Ana-Marija Ozimec, Martin Natter, & Thomas Reutterer

Geographical Information Systems–Based Marketing Decisions: Effects of Alternative Visualizations on Decision Quality

Marketing planners often use geographical information systems (GISs) to help identify suitable retail locations, regionally distribute advertising campaigns, and target direct marketing activities. Geographical information systems thematic maps facilitate the visual assessment of map regions. A broad set of alternative symbolizations, such as circles, bars, or shading, can be used to visually represent quantitative geospatial data on such maps. However, there is little knowledge on which kind of symbolization is the most adequate in which problem situation. In a large-scale experimental study, the authors show that the type of symbolization strongly influences decision performance. The findings indicate that graduated circles are appropriate symbolizations for geographical information systems thematic maps, and their successful utilization seems to be virtually independent of personal characteristics, such as spatial ability and map experience. This makes circle symbolizations particularly suitable for effective decision making and cross-functional communication.

Keywords: data visualization, spatial marketing decisions, symbolization, geographical information systems thematic maps, cartograms

Approximately 75% of the data that decision makers use include at least one spatial component, such as a customer address, population distribution, purchasing power, target group coverage, trading area, competition, or the demographic distribution of customers (Tonkin 1994). Retailers and direct marketers routinely use many of these types of spatial data to make strategic and tactical decisions with respect to management of pricing and promotions (Bronnenberg and Mahajan 2001; Jank and Kannan 2005), targeted advertising (Carton 2003; Parker 2004), direct marketing campaigns (Steenburgh, Ainslie, and Engebretson 2003), retail site selection (Hernández and Bennison 2000; Ter Hofstede, Wedel, and Steenkamp 2002), and sales force planning (Zoltners and Sinha 2005).

In recent decades, a variety of visual decision aids have become essential tools for supporting marketing analysts in many domains. Geographical information systems (GISs) are widely used tools in marketing practice (Goodchild 1991) that combine data on geographical entities (e.g., zip code areas) with digital maps (Fischer and Getis 2010). To avoid information overload, these data often need to be filtered, condensed, and represented in a manner that is compatible with the psychology of decision makers (Hoch and Schkade 1996; Van Bruggen, Smidts, and Wierenga 1998). To represent quantitative spatial data (e.g., purchasing power), a GIS typically allows users to choose from among a set of predefined thematic maps. These GIS thematic maps differ in the way they make use of certain symbolizations (e.g., circles, bars, area distortions, color shading) to visualize the same underlying spatial data. However, there is little knowledge on which kind of symbolization is the most adequate in which problem situation. To date, the user is left to his or her own devices when choosing among the available GIS thematic map options, which is especially problematic when the tasks become more complex, such as in a typical geospatial marketing decision context. The current study attempts to close this research gap by attaining more in-depth insights into the relative capabilities of various symbolizations to support better decision making. Given the long-term profit impact of strategic decisions, such as site selection, the importance of gaining substantial insight into the relative merits and drawbacks of such alternative GIS thematic maps is clear.

Learning more about GIS thematic map effectiveness is of crucial relevance to both decision makers and GIS designers. If the data representation matches the underlying spatial task and the cognitive capabilities of decision makers, more rapid and more accurate decisions will result. In

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addition, GIS designers will be able to improve their data visualization tools.

We investigate GIS-assisted decision making by performing a large-scale online experiment (1349 participants with a heterogeneous professional and prior GIS experience background), in which we test relevant GIS thematic maps in a mixed between-subjects (symbolization, time pressure) and within-subjects (degree of task complexity) design. In this experiment, the participants made a series of site selection decisions, choosing the best of five competing sites on GIS thematic maps. We find that the choice of the symbolization significantly affects participants' ability to locate the objectively best solution. The results demonstrate that circles outperform other relevant symbolizations of quantitative data. We further find that making accurate decisions based on GIS thematic maps depends little on the personal characteristics of the decision makers. Thus, if the appropriate symbolization is used, even people with moderate spatial ability and hardly any map experience can identify good solutions. Our findings underline the potential of GIS thematic maps as an effective decision support tool. Thus, we provide valuable insights into the successful utilization of GIS in marketing, and we point to the relevance of choosing appropriate symbolizations that fit multicriteria marketing decision problems.

After summarizing the related literature, we develop a conceptual framework that links alternative symbolizations under varying degrees of task complexity and time pressure to decision performance metrics. Subsequently, we describe the experimental setting and follow up with a discussion of our findings. Finally, we draw conclusions and outline an agenda for future research endeavors.

Related Literature

Research into different mental representations derived by decision makers for structurally similar problems (problem isomorphs) suggests that decision makers perform significantly better when their problem-solving processes are compatible with the problem representation (Hayes and Simon 1977). In particular, visual representations tend to support simultaneous information processing and are likely to lead to more intuitive and holistic, rather than piecemeal, information processing (Holbrook and Moore 1981; Sloman 1996). This suggests that visual representations can enhance a decision maker's capability to effectively evaluate information on the basis of multiple decision criteria. Thus, GISs appear to be particularly useful for multifaceted marketing decisions, which require several spatial components to be inspected simultaneously and combined with one another.

Table 1 summarizes the contributions from prior studies that can be considered the most important in the context of the current research. All these studies explore the effects of different representations of quantitative data on one or more dependent variables measuring decision performance. Cognitive fit theory, developed by Vessey (1991), proposes that decision performance significantly depends on the match or "cognitive fit" between the decision task and the problem representation—that is, the way of presenting the problem-related information to the decision maker. Dennis and Carte (1998) extend the research on Vessey's cognitive fit theory to GIS thematic maps versus tabular information representations. They find that decision makers who use GIS thematic maps make faster and more accurate decisions when tasks require the consideration of adjacency relationships. Note that our empirical approach focuses on marketing problems that involve such geographical adjacencies. Smelcer and Carmel (1997) report that especially with increasing task complexity, the use of maps with specific properties can enhance decision performance. These findings highlight the importance of a profound understanding of decision performance as associated with the use of alternative GIS thematic maps in marketing.

Several empirical studies in early cartographic research (MacEachern 1982a) have demonstrated that the power of thematic maps to facilitate decision making depends on the complexity of the symbolization employed. Thus, differences in the complexity reduction capabilities of the available methods of symbolization deserve careful attention. Some of these studies have focused exclusively on the relative effects of variations within one specific type of symbolization (e.g., bar charts versus divided bar charts, use of colors versus shading) on decision outcomes (for an overview, see Slocum, McMaster, and Kessler 2009; Tufte 2001). Though working at an elementary level, using only one decision criterion, MacEachern (1982a, b) provides some of the few contributions that explicitly compare the relative performance of different symbolizations.

Another notable exception is the theory of elementary perceptual tasks that Cleveland and McGill (1984) developed. They suggest a set of ten elementary perceptual tasks involved in visual decision making. However, this conceptual framework is not directly transferable to the context of multicriteria marketing decision making based on GIS thematic maps. First, it disregards symbol overload on GIS thematic maps, a phenomenon that typically occurs when many symbols need to be portrayed in a small area of the map. Excessive symbol overload can (negatively) affect the ultimate decision (Cleveland and McGill 1984; Jarvenpaa 1989) and therefore should be considered when assessing symbolizations. Second, Cleveland and McGill's investigations were restricted to the completion of rather simple tasks, such as estimating the perceived relative values of single symbolizations. In contrast, marketing decision problems are usually multidimensional by nature. For example, site selection planning requires the analyst to compare several aggregates of multiple (partially enclosed) zip code areas of varying attractiveness within a catchment area across multiple decision criteria. We are not aware of any prior studies that have sufficiently studied such a visual aggregation across multiple symbolic representations, and this raises doubts as to whether Cleveland and McGill's insights also hold in the context of complex marketing decision problems. Against this background, we develop a conceptual framework that explicitly links combinations of different symbolizations and options for coping with symbol overload with decision performance.

