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Author(s): Nicholas H. Lurie and Charlotte H. Mason

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Nicholas H. Lurie & Charlotte H. Mason

Visual Representation: Implications for Decision Making

A large number of visualization tools have been created to help decision makers understand increasingly rich databases of product, customer, sales force, and other types of marketing information. This article presents a framework for thinking about how visual representations are likely to affect the decision processes or tasks that marketing managers and consumers commonly face, particularly those that involve the analysis or synthesis of substantial amounts of data. From this framework, the authors derive a set of testable propositions that serve as an agenda for further research. Although visual representations are likely to improve marketing manager efficiency, offer new insights, and increase customer satisfaction and loyalty, they may also bias decisions by focusing attention on a limited set of alternatives, increasing the salience and evaluability of less diagnostic information, and encouraging inaccurate comparisons. Given this, marketing managers are advised to subject insights from visual representations to more formal analysis.

Marketing managers and consumers have more information than they know what to do with. High-speed land and wireless networks, scanning and tracking technology, and large data warehouses offer increasing opportunities for managers to monitor and respond dynamically to changing market conditions (Alba et al. 1997; Blattberg, Glazer, and Little 1994). Product comparison Web sites, Web-based discussion groups, and online retailers provide consumers with easy access to product information and reviews to help them choose from an ever-expanding range of products and services. However, the benefits of all this information are often not realized, because managers and consumers are increasingly overloaded with information in electronic environments (Farhoomand and Drury 2002; Lurie 2004; Schwartz 2004).

Much of the information that managers and consumers receive is symbolic in nature, consisting of numbers and text. Processing this kind of information is inherently effortful because it involves rule-based reasoning, in which data are abstracted into values that, in turn, are given meaning through formal rules and deliberative analysis (Sloman 1996). At the same time, humans have evolved great visual and spatial skills, including the ability to detect edges and discontinuities, things that stand out, variations in color and shape, and motion; to recognize patterns; and to retrieve information using visual cues (Kosslyn 1994). This suggests that a solution to information overload could be to present information in ways that engage the use of the associative system, in which meaning is ascribed through gestalt and automatic processes, such as visual recognition (Sloman 1996). By drawing on humans' highly developed skills of perceptual sense making, the old adage that "a picture is worth a thousand words" may be replaced with "a picture is worth a thousand rows [of data]" (Youngworth 1998).

Importantly, the same complex technological innovations that enable the collection and dissemination of massive amounts of information have led to tools that promise to help decision makers reduce large data sets to simple visuals. These visualization tools range from common bar graphs to sophisticated virtual environments. Information visualization offers a way to shift cognitive load to the human perceptual system through graphics and animation (Lohse 1997; Zhang and Whinston 1995). Visual representations can enlarge problem-solving capabilities by enabling the processing of more data without overloading the decision maker (Tegarden 1999).

Although visualization tools are increasingly available to consumers (e.g., Fidelity Investments's [2006] visual map of the stock market from SmartMoney.com) and there is growing interest from managers and academics, particularly among researchers in information technology (Card, Mackinlay, and Schneiderman 1999), little is known about the implications of such tools for marketing managers and consumers. Vendors claim that their tools will lead to better, faster, and more confident decisions, and indeed there is some anecdotal evidence that these tools can make a difference (Borzo 2004; Esfahani 2005; Miller 2004). However, there has been little systematic analysis of the implications of these tools for decision making.

Visualization tools are particularly common in fields such as genetics and biology (Kraemer and Ferrin 1998; Montgomery et al. 2004), as well as medicine (Sinha et al. 2002; Trelease 2002), but business applications are said to lag the sciences by as much as ten years (West 1995). More

Nicholas H. Lurie is Assistant Professor of Marketing, College of Management, Georgia Institute of Technology (e-mail: lurie@gatech.edu). Charlotte H. Mason is Associate Professor of Marketing, Kenan-Flagler Business School, University of North Carolina, Chapel Hill (e-mail: charlotte_mason@unc.edu). The authors thank Rashi Glazer, Ryan Hamilton, Marti Hearst, Donna Hoffman, and Stacy Wood for their helpful comments.

