to implement various sound variables in their seriation software into which data matrix and maps are integrated.

Meanwhile, the term "haptics" refers to sensing and manipulation through the sense of touch. Haptics is the study of coupling the human sense of touch with a computer-generated world. Force feedback is the area of haptics that deals with devices that interact with the muscles and tendons to give the human sensation of a force being applied. Researchers have started to develop various haptic input/output devices and software, such as MIT's frequently-used Phantom haptic interface (Salisbury and Srinivasan, 1997). Along with auditory displays, haptic research in GIS is emerging. For example, Jeong (2000) tested his ordering tasks in auditory and haptic display with 23 subjects and found that subjects had better performance with haptic display than with auditory-only display and with auditory/haptic combined displays.

Research Question

Conventional bivariate choropleth (thematic) maps have been represented by two different color schemes, which are arbitrarily assigned (one color scheme for each variable) and generate random color combinations for overlapping sections. Those maps are extremely difficult to understand because the users need to constantly refer to the arbitrary legend. However, if one dimension is represented by a color scheme and the other dimension is rendered by haptic or auditory display, it may be easier to understand the maps because haptic and auditory displays have more intuitive hierarchical orders than colors. In addition, with multimodal and multi-property representations in auditory and haptic displays, a solution is provided for multi-variate maps beyond two variables, in other words, we can display three, four, or five different variables simultaneously in a single map. Jeong and Gluck (2003) confirmed this potential advantage with 9-state U.S. maps.

The purpose of this study is to expand the previous findings into multimodal trivariate thematic maps by utilizing auditory and haptic

displays, which can be rendered easily by the current technology and devices. Byron (1994) proposed a trivariate thematic map with RGB color combination in computing for soil components. However, with colors, it's very difficult to identify many points, and some "blind" spots occur where only two variables are available such as near each angle.

Experiment I

Variables

There are two modes for the independent variable: the display with RGB color combination and the display with color, auditory, and haptic display. The dependent variable is the completion time for each mode measured in seconds.

Maps and Legends

The maps, which were simplified into a table-like shape (Figure 1), consist of 30 adjacent counties in the state of Kansas in the United States. Each variable had three values, so there were 27 possible trivariate combination values ($3 * 3 * 3$) for each state. The value of each state was artificially assigned to have one of the 27 combinations. Three combinations were assigned to two states. Each map has a legend to provide a reference for stimuli. Both in legends and maps, all the stimuli, including colors, are available only when a participant moves a mouse over an individual cell, and they are unavailable once the mouse is out of the cell. The reason for this manipulation is that usually colors are available all the time when we explore a thematic map, while auditory and haptic (vibration in this experiment) displays are only available when they are rendered by users' input. Each county name is displayed in each cell, and each variable was made artificially to avoid any demographical bias: variable A, variable B, and variable C.

Var A	Var B	Var C	Color
H	H	H	
H	H	M	Yellow
H	H	L	Yellow
H	M	H	Pink
H	M	M	Red
H	M	L	Orange
H	L	H	Magenta
H	L	M	Pink
H	L	L	Red
M	H	H	Cyan
M	H	M	Light Green
M	H	L	Light Green
M	M	H	Blue
M	M	M	Grey
M	M	L	Olive
M	L	H	Purple
M	L	M	Dark Purple
M	L	L	Dark Red
L	H	H	Cyan
L	H	M	Light Green
L	H	L	Light Green
L	M	H	Blue
L	M	M	Teal
L	M	L	Dark Green
L	L	H	Blue
L	L	M	Dark Blue
L	L	L	Black

Cheyenne	Rawlins	Decatur	Norton	Phillips
Sherman	Thomas	Sheridan	Graham	Rooks
Wallace	Logan	Gove	Trego	Ellis
Greeley	Wichita	Scott	Lane	Ness
Hamilton	Kearny	Finney	Gray	Hodgeman
Stanton	Grant	Haskell	Ford	Kiowa