TABLE 1
Experimental Studies on the Effects of Symbolic Data Representations on Decision Making

Performance Differences Studied	Selected References	Multiple Decision Criteria	Geocontext (Adjacency)	Issue of Symbol Overload Considered	Dependent Variables: Objective	Dependent Variables: Subjective	Major Findings
Tabular versus graphical representations	Vessey (1991)	+/–	– (–)	–	Accuracy, efficiency	–	•Performance on a task will be enhanced when there efficiency is a cognitive fit (match) between the information emphasized in the representation type and that required by the task type (cognitive fit theory).
	Dennis and Carte (1998)	+	+ (+)	–	Accuracy, efficiency	–	•When adjacency relationships among geographical entities are relevant, maps are more effective and more efficient than tables.
	Smelcer and Carmel (1997)	+	+ (–)	–	Accuracy, efficiency	–	•As task difficulty increases, maps are more effective for problem-solving tasks than tables.
Within the same symbolization type	Simkin and Hastie (1987)	–	– (–)	–	Accuracy, efficiency	–	•Performance: bar charts > divided bar charts > pie charts.
	Mersey (1990)	–	+ (–)	–	Accuracy, efficiency, recall	–	•Recommendation for representing numerical data: shading > color.
	Flannery (1971)	–	+ (–)	–	Accuracy	–	•Perceived magnitude of proportional symbols (e.g., circles) does not correspond to their physical size (people tend to underestimate the magnitude of large symbols). This study recommends optimal grading calculation of proportional symbols.
Between different types of symbolizations	Cleveland and McGill (1984)	–	+/– (–)	–	Accuracy	–	•Ten elementary tasks ordered from most to least accurate: (1) position along a common scale; (2) positions along nonaligned scales; (3) length, direction, and angle; (4) area; (5) volume, and curvature; and (6) shading and color saturation (theory of elementary perceptual tasks).
	MacEachren (1982b)	–	+ (–)	–	–	Perceived ease of task	•Choropleth maps are more complex than isopleth maps.
	MacEachren (1982a)	–	+ (–)	–	Recall	–	•Isopleth maps are more effective than choropleth maps.
	Our study	+	+ (+)	+	Accuracy, efficiency	Decision confidence, perceived ease of task	

Notes: "+" indicates that the authors considered it in the study, and "–" indicates that the authors did not considered it in the study.

Conceptual Research Framework and Hypotheses

The most commonly used GIS thematic maps in marketing practice are choropleth, proportional symbol, and diagram maps. To cover recent developments in cartography, we also consider cartograms, a relatively new kind of GIS thematic map. Successful implementations in diverse disciplines such as statistics (Barford and Dorling 2007), politics (Gastner and Newman 2004), and medicine (Dorling 2007) underscore the potential usefulness of cartograms. To facilitate a clearer understanding of the specific properties and limitations of the respective mapping approaches, Figure 1 provides illustrative examples of GIS thematic maps when two decision criteria are to be represented. Note that the representation of multiple variables may result in a different number of maps depending on the characteristics of the map type used.

The GIS thematic maps differ in the way they symbolize the distribution of a quantitative spatial variable across geographic areas (e.g., zip code regions). In what follows, we focus on typically used symbolizations on each of the four GIS thematic maps. Choropleth maps (Figure 1, Panel A) use shading proportional to the magnitude to be represented (Tyner 1992). Cartograms are maps (Figure 1, Panel B) in which one variable is substituted for land area. Such a map attempts to achieve this by rescaling (distorting) the area of each geographic region according to the relative magnitude of this variable. If a second variable must be displayed in a cartogram, this is typically accomplished by shading the distorted areas (i.e., a combined symbolization of shading and distortions). Proportional symbol maps (Figure 1, Panels C and D) use circles drawn at the central point of each geographic area such that their expansions reflect the respective variable levels (Tyner 1992). Diagram maps (Figure 1, Panels E–G) place bar diagrams on the geographical areas of the map.

Note that unlike choropleth maps and cartograms, proportional symbol and diagram maps are potentially affected by symbol overload. With respect to symbol overload, GISs provide two options for proportional symbol maps (symbol squeezing and symbol overlap; see Figure 1, Panels C and D) and three possibilities for diagram maps (symbol squeezing, symbol overlap, and symbol dislocation; see Figure 1, Panels E–G).

Our research framework relates alternative symbolizations (shading, shading and distortions, circles, and bars) used in GIS thematic maps and their symbol overload–handling options to decision performance metrics (see Figure 2). In accordance with Crossland, Wynne, and Perkins (1995) and Smelcer and Carmel (1997), we assume that this relationship is moderated by task complexity (the number of decision criteria and similarity of the alternatives) and user attributes (spatial ability and map experience). Furthermore, because marketing decisions must often be made under time pressure, we include this variable as a moderator in our research framework.

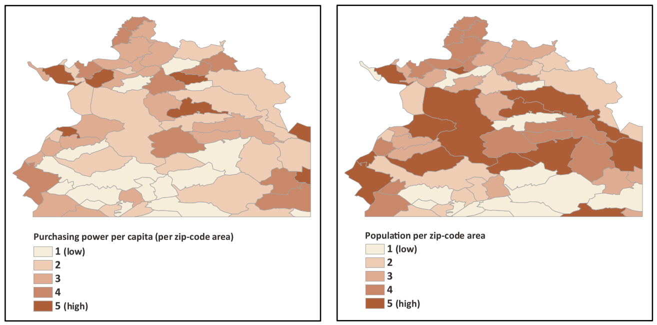
We assume that the combination of all decision-relevant criteria results in a certain revenue level for each location. Decision makers must visually assess the competing locations according to these criteria and choose the location with the highest expected revenue. We decompose decision performance into objective and subjective criteria related to decision quality and the decision process. As an objective metric of decision quality, we use decision accuracy, defined as the average revenue of the location actually chosen by decision makers relative to the revenue of the optimal location (expressed in percentage). Decision efficiency serves as an objective metric of the decision-making process, which is measured as the duration the decision maker needs to solve a task (the lower, the more efficient). As a subjective metric of decision quality, we specify the decision confidence of the decision maker, whereas perceived ease of task serves as a subjective metric of the decision process. According to the proposed metrics, superior decision performance is indicated by both higher decision quality (i.e., higher decision accuracy and higher decision confidence) and a facilitated decision process (i.e., higher decision efficiency and higher perceived ease of task). Note that objective decision performance is relevant for primary tool evaluation, whereas subjective decision performance is an important driver of tool usage (Kayande et al. 2009; Van Bruggen 1992; Wierenga and Oude Ophuis 1997). To develop our hypotheses with respect to the relative decision performance of symbolizations, we draw from Bertin's (1983) sign system, Gestalt theory (Wertheimer 1923), and guided search theory (Wolfe 1994).

Types of GIS Symbolization

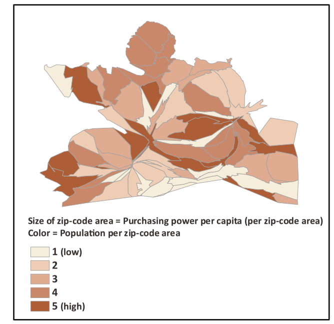
Bertin's (1983) sign system is a universally recognized concept used to examine the cartographic transcription of geographic information (MacEachren 1992; Robinson et al. 1984; Slocum, McMaster, and Kessler 2009). Bertin proposed a systematical approach to communicating information visually. He lists six elementary visual variables (size, value, texture, color, orientation, and shape) and discusses the effects of varying the perceptual properties of the visual variables to derive meaningful representations (see Figure 3). According to their perceptual properties, these visual variables have different levels of organization (measurement scales): associative, selective, ordered, and quantitative. Presentation techniques for given data should be selected in such a way that each data variable is represented by a visual variable with the corresponding level of organization. Against this background, only symbolizations based on Bertin's visual variables of size and value have the perceptual property of being able to adequately represent ordered (interval-scaled) or even numerical data. This property makes them particularly useful for visualizing quantitative marketing data, such as data regarding purchasing power and the like, in a geospatial context. Thus, we sharpen our research focus on variations in these two visual variables. More specifically, the visual variable size symbolizes quantitative data by varying the degree of its apparent expansions, such as the area of circles, the length of bars, or the distortion of zip code areas. The visual variable value symbolizes quantitative data through shading—that is, relative brightness or darkness (whether in black or any other color) proportional to the magnitude to be presented (Robinson et al. 1984).