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important, the aspects of common interest to information technology researchers, such as speed and accuracy on well-defined and simple tasks (Bederson et al. 1998; Byrne 1993; Kobsa 2001; Plaisant 2004), provide few insights into the potential implications of visual representation for decision-making processes and outcomes in field settings in which data exploration and discovery are necessary (Cleveland 1987). In this article, we present a framework of how visual representations are likely to affect the decision processes or tasks that marketing managers and consumers commonly face, particularly those that involve the analysis or synthesis of substantial amounts of data. Within this framework, we develop a set of testable propositions that serve as an agenda for further research.

Visual Representation

Early work extending visual representation beyond simple charts and graphs found that graphic displays enable scientists to "make use of the uniquely human ability to recognize meaningful patterns in the data" and to see "patterns in data that would never have been picked up with standard statistical methods" (Kolata 1982, p. 919). Among scientists, graphic representations increased in popularity with greater acceptance of empirical, as opposed to rational, approaches in which evidence, not just theory, drove scientific investigation (Wainer and Velleman 2001). Importantly, the scientific revolution that began in the eighteenth century was accompanied by a change in how graphics were created, from being almost fully deductive and driven by theoretical models to empirical approaches based on the display and interpretation of observed data (Wainer and Velleman 2001).

Researchers have used the terms "information visualization" (Card, Mackinlay, and Shneiderman 1999), "data visualization" (Green 1998), and "scientific visualization" (DeFanti, Brown, and McCormick 1989) to refer to the presentation of information in visual form. These terms are not mutually exclusive and are not always used consistently. Distinctions among these terms are often based on whether the underlying data are numerical or nonnumerical, whether the data are tied to physical or abstract attributes, whether absolute or relative values of data are represented, and the number of variables that are simultaneously represented. Another form of visualization is virtual reality, in which a computer display simulates a three-dimensional, interactive visual environment. In this article, we use the term "visual representation" to encompass these various forms of visualization. Specifically, visual representation involves the selection, transformation, and presentation of data (including spatial, abstract, physical, or textual) in a visual form that facilitates exploration and understanding. We use the term "visualization tool" to refer to a specific implementation, including software applications, of visual representation.

Visualization tools are an intermediate step in converting data into insight (Green 1998). Data characteristics such as dimensionality (both the number of cases and the number of variables), scale (categorical, ordinal, and metric), and cardinality (e.g., binary versus "massively categorical variables") affect which tools are appropriate. Although different visualization tools use different algorithms, all implicitly or explicitly preprocess the raw data. Visualization techniques include using color, size, shape, texture, orientation, and brightness to portray some dimensions; distortion approaches to highlight some data while providing context; graphic portrayals of hierarchical and network relationships; and interactivity (Green 1998).

Importantly, these transformations potentially affect the ultimate insights derived from the data. By changing the presentation of information, visualization tools have implications for both decision processes and outcomes (Bettman and Kakkar 1977). For example, visual representations may make it easier to see patterns and outliers, make certain information more salient and other information less salient, and show detailed information on specific alternatives or provide a context for evaluating focal information. This may improve decision quality. At the same time, visual representations may accentuate biases in decision making and lower performance by increasing attention to particular attributes or less diagnostic information (Glazer, Steckel, and Winer 1992; Jarvenpaa 1990; Mandel and Johnson 2002).

Drawing on prior research in information technology and computer science, as well as decision making and marketing, we focus on two characteristics of visual representations that are particularly likely to affect marketing managers and consumers: (1) the "visual perspective," which is determined by task variables, such as whether a representation can be manipulated by the user (i.e., its interactivity) and the extent to which a representation allows the user to see contextual and/or detail information (i.e., the depth of field), and (2) the "information context," which is determined by context variables that affect the vividness, evaluability, and framing of information. Task variables are general characteristics of information environments, including how much information is presented and how the decision maker can interact and respond to information, whereas context variables refer to data values, colors, and shapes specific to a given decision problem (Bettman et al. 1993; Lurie 2004). Each of these has important implications for how decision makers access and process information and make decisions. For example, in terms of visual perspective, interactivity may enhance realism and, therefore, the extent to which visual representations substitute for terra firma information search (Burke 1996; Burke et al. 1992), and depth of field may change the number of alternatives considered and the perceived differences among choice alternatives. In terms of information context, the effects of alternative visualizations on vividness and evaluability may change the relative ease with which different attributes may be compared and, therefore, choice outcomes (Hsee 1996).

