# COGNITIVE ASPECTS OF DESIGNING STATISTICAL MAPS

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## Introduction

Compared to their extensive research in pretesting and investigating ways to collect information from respondents, statisticians have paid much less attention to pretesting and investigating ways to present information to data users (Mosteller, 1988). In this paper we extend the cognitive research methodology that we have found effective over the past eight years in improving the design of survey questionnaires to improving the design of statistical maps.

The fundamental ingredient of the cognitive revolution in survey research has been the alteration of the model of the survey response process. Figure 1 compares the behaviorist model formerly used by survey researchers with the cognitive model commonly in use today (Jobe & Mingay, 1991). Both models assume an initiating stage in which the survey question is administered to the respondent and a final stage in which the respondent answers the question. In order words, both models assume that the survey question serves a stimulus that elicit the respondent's answer. The difference between the models is that the cognitive model also assumes that a stage of information processing occurs after the question presentation that leads to the response.

Survey research based on the behavioral model was concerned primarily with associating the design properties of the survey instruments and the quality of response. In so doing, this research largely ignored why and how the design features affect response quality. In contrast, because the cognitive model explicitly recognizes the cognitive processing stage that intervenes between the survey stimulus and response, it focuses attention on the "why" and "how" questions.

In other words, the cognitive model fosters research not only on associating the survey instrument design with response quality but also on investigating why and how the mental tasks respondents perform in responding to the survey instrument "cause" response errors. With respect to understanding the causes of survey response errors, we have proposed (Sirken, 1992) the following cognitive paradigm: "Survey instruments elicit poor quality responses when they impose mental tasks on respondents that challenge or exceed the respondents' capacities."

Based on the cognitive paradigm, NCHS has developed two kinds of programs for improving the design of survey questionnaires. One program involves pretesting questionnaires before they are field administered. It detects and corrects defective questionnaire design features by observing the difficulties that respondents have in performing their mental tasks and then revises the questionnaires accordingly. The other program involves conducting mission oriented research on the cognitive aspects of answering survey questions. It conducts experiments that investigate the abilities and capacities of survey respondents to perform the kinds of mental tasks that are required by survey questionnaires. Both programs are conducted primarily in the setting of the cognitive research laboratory.

## Conceptual Framework

In this section, we focus on the cognitive stage of the survey response process. We describe the basic cognitive processes that are involved in the processing of information, and the kinds of mental tasks these basic processes imply when survey information is being processed. We compare the mental tasks involved in answering survey questionnaires and in reading statistical maps.

Figure 2 lists the cognitive processes that are currently held to be involved to varying degrees when performing cognitive tasks generally. Our premise is that the cognitive processes and implied cognitive tasks listed in Figure 2 are generic to processing all kinds of information but that the mental tasks implied by them vary according to the kind of information being processed. Thus, it is not surprising that the mental tasks involved in answering survey questions are not the same as those for reading statistical maps.

Figure 3 compares the mental tasks for answering survey questions and reading statistical maps. For example, the auditory and visual senses respectively are the input mechanisms for responding to survey questions (administered in a face-to-face mode) and viewing statistical maps. Also, recall involves primarily autobiographical memory in answering questions (in retrospective surveys) and primarily non-autobiographical (semantic) memory in reading statistical maps. Certainly the tasks associated with comprehending maps is very different from those of understanding survey questions.

We are currently demonstrating that the cognitive laboratory methods were developed for testing survey questionnaires and for conducting questionnaire design research are generally applicable for testing statistical maps and conducting map research. The mental task differences between questionnaires and maps noted above do not belie this achievement but rather indicate that much remains to be done in adapting the questionnaire methods to make them suitable for investigating the cognitive aspects of designing statistical maps.

## Cognition and Statistical Maps

In this section, we first briefly review the functions of statistical maps and the status of cognitive research on statistical maps. Then, we describe and illustrate research currently underway at NCHS in applying laboratory methods to test statistical maps and to conduct cognitive research on statistical maps.

Statistical maps convey statistical information as a function of geographic units. These maps are especially useful in that they permit the recognition of patterns in the geographic distributions of statistics that are often not evident when the statistics are distributed in tabular form.

Empirical research designed to test the effectiveness of various cartographic techniques has increased greatly in recent years, but like questionnaire research conducted during the behavioral era, most cartographic research has been essentially atheoretical. Thus, most map research has been designed and interpreted without the benefit of framework conceptualizing the cognitive processes people use to interpret and understand the statistics presented in maps.

## Pretesting Statistical Maps

Our research group has pretested statistical maps in a laboratory setting. For example, we pretested several styles of maps being considered for use in a national mortality atlas. The national mortality atlas will present maps by cause of death for the major causes in the United States for 1989-1991. We asked a panel of NCHS experts to estimate and compare rates for specific areas using thirteen different candidate styles for map presentation in the atlas. We combined the focus group concept with an initial cognitive interview. These maps presented the same data set in various traditional forms by using points (symbol map), lines (isopleth map), or areas (choropleth map) to represent mortality rates. The maps also varied in their texture, hue, saturation, and intensity of color. The styles tested included five classed maps, four unclassed maps, and four maps of rates smoothed using statistical models.

We found that respondents had difficulty reporting the correct rate for individual areas with monochrome dot maps. This difficulty did not show up for other forms of non-smoothed, classed maps. For unclassed monochrome maps, respondents significantly overestimated rates below the median and provided highly variable estimates for high rate areas. Of the smoothed maps, those using contour lines induced errors in response. The respondents found it difficult to distinguish one shade or dot size from another using unclassed maps, especially in non-adjacent regions. They commented that a multi-hue scheme made regional comparisons difficult because they had difficulty remembering the color key. Maps using these styles were eliminated from further consideration.