Figure 1. Color Only Interface

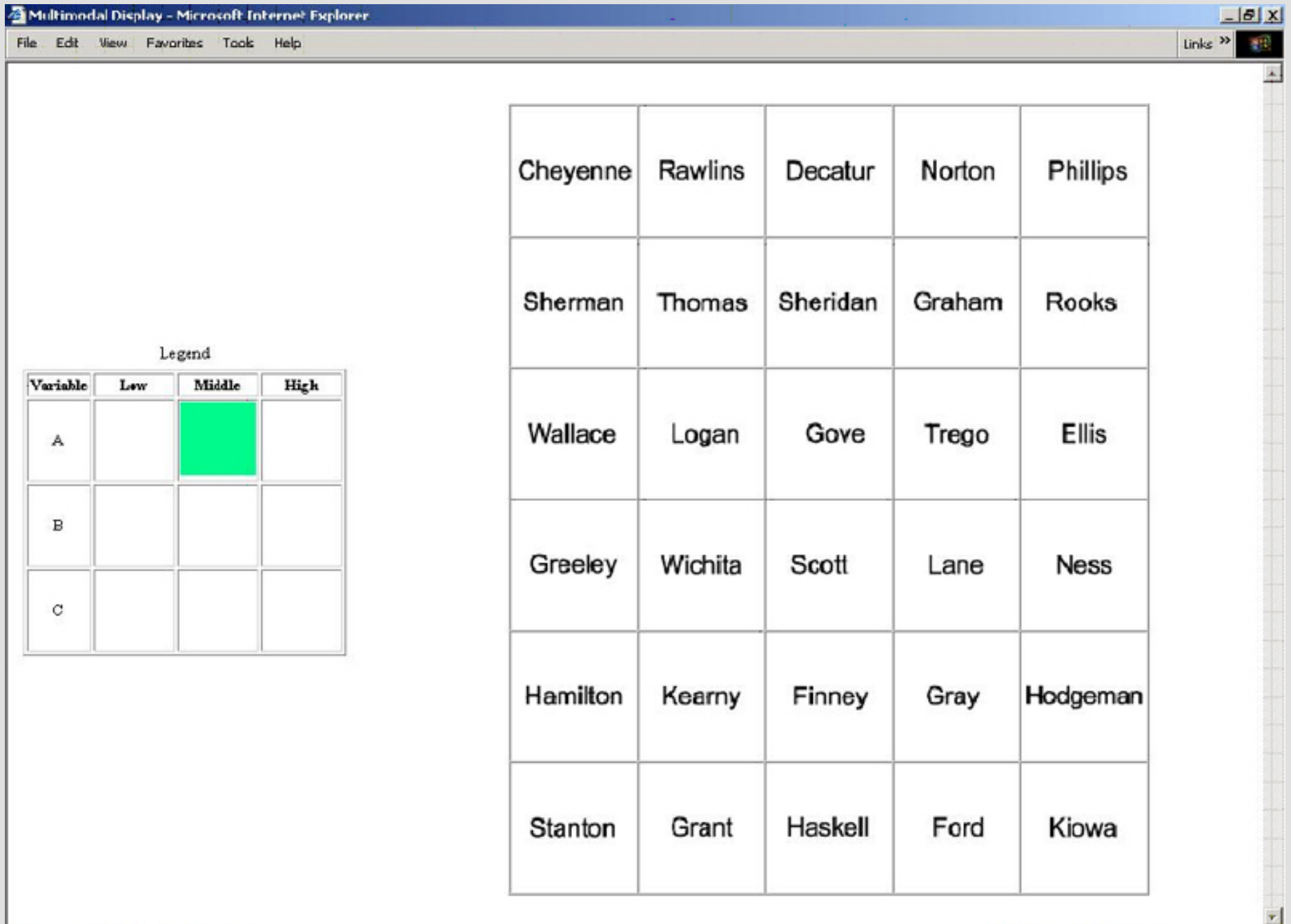




Figure 2. Multimodal Interface

Color Display

For the color-only mode, using RGB (red, green, blue) function in graphics, 27 different colors were generated. Each color has three values (0, 128, 255) and each value is associated with "low", "middle", and "high" accordingly. With a value for each color, all 27 colors had some meaning: for example, "white" means "high, high, high" and "black" means "low, low, low."