Table 1 provides examples of commonly available visualization tools with applications for marketers and consumers. For each tool, Table 1 indicates whether it affects the visual perspective and/or the information context.

We propose that the visual perspective and information context influence decision processes and outcomes by changing the decision-making frame—that is, what information a decision maker uses and how he or she uses it to

TABLE 1
Examples of Visualization Tools

Visualization Tool	Characteristics Affected: Visual Perspective	Characteristics Affected: Information Context
TableLens (http://www.inxight.com/products/sdks/tl/) TableLens creates a visual representation of large amounts of tabular (e.g., spreadsheet) data, including an interactive interface that enables the user to sort columns, expand and contract rows, and drill down for more details.	✓	
SmartMoney.com's MarketMap (http://www.smartmoney.com/marketmap/) A Treemap (i.e., a two-dimensional representation of hierarchical data in which each element is represented by a cell whose arrangement, size, and color represent attributes of that data element) application used for the reporting of stock portfolio information.	✓	✓
Newsmap (http://www.marumushi.com/apps/newsmap/newsmap.cfm) A Treemap application that visually reflects patterns in news reporting.	✓	✓
ArcGIS (http://www.esri.com/products.html) Geographic information software used for business-mapping applications, such as displaying results by sales territory or other regions.		✓
Lands' End's My Virtual Model (http://www.landsend.com/) An interactive virtual reality application that enables customers to build a virtual image of themselves and then "try" on clothing.	✓	
Fish-Eye Visualizations Nonlinear magnification enables the user to see details of immediate interest (i.e., focus) and the overall picture (i.e., context). Examples include maps, charts, and text-based applications.	✓	

Notes: Table 1 identifies which characteristics of visual representation a given tool is likely to affect: (1) the visual perspective (i.e., interactivity or depth of field) or (2) the information context (i.e., vividness, evaluability, or framing).

gain insights and make decisions. Figure 1 provides an overview of the aspects of visual representations, outcome variables, and associated propositions that are the focus of this article. Although these aspects are by no means exhaustive, they offer a starting point for understanding how visual representations are likely to affect the decisions of marketing managers and consumers. In this article, we focus on main effects of visual representations. For completeness, Figure 1 also includes user characteristics that are likely to moderate the proposed main effects on decision-making processes and outcomes. We examine some of these in the "General Discussion" section. However, for brevity, we limit our discussion and do not develop formal propositions about these moderators.