FIGURE 1
Illustrative Examples of GIS Thematic Maps

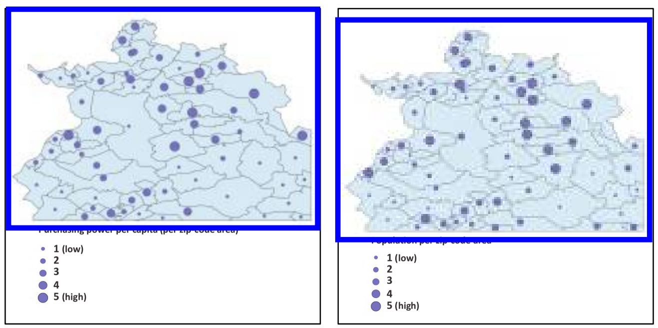
A: Choropleth Maps



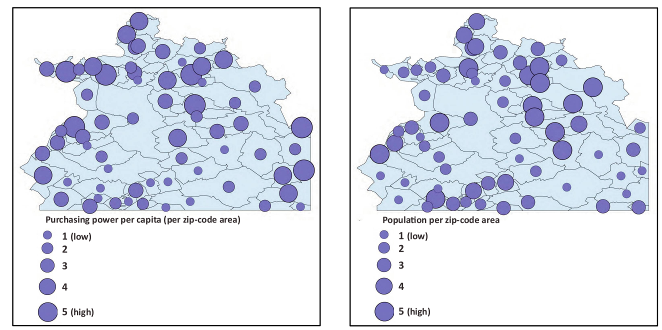
B: Cartogram



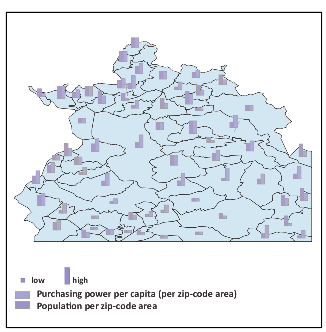
C: Proportional Symbol Maps (Squeezing)



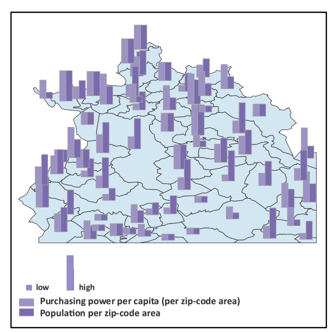
D: Proportional Symbol Maps (Overlap)



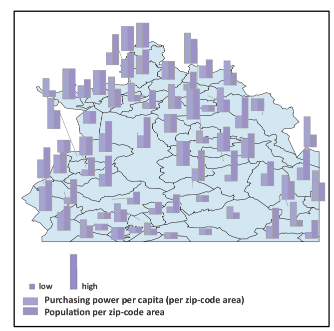
E: Diagram Map (Squeezing)



F: Diagram Map (Overlap)

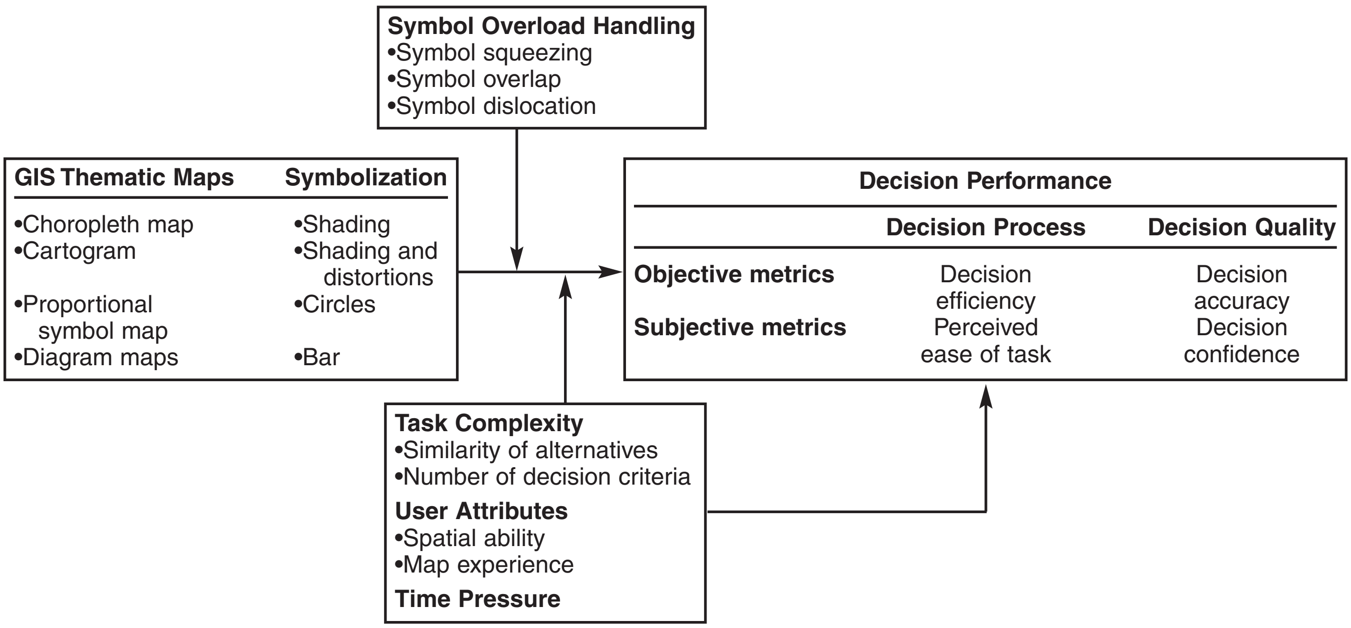


G: Diagram Map (Dislocation)



Notes: We represent two geospatial variables—purchasing power per capita and population per zip code area—using choropleth maps (two maps), a cartogram, proportional symbol maps (two maps), and diagram maps.

FIGURE 2
Conceptual Framework



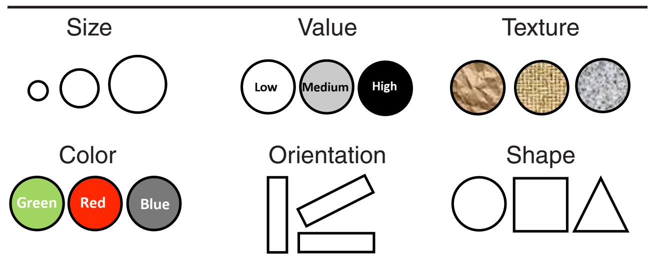
On the basis of Bertin's (1983) sign system, we can organize the symbolizations used in GIS thematic maps for representing quantitative data as the visual variables size (circles, bars, and distortions) and value (shading). Table 2 illustrates the relationship among GIS thematic maps (Column 1), their type of symbolization (Column 2), available options for symbol overload handling (Column 3), the visual variables according to Bertin (Column 4), and the respective apparent expansions in size (Column 5).

According to Bertin's (1983) sign system, the visual variable size allows for a quantitative and value-based representation of ordered information (see Figure 3). This property implies that when size is used to visualize quantitative data, human vision enables decision makers to infer (without a legend) the scale unit of the represented variable. For example, the length (area) of one symbol can be perceived as equal to x times the length (area) of another symbol. In contrast, when value is used to represent the same data, decision makers can only perceive ordinal differences. For example, gray is perceived as intermediate between white and black. Because of this, quantitative data can be accurately represented only by variations in size (Bertin 1983; MacEachren 1992; Slocum, McMaster, and Kessler 2009). Accordingly, we propose the following:

> H_1: GIS thematic maps result in superior decision performance if they employ the visual variable size (circles or bars) rather than value (shading).