Auditory Display

To create audio files with different volumes, a short WAV file (Microsoft Windows' Chimes Sound) is manipulated in Magix Music Maker. Putting the original volume (-6dB) as the middle one, the louder one had 16 times of the original one, and the softer one had 1/16 times of the original one. Once a mouse is moved over a cell in the tables, a musical sound clip is played through headphones so that a subject can hear the sound.

Haptic Display

The haptic interface was built with Immersion Studio and Immersion Web Designer. Different forces were made using Immersion Studio's periodical effect, with vibration option. Since the periodical effect provides only 0 to 10,000 units of magnitude, the 5,000

units were used for the middle value, 1,000 units for the lower one, and 10,000 units for the stronger one, respectively. Once a mouse is moved over a cell, a force of vibration is created in a force-feedback mouse (Logitech's iFeel wheel mouse), so that a subject can feel the force.

Experiment Procedure

Once a participant was introduced to the experiment, s/he was asked to complete a pre-test questionnaire for demographic information. In the main experiment, the task was to identify the trivariate value for each county. The participants were asked to circle the correct answers on a given answer sheet. The answering was monitored, and when a wrong answer was marked, immediate feedback was given to let them try again. Each task continued until the user obtained all the correct answers for the 30 counties. The time between the start and finding all the correct answers was measured in seconds. Three consecutive sessions were conducted by each participant. There were 20 participants and they were recruited from an undergraduate class of the School of Information Studies at the University of Wisconsin in Milwaukee, USA.

Result

As seen in Figure 3, the most interesting finding in terms of completion time, once the participants knew how use the multimodal legend, is that there is little difference between two modes. Even at the third session, the performance reversed slightly. This confirmed a possibility of using multimodal thematic maps. The reason for not having great learning effect on color-only mode is speculated because of the complexity of the task itself and vagueness or confusion of several colors, even if the color legend was always available.