Visual Perspective

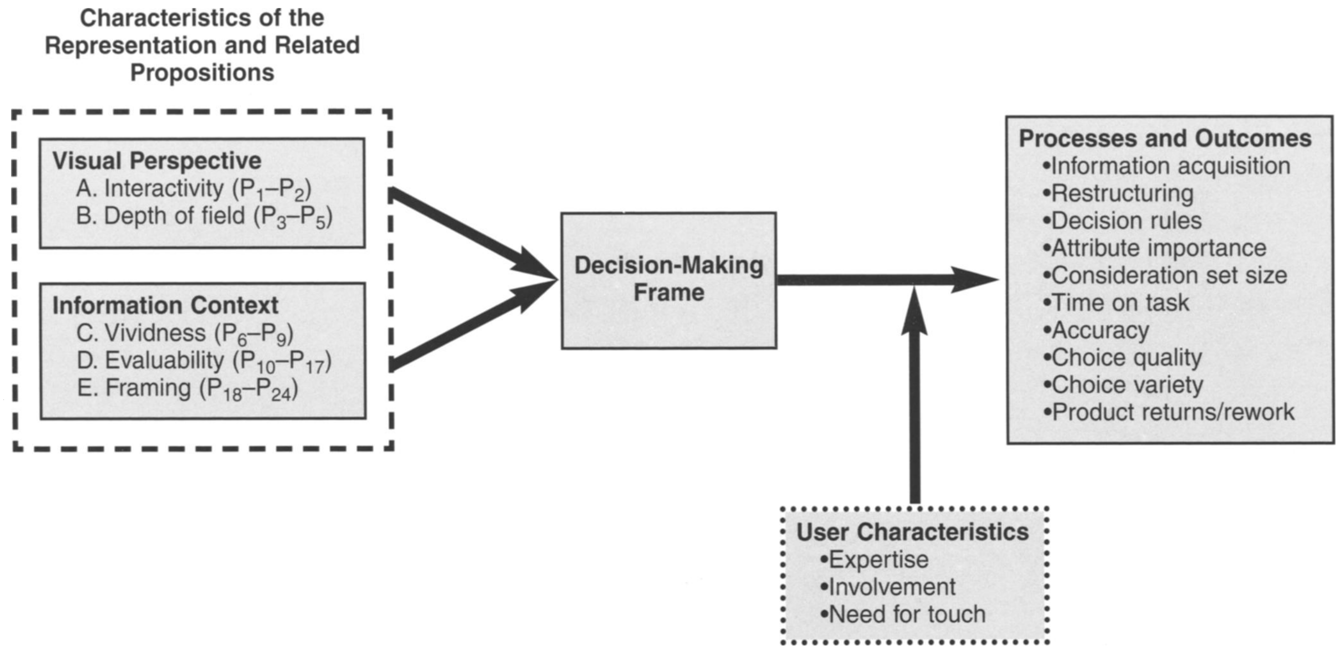
We use the term "visual perspective" to refer to how a given visual representation changes the relationship between visual information and the decision maker. The first aspect of visual perspective is "interactivity," or the user's ability to change perspective, for example, by rotating or simulating movement around an image. The second aspect of visual perspective is "depth of field," which refers to whether a tool provides context by displaying an overview of large numbers of data points and/or more focused detail information on particular data points of interest.

Interactivity

Interactivity distinguishes many current visualization tools from more traditional graphic representations. Such tools enable the user to restructure the representation of information (Coupey 1994) by interactively changing which variables are shown, cut points for displaying variables, and whether particular variables are shown by colors or shapes. For example, Spotfire's DecisionSite (2006) enables the user to determine interactively which variables to display and the range of values shown. Other tools allow users to group objects and move selected objects into focus (Chuah et al. 1995) or to prune information from display (Kumar, Plaisant, and Scheiderman 1997). By giving users increased control over the information flow (Ariely 2000), interactive visualization tools have important implications for decision making.

By enabling decision makers to restructure the information environment, interactive visualization tools may create a better match between the task and the decision environment, which should improve decision quality and/or reduce the effort required (Eick and Wills 1995). Because restruc-

FIGURE 1
Characteristics of Visual Representations and Implications for Decision Making



Notes: This figure proposes that characteristics of visual representations, including the visual perspective (interactivity and depth of field) and information context (vividness, evaluability, and framing), combine to form the decision-making frame, which in turn has implications for decision-making processes and outcomes. Figure 1 includes a partial list of these processes and outcomes. User characteristics, such as expertise, involvement, and need for touch, are proposed to moderate the effect of the decision-making frame on processes and outcomes. For example, expertise is likely to moderate the extent to which interactivity leads to greater information restructuring (see the "General Discussion" section).

turing leads to more compensatory decision making but is contingent on the effort involved (Coupey 1994), interactive visualization tools that lower the cognitive cost of restructuring information can also lead to more compensatory processing. This suggests that marketing managers using interactive visualization tools will be more likely to consider multiple factors than managers using traditional reports.

