Multimodal Bivariate Thematic Maps with Auditory and Haptic Display

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ABSTRACT

The purpose of this study is to explore the possibility of multimodal bivariate thematic maps by utilizing auditory and haptic displays. With four different modes of display, the completion time of tasks and the recall (retention) rate were measured in two separate experiments. In terms of the completion time, haptic displays seem to interfere with other modalities. However, Color-Auditory displays performed similarly to Color-Color displays. For the recall rate, multimodal displays have higher recall rates, with users performing the best on Auditory-Haptic displays. These findings confirmed the possibility of using auditory and haptic displays in visually dominant geographic information systems (GIS). We speculate that the natural quantitative hierarchies in auditory and haptic displays provide an advantage in the use of multiodal displays.

1. INTRODUCTION

In everyday life, various sensory modes are used to acquire the optimal amount of information from the environment: vision, audition, smell, taste, skin sense (temperature, pain, and touch), vestibular and kinesthetic senses [1]. For example, driving a car, we listen to radio news. In a concert or a conference, we switch our pagers or cellular phones to the vibration mode because the auditory cues are not appropriate. For the hearing-disabled, some telephones have blinking lights instead of ringing bells when a call is received. However, in computer-based information systems, the interactions between humans and systems have been predominantly visual. The tools to utilize multiple sensory modes are emerging to augment our traditional visual interaction, and geographic information systems (GIS) are among them.

It is believed that multimedia enhances GIS applications and among the efforts of multimedia in GIS, sound predominates. Krygier suggested the abstract sound variables that can be implemented in GIS: location, loudness, pitch, register, timbre, duration, rate of change, order, and attack/decay [2]. Weber examined the possibility of using musical harmony to represent spatial distance in a map [3]. 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 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, and the results showed 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 [4]. Gluck and his colleagues are trying to implement various sound variables in their seriation software in which data matrix and maps are integrated [5][6].

Meanwhile, the term "haptics" refers to sensing and manipulation through the sense of touch [7]. Haptic is the study of how to couple 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 that give the human sensation of a force being applied [8]. Researchers have started to develop various haptic input/output devices and software, such as the frequently used MIT's Phantom haptic interface [9]. Along with auditory displays, haptic research in GIS is emerging. For example, Jeong 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 [10].

2. 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 refer to the arbitrary legend all the time. 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. The purpose of this study is to explore the possibility of multimodal bivariate thematic maps by utilizing auditory and haptic displays, which can be rendered easily by the current technology and devices.

3. EXPERIMENT I

3.1. Variables

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

3.2. Maps and Legends

The maps, which were simplified into a table-like shape (Figure 1), consist of 9 adjacent states in the United States. Each variable had three values so there were 9 possible bivariate combination values for each state. The value of each state was artificially assigned to have one of the 9 combinations. Each map has a legend to provide 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 state name is displayed in each cell, and the two variables were made artificially to avoid any demographical bias: the number of dogs and the number of cats per capita in each state. [11]

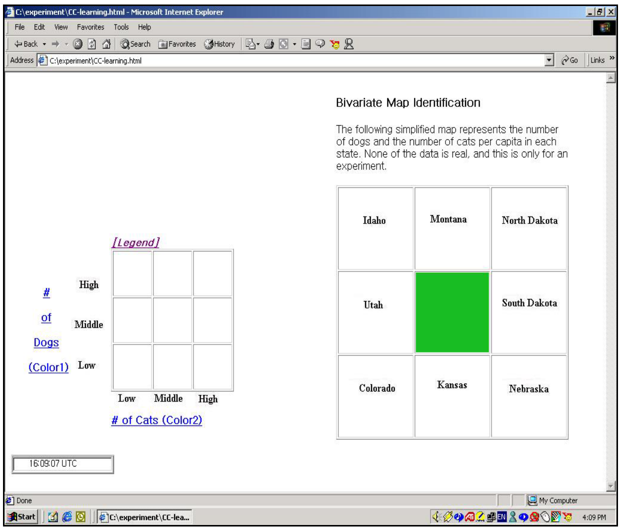

Figure 1. *Experimental Interface*

3.3. 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 -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. The participants adjusted the actual volumes for their comfort.

3.4. 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 and 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 (see Figure 2 for the experimental setting).


Figure 2. *Experimental Setting*

3.5. Experimental Procedure

Once a participant was introduced to the experiment, she or he was asked to complete a pre-test questionnaire for demographic information. Then she or he was asked to do a learning phase to get accustomed to the experimental interface. The learning phase was identical to the main experiment, including type of tasks, number of tasks, and interface, to minimize the potential learning effect.