Note that decision performance is measured in terms of objective and subjective metrics of decision quality and decision process characteristics, as Figure 2 shows. In a context with multiple decision criteria, pure symbolizations (i.e., based only on shading, circles, or bars) or combined (or hybrid) symbolizations (i.e., shading and distortions)

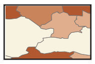
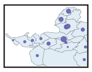
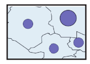
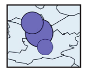
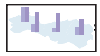
FIGURE 3
Bertin's (1983) Visual Variables and Their Respective Levels of Organization Properties



Visual Variable	Level of Organization: Low ← → High			
	Associative	Selective	Ordered	Quantitative
Size		X	X	X
Value		X	X	
Texture	X	X		
Color	X	X		
Orientation	X	X		
Shape	X			

can be used. Guided search theory (Wolfe 1994) provides some indication that hybrid representations may be superior to pure symbolizations. Here, it is argued that pure symbolizations typically enable decision makers to process only one partial representation after another in a serial manner. The theory proposes that this is due to limitations of human cognition in adequately dealing with two or more requests simultaneously in the parallel-processing stage of percep-

TABLE 2
Relationship Between Symbolizations and Visual Variables

GIS Thematic Maps	Symbolization	Symbol Overload Handling	Visual Variables According to Bertin (1983)	Apparent Expansions of Size
Choropleth map	 Shading	—	Value	—
Cartogram	 Shading and distortions	—	Value and size	Area
Proportional symbol map	 Circles	 Symbol squeezing	Size	Area
		 Symbol overlap		
Diagram map	 Bars	 Symbol squeezing	Size	Length
		 Symbol overlap		
		 Symbol dislocation		

tual cognition. In line with these arguments, we propose the following hypothesis:

> H_2: A combination of shading and distortions results in better decision performance than multiple pure symbolizations.

In contrast to the theory of elementary perceptual tasks, the geographical literature apparently favors circles (i.e., area) to bars (i.e., length) for representing quantitative data. Here, it is argued that circle symbols produce visually stable representations, conserve map space, and therefore enable the viewer to infer the spatial distribution of data from circle expansions (Brewer and Campbell 1998; Cabello et al. 2006; Griffin 1985). Symbols placed on a narrow edge (e.g., bars) appear visually unstable. Circles avoid this and also tend to be less demanding in terms of map space than bars. Our research framework focuses on data visualizations involving spatial structures. Thus, we expect that circles are more appropriate symbolizations for representing quantitative data on GIS thematic maps than bars.

> H_3: Circles result in better decision performance than bars.

Symbol Overload Handling

Intuitively, a good representation should enable the viewer to see at least some part of all symbols on the map and to judge their magnitudes as correctly as possible. The accuracy with which the magnitude of a symbol can be judged is proportional to the part of its boundary that is visible (Cabello et al. 2006). Because overlap is a result of the data distributions that must be displayed, overlap is often difficult to avoid. It is possible to create relatively small diagrams that hardly overlap. Thus, we expect that the avoidance of symbol overlap by proportionally reducing the relative magnitudes of circles or bars (squeezing) will prove more effective than allowing overlap.

For proportional symbol mapping, different algorithms are available for arranging given sets of overlapping circles such that all of them can be seen as well as possible. For example, symbols are often stacked on top of each other to improve symbol visibility (see Figure 1, Panel D). Although symmetric symbols (e.g., circles) can overlap, it is virtually impossible to accept overlap between columnar symbols (see Figure 1, Panel F), such as bars (Keates 1973). When more than one variable is represented by bars, it is not always possible to stack diagrams in order from small to large. As a consequence, overlapping diagrams often can no longer be easily assigned to the corresponding area and tend to lead to confusion (Kraak and Omerling 1996; Slocum, McMaster, and Kessler 2009). When the length of a bar is covered by another bar (overlap), it is not possible to determine the value of the represented variable. In contrast, circle symbols make it possible to determine the value of the represented variable as long as the radius of the circle is inferable. In addition, Gestalt theory's principle of closure (see the Glossary in the Appendix) suggests that symbols such as circles are visually completed by the viewer, even if only parts of a circle are covered (Wertheimer 1923). Accordingly, we propose an interaction effect between the handling of symbol overload and the type of symbolization employed:

> H_4: The use of overlapping bars more negatively influences decision performance than the use of overlapping circles.

An alternative way of avoiding bar overlap commonly implemented in GIS is to place bars outside the map and link them to their respective areas by a line (this is called "symbol dislocation"; see Figure 1, Panel G). When bars are dislocated from the map, however, it is not easy to match zip code areas with the variable of interest anymore, and a greater degree of cognitive effort is required to complete the task. Thus, dislocation complicates the development of a Gestalt (principle of proximity) understanding of the relationships among the relevant data and hinders the perceptual processes required for the successful solution of spatial tasks. In accordance with this argumentation, we theorize that dislocation moderates the decision performance of bars:

> H_5: The use of bar dislocation leads to poorer decision performance than bar overlap.

Task Complexity

Several studies have shown that the success of computer-based information systems depends on task complexity (e.g., Guimaraes, Igbaria, and Lu 1992; Pieptea and Anderson 1987; Sanders and Courtney 1985). Researchers typically investigate indicators of objective task complexity, such as the number of decision criteria (Yoon, Guimaraes, and O'Neal 1995) and, less frequently, the similarity of alternative options (Wolfe 1994). Increasing numbers of decision criteria (indicating problem size) and greater similarity among the available alternatives reflect greater task complexity (it is more difficult to select the better solution from very similar than from very different alternatives). Research has found that task complexity negatively influences decision accuracy (Crossland, Wynne, and Perkins 1995; Hwang 1994; Topi, Valacich, and Hoffer 2005) and decision efficiency (Crossland, Wynne, and Perkins 1995). Smelcer and Carmel (1997) observe interactions between the representation form and task complexity, which we expect to hold in our context as well. However, we extend this view by proposing additional moderating effects of task complexity on the decision performance of alternative types of symbolizations.

Symbolization shading is usually employed in choropleth maps and cartograms for portraying the spatial distribution of a quantitative variable. Research in cognitive psychology suggests that people tend to interpret the expansion of a zip code area as an indication of its importance (Brewer and Campbell 1998). Because zip code area size per se does not carry any information in pure shading symbolizations (choropleth maps), systematic biases in the judgment of the attractiveness of alternatives could emerge (Wedel and Pieters 2008). In contrast, the combined symbolization of shading and distortions is not expected to be vulnerable to this type of bias because the distortion of zip code areas is actually used to represent one of the decision criteria. When alternatives are more similar, biased perceptions may more easily outweigh real differences. Thus, we expect that the similarity of alternatives moderates the effects of alternative symbolizations (shading versus shading and distortions) on decision performance:

> H_6: A greater similarity of alternatives improves the decision performance of the shading and distortions combination compared with multiple pure shading.

User Attributes and Time Pressure

Because of our focus on symbolizations and factors under the control of GIS designers and users, we do not formulate explicit hypotheses pertaining to user attributes and time pressure. However, in line with related literature, we expect several effects of user attributes and time pressure on decision performance.

User attributes can exert a significant influence on decision performance and therefore should be considered when symbolizations are assessed. In particular, cognitive skills tend to have a strong impact on decision making. Ekstrom, French, and Harmann (1976) divide cognitive skills into spatial ability, verbal fluency, and logical reasoning. The types of cognitive skills required during the decision-making process depend on the type of problem. It has been shown that the resolution of spatial tasks and working with maps require good spatial ability (Cooper 1980; Ekstrom, French, and Harmann 1976; Golledge and Stimson 1997). Spatial ability tests are particularly effective at predicting performance differences among people in geographical map reading (Lloyd and Bunch 2005). These tests require respondents to combine spatial information from multiple figures, as in the tasks in our experiment in which respondents must develop a summary assessment of information distributed on several maps. Thus, we expect that people with better spatial ability will make more accurate and efficient decisions. We expect that users with less map experience (in general) will need more time and be more likely to choose suboptimal decision alternatives. Following Van Bruggen's (1992) findings, we expect that decision makers with greater map experience will report higher decision confidence. We also expect that spatial ability and map experience moderate the effect of task complexity on decision performance. Although simpler tasks should also be successfully completed by people with moderate spatial abilities, we expect them to have increasing difficulty with more complex tasks. Finally, we expect analysts with map experience to be equipped with knowledge about the strengths and weaknesses of alternative GIS thematic maps and to be partly able to counterbalance these effects.