In addition to information restructuring, many visualizations allow decision makers to interact with the visual representation. An increasingly common interactive visualization tool, particularly for consumer marketing, is virtual reality, in which a real or imagined environment is visually simulated (potentially with sound, motion, and other effects) and explored interactively. Sprint's (2006) 360-degree views of telephones and Volkswagen's (2006) full-motion tour enable users to walk around or through a product. Others, such as Nike's (2006) iD, Trek's (2006) Project One, Lands' End's (2006) My Virtual Model (see Figure 2, Panel A), and La-Z-Boy's (2006) room planner, allow users to create and see customized products, to see what they would look like in a particular outfit, or to see how new furniture would look in their homes. Interactive virtual reality tools can also be used to test new products (Urban et al. 1997; Urban, Weinberg, and Hauser 1996) and to examine the effects of alternative promotion, display, and pricing schemes (Burke 1996; Burke et al. 1992).

By mimicking the act of touching and feeling products, interactive virtual reality visualizations may be better substitutes for haptic experiences than textual information. This is likely to increase consumers' confidence in their choices and lower the proportion of physical search relative to online search. For example, a couple buying a house may first use traditional (text) online information to screen alternatives and then virtually "visit" more houses than they otherwise would have physically visited. Virtual reality tools may also enable them to screen out more houses before physically visiting them.

By making users more comfortable, interactive virtual reality tools can increase product trial and adoption (Ganapathy, Ranganathan, and Sankaranarayanan 2004; Urban et al. 1997). In support of this, a recent report shows that Lands' End's online customers who use My Virtual Model have a 34% higher conversion rate and an 8% higher average order value (Miller 2004). Similarly, users of Restoration Hardware's eCatalog viewer, which enables customers to design furniture and lighting, have twice the conversion rates of those who use the traditional Web interface, and Timberland's Boot Studio, which allows shoppers to customize their boots, gets three times as many hits and higher conversion rates than the basic Web site (Esfahani 2005; Scene7 2005). In addition, differences between expectations and the delivered product are likely to be lower, thus

FIGURE 2
Visual Perspective: Interactivity and Depth of Field

A: Interactivity

Lands' End's My Virtual Model enables customers to create a model that looks like them and then virtually try on different outfits.

B: Depth of Field

SmartMoney.com's MarketMap provides both overview and detailed information about stock performance. Stocks are grouped by sector into rectangles whose size shows the firm's market capitalization and whose color shows performance. Green indicates that stock price is up (the brighter the green, the greater the gain), red indicates that stock price is down, and black means no change.

increasing postpurchase satisfaction (Ganapathy, Ranganathan, and Sankaranarayanan 2004; Oliver 1980). Finally, because interactive visualization tools, such as Nike's iD and Trek's Project One, allow consumers to see what different product configurations look like (e.g., whether a particular color combination on a bicycle will be attractive), consumers who use interactive visualizations are likely to make more heterogeneous choices than those who use text-based tools or photos of stock models.[1]

From a managerial standpoint, interactive virtual reality tools are likely to lead to better forecasts of demand, more accurate estimates of elasticity, and more profitable product displays because consumer behavior is more externally valid in virtual than in paper-based environments (Burke 1996; Burke et al. 1992). In particular, virtual reality tools can help managers understand how consumers will interact with a product. As with consumers, business buyers may be more likely to customize virtually presented products and require less product reworking.

This discussion leads to the following testable propositions:

P_1: Compared with noninteractive displays, interactive visualization tools lead to
- a. more information restructuring,
- b. information acquisition that more closely reflects the decision maker's preexisting preferences or knowledge structures,
- c. enhanced use of preexisting decision rules,
- d. more compensatory decision processes, and
- e. more accurate decisions.

P_2: The use of interactive virtual reality visualization tools leads to
- a. higher prepurchase confidence,
- b. proportionally less physical than online search,
- c. greater product trial and adoption,
- d. smaller differences between actual and expected product performance,
- e. higher levels of postpurchase satisfaction,
- f. more heterogeneous choices,
- g. more accurate forecasts of demand and price elasticity when product testing occurs in virtual reality, and
- h. less postpurchase product reworking (returns and exchanges).