After the learning phase exercise, the main experiment was introduced. The task was to identify the bivariate value for the number of dogs and cats per capita in each state. The participants were asked to circle the correct answers on a given answer sheet. The only difference from the learning session is the arrangement of values in the maps. 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 got all the correct answers for the 9 states. The time between the start and all the correct answers was measured in seconds. Each mode has one task, resulting in 4 tasks in total. To minimize the learning effect, the order of tasks was counter balanced.

There were 39 participants in the experiment. They were recruited from an undergraduate class of the School of Information Studies at the University of Wisconsin in Milwaukee, USA.

3.6. Result

The collected data was analyzed by Repeated Measure ANOVA, since a participant went through all four modes, in other words, a within-subject experiment was conducted. SPSS version 7.5 was used for the statistical analysis.

As seen in Table 1 and Figure 3, haptic displays seem to interfere with other modalities. However, interestingly enough, Color-Auditory display performed very closely to Color-Color display. This confirms the possibility of using sound in GIS. However, Color-Haptic, and Auditory-Haptic display took more time than the first two displays, and the differences are statistically significant, as seen in Table 2.

Color is so powerful, even if it is believed that a haptic display has potential and its hierarchical properties are natural. Therefore, we need to investigate other aspects such as retention (recall) rate to observe haptic and sound's more subtle effects, which are done in Experiment II.

Table 1. *Mean Completion Time*

Mode	Mean Completion Time (seconds)
Color-Color	86.56
Color-Auditory	88.51
Color-Haptic	97.30
Auditory-Haptic	121.20

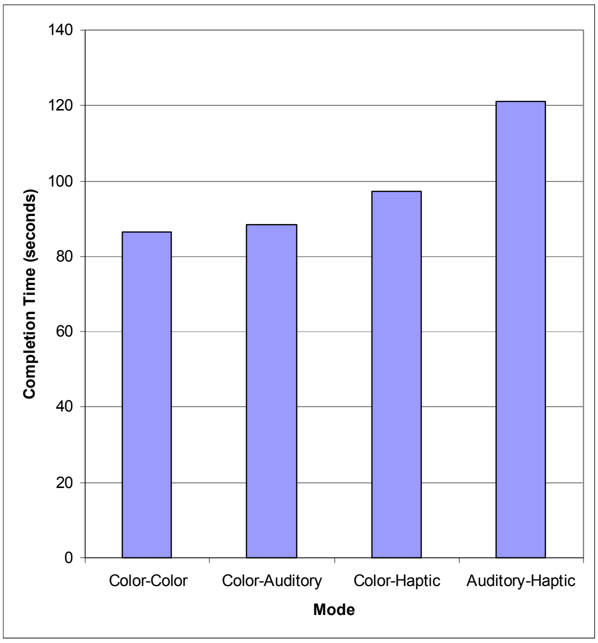

Figure 3. *Completion time by mode*

Table 2. *ANOVA table for completion time*

Pairwise Comparisons

Measure: Completion Time

(I) FACTOR1	(J) FACTOR1	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	Upper Bound
Color-Color	Color-Auditory	-1.9487	2.823	.494	-7.664	3.767
	Color-Haptic	-10.7436*	3.863	.008	-18.563	-2.924
	Auditory-Haptic	-34.6410*	4.660	.000	-44.074	-25.208
Color-Auditory	Color-Haptic	-8.7949*	3.859	.028	-16.606	-.984
	Auditory-Haptic	-32.6923*	4.362	.000	-41.523	-23.862
	Color-Color	1.9487	2.823	.494	-3.767	7.664
Color-Haptic	Color-Auditory	8.7949*	3.859	.028	.984	16.606
	Auditory-Haptic	-23.8974*	4.450	.000	-32.906	-14.889
	Color-Color	10.7436*	3.863	.008	2.924	18.563
Auditory-Haptic	Color-Auditory	32.6923*	4.362	.000	23.862	41.523
	Color-Haptic	23.8974*	4.450	.000	14.889	32.906
	Color-Color	34.6410*	4.660	.000	25.208	44.074

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

4. EXPERIMENT II

4.1. Variables

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

4.2. Experiment Procedure

During experiment I, if time permitted, another set of tasks was introduced. The interface was identical to experiment I except users saw no legend. The task was still to identify both values for each state, but in a limited time: 60 seconds. After 60 seconds, the current experimental session disappeared automatically. The tasks reproduced all four 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. As in Experiment I, the order of tasks was counter balanced to minimize the possible learning effect.