The time available to solve a problem is an important factor for assessing the efficiency of symbolizations because managers must often inspect a large number of potential alternatives and make decisions under time pressure (Hwang 1994). Time pressure typically has a negative impact on objective decision performance (Zakay and Woller 1984). Furthermore, we expect that the perceived ease of task (Hwang 1994; Payne 1976) and decision confidence will be lower under time pressure.

Experimental Study

We tested the hypotheses reflected in our conceptual model in an online experiment using a mixed between-within subjects experimental design (see Table 3). The between-subjects design variation was 7 (map groups) × 2 (time pressure and no time pressure). Each respondent within a map/time pressure group completed four tasks of varying complexity from the domain of retail site selection.

After a brief introduction and one learning task (Kayande et al. 2009) to familiarize the respondents with the usage of the relevant GIS thematic maps, we randomly assigned them to one of the experimental groups. In each task, we instructed the respondents to choose the most attractive of five potential store locations for a furniture retailer that planned to enter a new market. The learning tasks were comparable to the tasks in the main part; how-

TABLE 3
Mixed Between-/Within-Subjects Experimental Design

GIS Thematic Maps	Symbolization	Symbol Overload Handling	Resulting Map Groups	
Between Subjects				
Choropleth map	Shading	___	1	× **Time Pressure** (Yes, no)
Cartogram	Shading and distortions	___	2	
Proportional symbol map	Circles	Symbol squeezing	3	
		Symbol overlap	4	
Diagram map	Bars	Symbol squeezing	5	
		Symbol overlap	6	
		Symbol dislocation	7	

	Task Complexity	
	Similarity of Alternatives	**Number of Decision Criteria**
Within Subjects		
Task 1	60%	2
Task 2	30%	2
Task 3	60%	6
Task 4	30%	6

ever, the respondents were shown the correct solution after this task and the way it was calculated to ensure proper interpretation. The participants in the study were not aware of the varying degrees of task complexity before participating in the experiment. For the decisions in the main part of the experiment, we instructed them to base their decisions only on the information shown in the GIS thematic maps provided (for illustrative examples, see Web Appendix W1 at http://www.marketingpower.com/jmnov10). We also controlled for user attributes (map experience and spatial ability). In addition, we included questions about personal characteristics, such as sex, age, profession, and purpose of professional use of GIS (if any). In what follows, we first provide more details on the map groups, the manipulation of time pressure, and the task complexity of our experiment. Then, we describe how we measured the covariates and the decision performance metrics.

The seven map groups result from combinations of symbolizations and overload-handling options (see Table 3). Our experimental design was not fully balanced, because only the symbolizations bars and circles are actually affected by symbol overload. Furthermore, to keep the experiment manageable, we focused only on GIS symbolizations that are currently used in practice. We constructed all maps used in the experiment using ArcGIS 9. For simplicity's sake, catchment areas (depicted as spheres around locations) had the same magnitude for all locations.

We constructed time pressure as the second treatment factor. We told one subgroup of the respondents (time pressure group) up front that both the quality of the solution and the time required to solve the tasks are relevant. During task completion, we showed the respondents a countdown of the time remaining to complete the task. We fixed the time budget per task at the median problem-solving time of participants from the no-time-pressure experimental group. After the allotted time had elapsed, the map disappeared, and the decision needed to be made. When the respondent did not use the whole time budget, he or she was automatically directed to the next task. We told the remaining respondents to focus only on decision quality (no time pressure).

To control for task complexity, we considered the differences (in percentage) in revenues between the optimal store location and the second-best option and the number of decision criteria (see Table 3). Tasks including lower revenue differences and a higher number of decision criteria are more complex. For Tasks 1 and 2, the respondents considered two decision criteria: average purchasing power (E_i) and population (Z_i). Tasks 3 and 4 included the following four additional decision criteria: transport connection (P_i), target group share (R_i), parking space availability (C_i), and competitive intensity (A_i) per zip code area i. We computed the revenues for tasks with two variables using Equation 1, and we computed the revenues for tasks with six variables using Equation 2:

$$(1) \qquad S_2(p) = \sum_i d_i \times (E_i \times Z_i)(i = 1, ..., I), \text{ and}$$

$$(2) \qquad S_6(p) = \sum_i d_i \times (E_i \times Z_i \times P_i \times R_i \times C_i \times A_i)(i = 1, ..., I),$$

where $S_{2(6)}(p)$ denotes the revenues of site location p and d, a variable indicating the proportion of a zip code's area that belongs to the catchment area of this location. We considered zip code regions that only partially entered the catchment area proportional to the geographically overlapping area. Note that though Equations 1 and 2 imply a multiplicative attraction model, we manipulated our tasks in such a way that an additive functional form would yield the same site location as the optimal solution. We used Equations 1 and 2 to design appropriate tasks, to represent them on maps, and to calculate the decision accuracy. We designed the less complex tasks, 1 and 3, in such a way that the second-best store locations show a deviation from the optimal revenue of 60%, whereas Tasks 2 and 4 showed solutions that were closer together, with a deviation of approximately 30%. In addition, we controlled for the correlation (fixed at approximately .20) between the decision criteria across the zip code regions belonging to a catchment area because uncontrolled intercorrelations could affect the difficulty of decision making.

Different map characteristics determine the way multiple decision criteria can be visualized on the resultant maps. While choropleth and proportional symbol maps can deal with only one criterion, cartograms can display two criteria per map. Diagram maps can display up to three criteria without causing excessive symbol overload. Accordingly, for tasks with two (six) decision criteria, respondents received two (six) maps when assigned to symbol or choropleth maps. They received one (three) map(s) for cartograms and one (two) map(s) for diagrams (see Web Appendix W1 at http://www.marketingpower.com/jmnov10).

With respect to user attributes, at the end of the online questionnaire, we measured the spatial ability of respondents with tests developed by Ekstrom, French, and Harmann (1976): the form board, the paper folding, and the surface development tests (for more details and examples, see Web Appendix W2 at http://www.marketingpower.com/jmnov10). All respondents were told that they had six minutes to solve these tests across a total of 12 tasks. After this time, the questionnaire automatically ended, and the test score results were sent back to respondents who had elected to receive them. We measured map experience on a seven-point rating scale. Following the online experiment, we asked the respondents to provide information about their familiarity with and past experience in using diverse GIS thematic maps.

Our main variable for measuring the objective quality of each decision is the decision accuracy, defined as the percentage difference between the revenues (see Equations 1 and 2) of the optimal site and the revenue of the site the respondent chose. For the correct decision, the decision accuracy equals 100%; values lower than 100% can be interpreted as the respective site's percentage loss in revenues compared with those of the optimal site. Our second objective measure captured the time respondents took to solve a specific task: decision efficiency in seconds. We measured a respondent's decision confidence and perceived ease of task on seven-point rating scales.

Data and Results

In this section, we first report some important sample characteristics and then discuss the results in the context of the conceptual framework. The online experiment took place in May and June 2009. A total of 1349 respondents with an average age of 30.4 years participated in the study. The sample consisted of 41% female respondents. Broken down by occupation, 34.9% of the participants were GIS experts (they use GIS professionally), 19.4% were employed in the area of site location planning, 45.5% were students, and 8.6% were classified as "other." In our sample, site selection (75%) was the most frequent marketing application of GIS users, followed by customer segmentation (53%), direct marketing (40%), sales planning (34%), and sales force planning (33%). Our survey showed that the most frequently used GIS thematic maps in marketing practice are choropleth maps (with a mean of 4.53 on a seven-point rating scale, where 1 = "never used" and 7 = "often used"), followed by proportional symbol maps (M = 3.70) and diagram maps (M = 3.65). Cartograms (M = 1.94) are rarely used in practice. On average, respondents correctly solved 8.09 of 12 tasks in the spatial ability part of the questionnaire; mean map experience was 4.74.

The manipulation check for time pressure confirms that participants in the no-time-pressure group needed significantly (17.5 seconds; $p < .01$) longer to complete the task than the group with time pressure (the average task completion time was 35.5 seconds). We conducted a check of our task complexity manipulation by comparing the perceived ease of task (PET) across the four tasks. This comparison confirms that participants perceived the manipulation as we intended ($PET_{task1} = 5.32$, $PET_{task2} = 4.58$, $PET_{task3} = 3.88$, $PET_{task4} = 3.72$; $p < .01$).