Depth of Field

Visual representations vary in depth of field—that is, the extent to which they provide contextual overview versus detail information or enable decision makers to keep both levels in focus at the same time. Depth of field is likely to affect how information is accessed and evaluated. For example, by converting a data point into a pencil-thin bar line, TableLens displays more data in a given space than traditional spreadsheets (Ganapathy, Ranganathan, and Sankaranarayanan 2004). For a manager assessing product sales across different retail stores, this may lead to a better understanding of the range of values of the visualized attributes. In addition, by locating more data in a given visual field, such tools lower the cognitive costs of adding alternatives to a consideration set (Hauser and Wernerfelt 1990); for a consumer, this is likely to increase the number of alternatives considered. At the same time, visualization tools that provide more context rather than more detail and tools that enable more alternatives to be displayed in a given visual field may lead to relatively less compensatory (more selective) decision processes as decision makers eliminate alternatives from consideration (Payne 1976).

Other tools allow decision makers to focus on specific data points. Spotfire's zooming scrollbars enable marketers to change the level of detail to see characteristics of a specific item sold in a specific store on a specific day or to see sales of a product and those of its competitors in multiple retailers over time. More detailed views with more information on each alternative tend to limit the number of alternatives considered, leading to more alternative-based (compensatory) processing (Payne 1976). Thus, a detailed view may lead a manager to focus on why sales were particularly high or low on a given day, whereas a context view may lead the manager to examine why sales have changed over time relative to competitive products. Changes in depth of field may also lead to overconfidence or underconfidence. In particular, visual representations that provide greater detail may lead to overconfidence as users make assessments on the basis of fewer observations, whereas visualizations that provide greater context may lead to underconfidence as users fail to adjust for the larger sample size (Griffin and Tversky 1992).

Other visualization tools emphasize context by showing the relationships between different pieces of information. For example, trees and networks (Card, Mackinlay, and Shneiderman 1999) can represent choice alternatives or illustrate a sales force structure, customers, and product sales. A disadvantage of trees is that they often become unwieldy with large amounts of data. Treemaps (Johnson and Schneiderman 1991) overcome this problem by representing hierarchies through subdivided rectangles so that the tree fits a smaller (rectangular) space; this provides decision makers with overview as well as detailed information (Plaisant et al. 2003), which is likely to increase understanding of attribute values and decision confidence. SmartMoney.com's MarketMap (Fidelity Investments 2006; see Figure 2, Panel B) enables investors to view market, industry, and individual stock performance simultaneously. By increasing the accessibility of contextual information, such tools may also increase decision makers' use of category relative to alternative-specific information. Consequently, consumers using MarketMap may be more likely to use industry and market performance in stock selection than those using traditional line graphs of price changes for a single stock. However, using tools such as Treemaps can be

[1]A counterargument might suggest a reverse effect. In particular, virtual reality visualizations may enable consumers to converge on the most attractive model, thus leading to more homogeneous than heterogeneous choices. Whether virtual reality leads to greater heterogeneity or homogeneity in choices is likely to depend on the extent to which consumers share ideal points (Carpenter and Nakamoto 1989) and to which the choice context encourages variety-seeking behavior (Ratner and Kahn 2002). We thank an anonymous reviewer for this suggestion.

difficult for less experienced users (Bederson and Shneiderman 2003), suggesting that expertise is likely to moderate their relative advantages.

Still other tools combine context with detail views. For example, when choice sets are represented through a hierarchical tree structure, alternatives that do not meet a decision maker's criteria can be "grayed out," whereas alternatives that are still under consideration remain colored. This allows the user to focus on a subset of alternatives but remain cognizant of others (Kumar, Plaisant, and Shneiderman 1997). Another approach is to prune (i.e., remove from display) leaves (e.g., specific alternatives) or branches (e.g., sets of alternatives) that do not meet particular criteria. Research suggests that though fully pruned trees are associated with faster decisions, satisfaction with the interface is highest for partially pruned trees—that is, tree structures that provide visual information about the aspects of eliminated alternatives (Kumar, Plaisant, and Shneiderman 1997). In general, this suggests that choice satisfaction and confidence are likely to be higher for decisions made using partially versus fully pruned structures. In addition, consideration sets tend to be larger when decision makers are instructed to exclude unfavorable alternatives than when they are instructed to include favorable alternatives (Levin, Huneke, and Jasper 2000; Levin, Jasper, and Forbes 1998), implying that more alternatives may be considered for visual representations that involve pruning rather than adding alternatives. For example, a consumer using a Web site with a tree structure of consumer electronics is likely to consider more alternatives than a consumer who must select specific alternatives to compare.