4.3. Result

As in the first experiment, the collected data was analyzed by Repeated Measure ANOVA with SPSS. Among the participants in the experiment I, 24 participants did experiment II. As seen in Table 3 and Figure 4, multimodal displays have higher recall rates, with the best on Auditory-Haptic display. Statistically, as seen in Table 4, differences among modes are significant except for the difference between Color-Auditory and Color-Haptic.

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 un-hierarchical bivariate legends.

Table 3. *Number of Correctly Answered Questions*

Mode	Mean Frequency
Color-Color	1.75
Color-Auditory	3.41
Color-Haptic	3.75
Auditory-Haptic	5.50

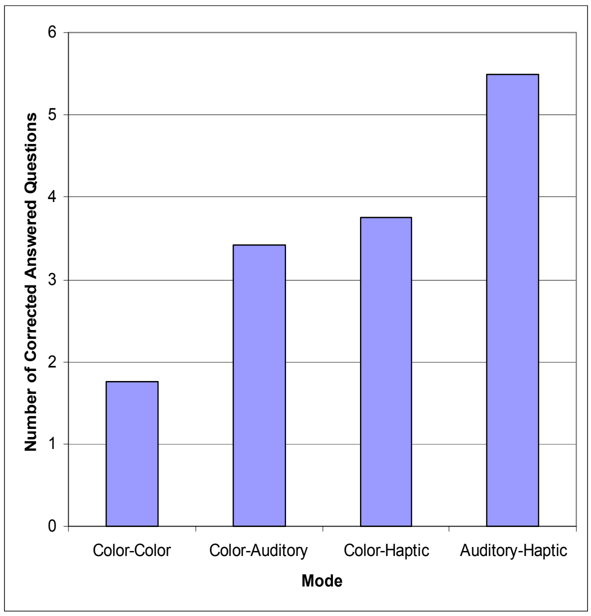

Figure 4. *Retention by mode*

Table 4. *ANOVA table for retention rate*

Pairwise Comparisons

Measure: Number of Correctly Answered Questions

(I) FACTOR1	(J) FACTOR1	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
Color-Color	Color-Auditory	-1.6667*	.554	.006	-2.812	-.521
	Color-Haptic	-2.0000*	.662	.006	-3.370	-.630
	Auditory-Haptic	-3.7500*	.479	.000	-4.740	-2.760
Color-Auditory	Color-Haptic	-.3333	.305	.286	-.964	.298
	Auditory-Haptic	-2.0833*	.617	.003	-3.359	-.808
	Color-Color	1.6667*	.554	.006	.521	2.812
Color-Haptic	Color-Auditory	.3333	.305	.286	-.298	.964
	Auditory-Haptic	-1.7500*	.738	.026	-3.276	-.224
	Color-Color	2.0000*	.662	.006	.630	3.370
Auditory-Haptic	Color-Auditory	2.0833*	.617	.003	.808	3.359
	Color-Haptic	1.7500*	.738	.026	.224	3.276
	Color-Color	3.7500*	.479	.000	2.760	4.740

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

5. DISCUSSION

5.1. Natural hierarchy in Auditory Display

As seen in Figure 3, auditory display can replace a color scheme with similar performance with a bivariate thematic map. We speculated that the natural hierarchy using different volumes played an important role. It is confirmed in Experiment II as seen in Figure 5. The retention rate for color-auditory display is much better than color only displays. The natural hierarchy in auditory displays was easily encoded to users' memory with longer retention, even if users never paid attention to the stimuli.

5.2. Unfamiliar Haptic Mode

Haptic display also had a high recall rate as seen in Figure 4, and the combination of auditory and haptic displays actually had the best recall rate. The natural hierarchy of both modes seemed to accelerate the encoding process. However, combining haptic displays interfered with the other mode (vision or auditory) as seen in Figure 3. It is thought that the interference resulted from the unfamiliarity of the haptic display to the participants. It is believed that with a certain amount of experience, users will benefit as much from haptic displays as from auditory displays.

6. CONCLUSION

This study showed that it is possible to utilize multiple modes with vision in GIS, especially in bivariate 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. In addition, with multimodal and multi-property representations in auditory and haptic displays, a solution is implied for multi-variate maps beyond two variables, in other words, we can display three, four, or five different variables simultaneously in a single map. Much work remains to apply these results within geographic information systems and to test them in other domains. Last, but not least, multimodal interfaces definitely provide various solutions for the disabled. The visually impaired may well benefit from audible and/or touchable GIS, and the hearing impaired people can use haptic displays to augment GIS.

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