Types of GIS Symbolization

We tested the hypotheses on the relevant relationships in our framework with a series of analyses of variance. With respect to the covariates spatial ability and map experience, we found no systematic differences between any subgroups that are tested against each other ($p > .05$). We hypothesized (H_1) the superiority of the visual variable size (symbolized with circles or bars) over the visual variable value (shading). The performance of the experimental groups with respect to objective metrics—namely, decision accuracy (DAcc) and decision efficiency (DEff)—clearly indicates significant differences between the GIS symbolizations circles or bars compared with shading ($p < .01$), providing support for Bertin's (1983) sign system. Figure 4 plots the means and confidence intervals for each of the respective decision performance measures and experimental cells. However, the subjective performance metrics provide only marginal support for higher decision confidence (DCon) for circles or bars versus shading ($p < .1$), and PET does not differ at all across these symbolizations.

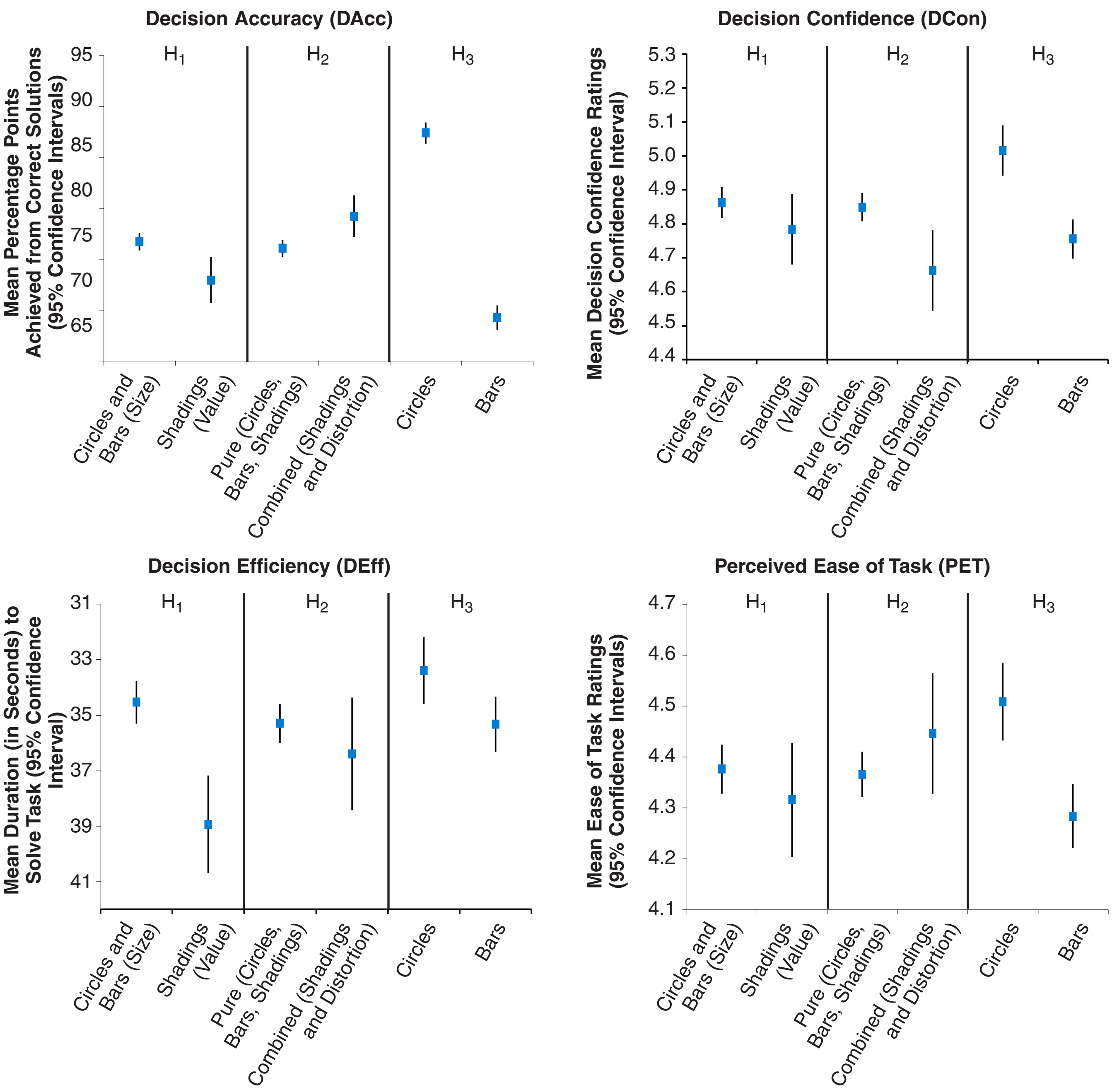
In partial support of H_2, we find that DAcc is higher for the combined symbolization than for multiple pure symbolizations ($p < .01$). However, DCon is lower for the combined symbolization ($p < .01$). We do not find any significant differences in DEff and PET. The low levels of experience with shading and distortions (see sample descriptives, which show relatively low usage of shading and distortions in marketing practice) could explain their lower subjective decision quality (Van Bruggen 1992).

We find further support of H_3, which hypothesizes the superior performance of circle over bar symbolizations. The plots in Figure 4 illustrate that circles clearly dominate bars in terms of all decision performance metrics (DAcc, DCon, PET: $p < .01$; DEff: $p < .05$).

Symbol Overload Handling

With respect to symbol overload–handling options for circles, the results (see Figure 5, Panel A) show that overlap (in contrast to our expectation) leads to better decision quality (DAcc, DCon: $p < .01$) than squeezing. In contrast, bars yield the highest decision quality for squeezing, followed by overlap (DAcc: $p < .01$; DCon: $p < .05$). Dislocation (a

FIGURE 4
Decision Performance for Experimental Cells Investigated Under H_1–H_3



frequently used option for handling bar overload in practice) results in the worst decision quality ($p < .01$).

Figure 5, Panel A, visualizes the interaction of symbolization and overload-handling options for all four performance metrics. The results largely support H_4 (Gestalt principle of closure)—that is, circles outperform bars when overlap is used to handle symbol overload (DAcc, DCon: $p < .01$; PET: $p < .05$; DEff: $p > .1$). Next, we find that using bar dislocation leads to poorer decision performance than bar overlap, providing clear support for H_5 in terms of all decision performance metrics (DAcc, DCon, PET: $p < .01$; DEff: $p < .05$).

Task Complexity

Regarding task complexity, the results support the expectations posited in our framework; that is, we find a negative influence of a greater similarity of alternatives on DAcc, DCon, and PET ($p < .01$). Consistent with H_6, a higher level of similarity among alternatives (i.e., increased task complexity) improves the relative performance of the combined symbolization shading and distortions compared with multiple pure shading (DAcc, DEff, PET, DCon: $p < .01$) in terms of both objective and subjective decision performance (Figure 5, Panel B).