Respondents felt that color helped them both estimate and compare rates for areas. They preferred a double-ended color scheme because it provided additional information of whether the area rate was above or below the U.S. rate. In further examining the pretest results, we noted that the respondents provided significantly more accurate regional comparisons when saturation, rather than hue or symbol size, was used to represent rate values. In the focus group, respondents also stated a strong preference for this symbology. The group both preferred and performed better using classed maps. The consensus of opinion and consistency between performance and opinion lead us to recommend maps using classed color saturation for the mortality atlas. The details of the methodology used during pretests of map styles for potential use in the production of a national mortality atlas are presented in Pickle, Herrmann, Kerwin, Croner, and White, published in these proceedings. Earlier examples of pretesting can be found in Beu, Mingay, & White, (1989).

## Mission Oriented Basic Research

Our research group has also conducted mission oriented basic research to investigate the cognitive properties of map design features. We have been investigating those particular map design features that will be important in designing the maps for the mortality atlas noted above. The simplest use of mortality maps is to read the rate of a particular geographic unit, either a particular state or region. In one series of experiments, laboratory subjects read the mortality rate for designated geographic regions. The time and accuracy of responses were measured as a function of the kind of map scaled used. Several types of maps were tested. For example, the subjects were presented with a map that represented mortality rates in a five category scale, with the degree of darkness of the grey scale increasing from low to high rates or with five different hues representing the rates. The results showed that while accuracy of reading maps was unaffected by the different kinds of scales, latency varied across scales, responses were slower to the multihue scale than to the grey scale (Hastie et al).

An important epidemiological function of NCHS mortality maps is to reveal clusters of two or more adjacent geographical units that have the same or similar mortality rates for a disease. Another series of experiments investigated the consistency of clustering across map scales. Laboratory subjects circled the clusters they perceived on the mortality maps and indicated each cluster midpoint. Analysis of the experiment's results indicated that the clusters perceived by subjects varied in consistency as a function of the kind of map scale (Lewandowsky, Herrmann, Behrens, Li, Pickle, & Jobe, in press).

Earlier in this paper we talked about map reading as if it were a single cognitive operation, albeit involving several cognitive processes (Tables 2 and 3). Because of the research reviewed above, we have concluded that map reading actually is best viewed as consisting of a series of reading stages: 1) Map Orientation, 2) Legend Comprehension, 3) Map/legend Integration, and 4) Discerning Spatial Patterns and Relationships. Each stage is seen to be due to a unique combination of the cognitive processes discussed earlier. For example, sensory processes are especially important in map orientation and the legend comprehension stages whereas the integration of the map with the legend depends more on perception, and the discernment of patterns makes use of comprehension, memory, and reasoning. This model is discussed in some detail in Herrmann, Pickle, Kerwin, Croner, White, Jobe, and Jones, published elsewhere in these proceedings.

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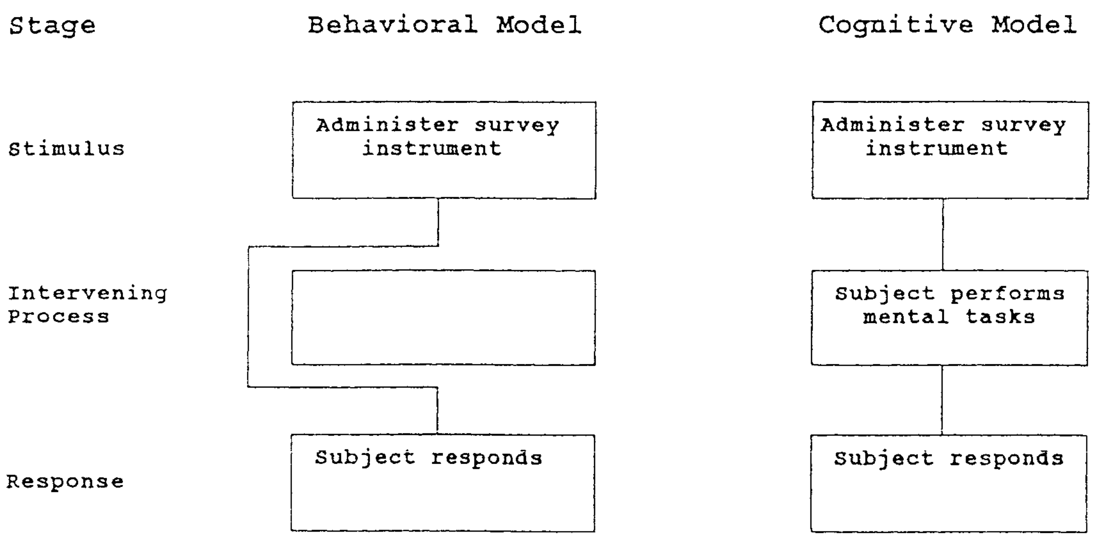
Figure 1 - Model The of Survey Response Process




## Figure 2 - Cognitive Processes and Mental Tasks Performed by Survey Subjects

| Cognitive process | Mental task |
|---|---|
| Sensation | Sensing input |
| Perception | Organizing sensory input |
| Comprehension | Understanding meaning of input |
| Recall | Assessing memory for relevant information |
| Reasoning | Arriving at the response |
| Decision-making | Taking action |

Figure 3 - Cognitive Processes in Answering Questions and Reading Maps

| Cognitive process | Answering question | Reading maps |
| --- | --- | --- |
| Sensation | Auditory | Visual |
| Perception | A request for information | A geographic display |
| Comprehension | Understanding question meaning | Understanding map's display and objectives |
| Memory | Autobiographical primarily | Knowledge primarily |
| Reasoning | Deciding on the answer | Drawing ecological conclusions |
| Decision making | Answering the survey question | Applying map knowledge |