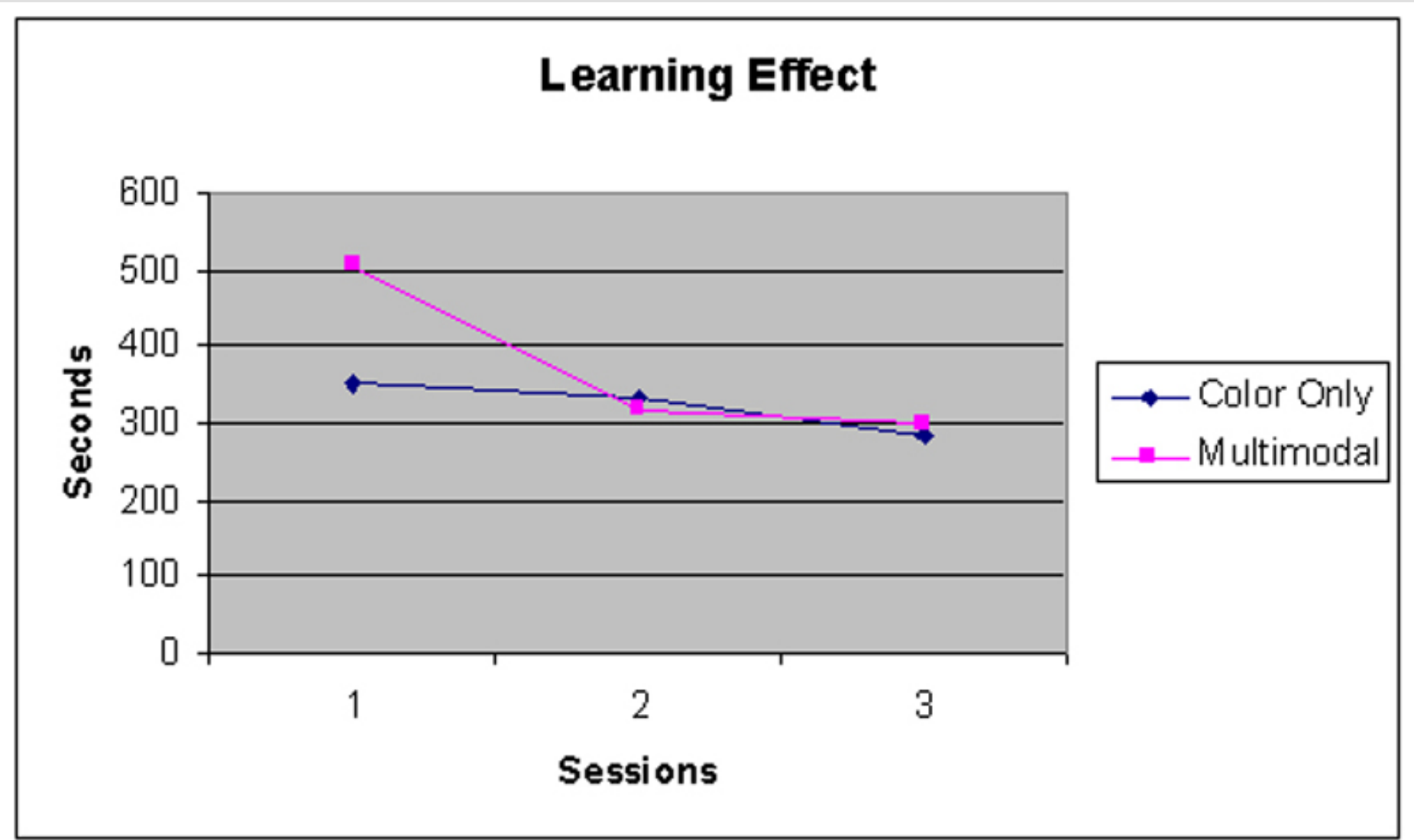


Figure 3. Learning effect between two modes

Experiment II

Variables

As in Experiment I, there are two modes for the independent variable: the display with RGB color combination and the display with color, auditory, and haptic display. The dependent variable is the number of correct answers for each mode, which represents the recall rate.

Experiment Procedure (II)

After three sessions in experiment I, another set of tasks was introduced. The interface was identical to experiment I with the exception that users saw no legend. The task was the same - to identify three values for each county - but with a time limit of 120 seconds. After 120 seconds, the current experimental session disappeared automatically. The tasks reproduced both modes. The participants were asked to mark the correct answer as best they could, and the number of correct answers recorded to explore the difference in recall rate among modes.

Result

As seen in Figure 4, the multimodal display has much higher recall rates than color-only display (2 for color-only displays vs. 15 for multimodal displays). Since haptic and auditory displays are "naturally" hierarchical, they are easily and naturally encoded. Without a special attention, colors are difficult to encode, especially for nonhierarchical trivariate legends.



Figure 4. Recall by mode

Discussion

Natural hierarchy in Auditory and Haptic Display

The recall rate for multimodal display is much higher than color only display. The natural hierarchy in auditory displays was easily encoded to users' memory with longer retention. Especially in this kind of complex situations, many colors are not an effective way to deliver multiple pieces of information.

Unfamiliar Haptic Mode

As seen in Figure 3, the striking learning effect on multimodal display implies that a minimal training may facilitate the use of multimodal interfaces. This finding suggests that it is very likely to be able to implement multimodal interface in many areas, such as education and computing.

Conclusion

The study shows that it is possible to utilize multiple modes with vision in GIS, especially in trivariate thematic maps, and that the new multimodal interfaces may enhance performance of GIS users by invoking the natural hierarchy of auditory and the haptic displays.

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