FIGURE 5
Decision Performance for Experimental Cells Investigated Under H_4–H_6

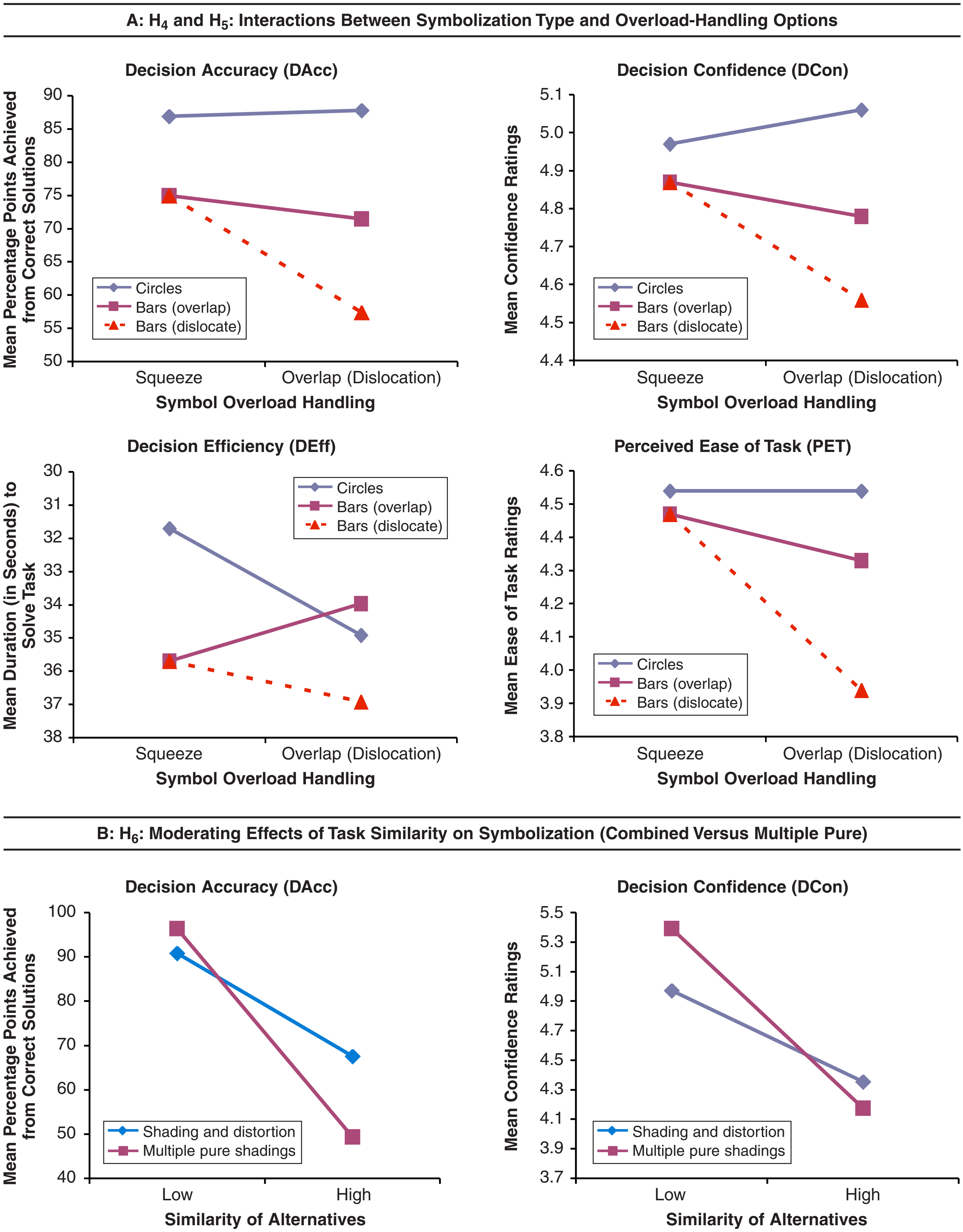
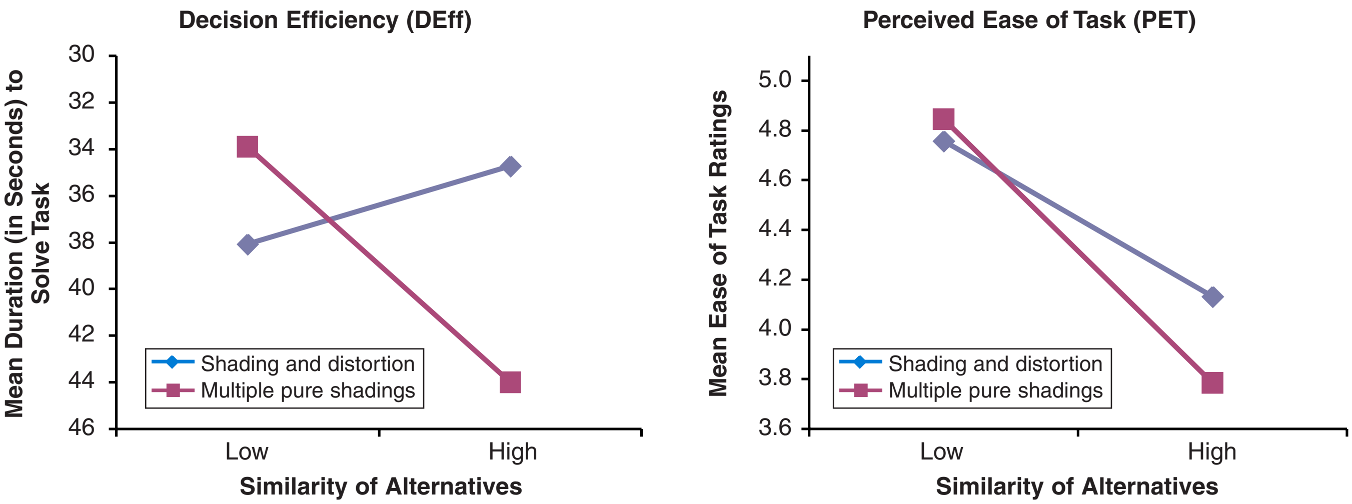


FIGURE 5
Continued

B: H_6: Moderating Effects of Task Similarity on Symbolization (Combined Versus Multiple Pure)



User Attributes and Time Pressure

Regarding the potential influence of user attributes, general map experience is associated with higher objective (DAcc, DEff: $p < .05$) and subjective (DCon, PET: $p < .01$) decision performance. Higher levels of spatial ability do not influence decision accuracy. Even for more complex tasks, we find only marginal differences in decision accuracy. However, respondents with higher spatial ability complete the tasks more efficiently (DEff: $p < .05$) and show higher levels of subjective decision performance (DCon, PET: $p < .01$). For a further assessment of the overall relevance of user attributes with respect to decision accuracy, we split the sample into three groups: those with low, medium, and high map experience or spatial ability. However, average decision accuracy for the subgroups for map experience (spatial ability) showed rather similar values: $DAcc_{low}$ = 74.6%, $DAcc_{medium}$ = 75.5%, and $DAcc_{high}$ = 77.3% ($DAcc_{low}$ = 75.3%, $DAcc_{medium}$ = 76.8%, and $DAcc_{high}$ = 77%). Thus, the effects of user attributes turn out to be less evident than expected and lower than the size of effects caused by alternative symbolizations.

As we expected, time pressure negatively affects subjective decision performance metrics (DCon, PET: $p < .01$) and DEff (see manipulation check). Notably, however, this is not true for decision accuracy. The mind seems to be capable of efficiently processing a vast amount of visual information (i.e., the assessment of five site locations on up to six equally relevant GIS thematic maps) even under time pressure. We also checked whether time pressure moderates the relative decision performance of alternative symbolizations, which is not the case.

Conclusion, Limitations, and Further Research

In marketing practice, the use of GISs is becoming increasingly important. More than 50% of retailers and direct marketers integrate them into their decision support systems to visualize geospatial marketing data. A GIS typically provides the analyst with various GIS thematic maps (choropleth maps, cartograms, proportional symbol maps, and diagram maps). Each of these GIS thematic maps differs in the way it makes use of various symbolizations (shading, shading and distortions, circles, and bars) and the way it handles symbol overload (squeezing, overlapping, and dislocation of symbols) to represent the underlying spatial data of interest.

Given the practical significance of marketing decisions derived from GIS thematic maps, surprisingly little is known about errors that might occur during visually assisted decision-making processes. The fundamental premise of this article is that the various ingredients of GIS thematic maps affect the performance of decision makers. Drawing on prior elementary empirical findings and related literature, we developed a conceptual framework that enables us to experimentally explore several previously proposed interrelationships in a marketing decision-making context. In doing so, we systematically examine differential effects of manipulations conducted during a large-scale online experiment with 1349 participants who performed a series of site selection tasks. Our assessment distinguishes between objective (decision accuracy and decision efficiency) and subjective (decision confidence and perceived ease of task) metrics as surrogate measures of decision quality and the decision process. In addition to symbolization-related factors, we manipulated task complexity and time pressure in the experimental design. Because decision makers and GIS designers have less control over the tasks to be solved and users' background characteristics, we focus the initial discussion of our major insights on the proper choice of alternative symbolizations and devices for symbol overload handling.

Discussion of Findings

First, across all manipulated symbolizations, on average, respondents selected site locations that yield 23.4% lower revenues than the optimal sites (on average, randomly selecting one of the five sites across the four tasks would result in 56.2% lower revenues than the optimal sites). However, this figure varies significantly depending on the type of symbolization used, and our results suggest that much can be gained by choosing the proper symbolization. In decreasing order of decision accuracy, circles perform best in terms of objective decision quality, followed by combined shading and distortions, shading, and bars. The findings for all other decision performance metrics confirm the superiority of circles versus other symbolizations. This also holds for more complex decision tasks, including multiple criteria to be considered. However, our findings on the decision performance of alternative symbolizations do not correspond to their respective usage intensity in marketing practice, pointing to unused potential for improvement in marketing practice.

Second, our findings suggest that the way symbol overload is handled in GIS thematic maps based on circles and bars also matters. We find that compared with circles, bars show greater sensitivity to overlap-handling options. We also find that dislocated bars result in the most significant decline in decision quality. This is noteworthy because dislocation (probably due to its precision) is frequently used in practice for handling bar overload. This suggests that the most precise representation does not always lead to better decisions and indicates the importance of a creating a Gestalt understanding of the spatial relationships.

Third, across all investigated symbolizations and overload-handling options, the best decisions, with an average decision accuracy of 87.8%, resulted from overlapping circles; the poorest decisions were derived from bars using dislocation (decision accuracy = 57.4%) to handle overload. Thus, we conclude that alternative symbolizations for the same underlying quantitative data cause remarkable differences in expected revenues of up to 30.4 percentage points. With respect to time pressure, our overall results regarding objective decision quality remain remarkably stable. We find that time pressure exerts only a direct effect on subjective decision performance metrics.

Theoretical Contribution

With respect to our theoretical contribution, we note that our results uncover problematic aggregations across various size symbolizations in a GIS context. We confirm the findings of the extant cartographic literature (Bertin 1983) regarding such questions as the dominance of the visual variable size (symbolized with circles or bars) versus the visual variable value (shading) in terms of objective decision performance. In contrast, subjective decision performance indicates hardly any difference between the visual variables size and value. The lack of differences in subjective decision performance could explain the widespread use of these three symbolizations in practice. However, our results highlight large differences between alternative size symbolizations (circles versus bars) and suggest a need to carefully reflect the usefulness of GIS thematic maps at the level of individual symbolizations. Drawing on the principles of Gestalt theory, our framework further proposes to differentiate among the various options for symbol overload handling associated with specific symbolizations. In addition, we consider combined symbolizations (shading and distortions) and assess their usefulness for marketing decision making. From the literature from psychophysics-based guided search theory, we expected higher decision performance associated with the combination of shading and distortions. We identify significantly higher levels of decision accuracy for shading and distortions in relation to the other pure symbolizations. However, confidence in the derived decisions was lower. We explain this discrepancy between objective and subjective decision quality associated with shading and distortions as being due to low usage in practice.

We found that respondents with greater map experience performed better. However, we could not find any differences between respondents with varying spatial ability. Overall, we found that making correct decisions based on maps hardly depends on the personal characteristics of the decision makers. Thus, if the appropriate symbolization is used, even people with moderate spatial ability and little map experience can identify good solutions. This finding highlights the potential of GIS thematic maps as an effective decision support tool. The limited dependence of GIS thematic maps on user characteristics also points to the potential of GIS thematic maps in facilitating communication between managers with diverse professional backgrounds.

Managerial Implications

Designers of GISs developing new toolboxes for marketing applications, such as site selection or direct marketing campaigns, can use our findings to configure their default options, such as the choice of the appropriate symbolization or the way information overload is handled. In general, dislocation of symbolic representations should be avoided. In particular, proportional symbol maps and cartograms should be available (default) options for representing quantitative data in any GIS. The relatively good performance of cartograms indicates that further/new combinations of symbolizations should be evaluated. Even when multiple criteria need to be represented in multiple proportional symbol maps, they seem to be a better option than representing the same data in fewer diagram maps. The differences identified between subjective and objective decision performance indicate that users cannot always rely on their feelings about the relative performance of symbolizations. This emphasizes the relevance of feedback mechanisms or training modules for users of GIS (Kayande et al. 2009) in helping them learn more about the potential (objective) advantages and drawbacks of specific symbolizations. A higher level of confidence regarding the appropriate symbolizations should increase their usage and help people avoid significant costs associated with incorrect site selection decisions.

Limitations and Future Research Directions

To the best of our knowledge, the experimental study we present here is among the most complete and in-depth empirical examinations of the value of GIS thematic maps in assisting decision making in a marketing context. This study focuses only on static GIS thematic maps. It would be worthwhile for further research to investigate whether our results are generalizable to new visualization techniques, such as dynamic mapping techniques (see, e.g., the human–computer interaction laboratory [http://www.cs.umd.edu/hcil/] that is part of the University of Maryland's Dynamaps project, which focuses on displaying spatial information as well as associated attribute data). Visualizing spatiotemporal data in marketing could indeed provide valuable information about the movement of objects in space and over time. Dynamic mapping might be useful in marketing to support the identification of current or past changes at a site location, such as the development of revenues, competition, purchasing power, and so on, indicating trends in a site's attractiveness over time. However, because of the limited use of dynamic mapping in site selection practice and to avoid further experimental complexity, we focused only on static methods of symbolization in our study.

Appendix
Glossary

Cartogram: A map that purposefully distorts geographic space on the basis of the value of a theme (e.g., making the size of zip code area proportional to purchasing power) (Slocum, McMaster, and Kessler 2009).

Choropleth Map: A map in which enumeration units (or data collection units) are shaded with intensity proportional to the data values associated with those units (Slocum, McMaster, and Kessler 2009).

Diagram Map: A diagram map represents any event distribution by means of diagrams (bar or pie) that are placed on the map inside the structure of territorial division and that expresses the summarized value of this event within the limits of this territorial structure.

Dislocation: An alternative way of avoiding symbol overload in which diagrams (e.g., bars) are placed outside the map but are linked to their respective areas by a line.

Gestalt Theory: Emphasizes higher-order cognitive processes in the context of behaviorism. The focus of Gestalt theory is the idea of perceptual "grouping"—that is, characteristics of stimuli cause people's vision to structure or interpret a visual field or problem in a certain way (Wertheimer 1923). The primary factors that determine the perception of a grouping are as follows: (1) proximity—elements tend to be perceived as grouped together according to their nearness; (2) similarity—items similar in some respect tend to appear as being grouped together; (3) closure—items are perceived as grouped together if they tend to complete some entity; and (4) simplicity—items are organized into simple figures according to symmetry, regularity, and smoothness. These factors are called the principles of organization and are explained in the context of perception and problem solving.

Isopleth Map: A map displaying the distribution of an attribute (variable) in terms of lines connecting points of equal value (Slocum, McMaster, and Kessler 2009).

Symbolization: Different types of symbols that are available in GISs for the representation of quantitative data (circles, bars, shadings, and area distortion).

Proportional Symbol Map: Point symbols are scaled in proportion to the magnitude of data at the point locations; for example, circles of varying sizes are used to represent purchasing power (Slocum, McMaster, and Kessler 2009).

Overlap: An alternative way of avoiding symbol overload in which symbols, such as circles or bars, are stacked.

Size: A visual variable for which the magnitudes of the symbols are varied (e.g., using circle size, bar length, or the size of distorted areas to represent purchasing power).

Symbol Overload: A phenomenon that typically occurs when many symbols need to be portrayed in a small area of the map.

Symbol Squeezing: An alternative way of avoiding symbol overload in which symbols, such as circles or bars, are squeezed so that they do not overlap.

Thematic Map: A map used to emphasize the spatial distribution (or pattern) of one or more geographic attributes (e.g., population per zip code area) (Slocum, McMaster, and Kessler 2009).

Value (Shading): A visual variable that symbolizes quantitative data through shadings, with the relative brightness or darkness (whether black or any other color) proportional to the attribute (e.g., purchasing power) to be presented.

Visual Variables: A specified set of symbols that can be applied to data to translate information.

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