Other approaches to combining context and detail include using different windows to provide both overview and detailed views (Beard and Walker 1990); bifocal views, in which centrally located information is magnified and peripheral information is presented in a demagnified or billboard format (Robertson and Mackinlay 1993; Spence and Apperley 1982); and fish-eye views, which distort information such that focal information is larger and nonfocal information is smaller (Sarkar and Brown 1994). Some results show faster navigation and data identification when an overview is provided (Beard and Walker 1990), whereas others have found that though user satisfaction is higher, navigation may be slower because of the additional cognitive load of dealing with simultaneous views (Hornbæk, Bederson, and Plaisant 2002). Hornbæk and Frøkjær (2001) find that providing both overview and detailed views improves overall understanding of content, that detailed views alone lead to greater speed in answering specific questions, and that fish-eye views increase reading speed. This suggests that whether combining context and detail is superior to either one alone depends on whether the goal is to maximize accuracy or minimize effort (Payne, Bettman, and Johnson 1988). In particular, visual representations that provide contextual information should lead to more consistent preferences than those that do not. However, such representations are likely to involve greater decision-making effort and time.

This discussion leads to the following set of testable propositions:

P_3: Decision makers using visual representations that provide more context than detail or present more alternatives within a given visual field

a. consider more alternatives,

b. have a better understanding of the range of attribute values,

c. engage in less compensatory processing,

d. are less likely to exhibit overconfidence, and

e. exhibit more consistent preferences.

P_4: Decision makers using visual representations that involve pruning alternatives from consideration rather than adding alternatives for consideration

a. consider more alternatives and

b. engage in less compensatory processing.

P_5: Decision makers using partially pruned rather than fully pruned and unpruned visual representations are more satisfied with their choices.

Information Context

Although the visual perspective affects the general relationship between visual information and the decision maker by changing the decision maker's ability to manipulate information and see both details and overview information, the information context affects *which* information the decision maker attends to. Changes in the particular data values, colors, and shapes used in a given visual representation affect how information is accessed and compared. We examine three aspects of information context. The first aspect is "vividness," or the salience of particular information. The second aspect is "evaluability," or the ease with which information can be compared. The third aspect is "framing," or how a given representation changes the reference point or scale against which information is evaluated.

Vividness

Vividness (Nisbett and Ross 1980) refers to the saliency or availability of specific information. More vivid visual information is likely to be acquired and processed before less vivid visual information (Jarvenpaa 1990). Visualization tools are likely to affect vividness simply by presenting data in a form that uses preattentive graphic features, such as line orientation, width, length, and color, which are readily processed with little effort (Bederson and Shneiderman 2003; Healey, Booth, and Enns 1995; Julesz 1981; Treisman 1985). The vividness of graphic information leads to greater attention and, together with interactivity, enhances telepresence, in which the experience of the virtual environment becomes more real than the immediate physical environment (Hoffman and Novak 1996; Steuer 1992).

The vividness of graphic information may increase its use in decision making (Glazer, Steckel, and Winer 1992; Jarvenpaa 1990). An increased focus on graphic information may come at the expense of ignoring other (relevant) information (Glazer, Steckel, and Winer 1992), lead to increased weighting of more salient attributes (Mandel and Johnson 2002), or lead users to overweigh less diagnostic information (MacGregor and Slovic 1986). For example, research in an advertising context has found that when the copy and pictures contain different information, the graphic information disproportionately influences inferences (Smith 1991). Similarly, risk perceptions are higher when relative risk is presented graphically and cost is presented in text format (i.e., numerically) than when both are presented in text format (Stone, Yates, and Parker 1997). Consequently, if consumers are shown a graph of relative product performance and text information on relative product reliability, they are more likely to assess the product on performance. This effect should be reversed if reliability is presented graphically.

In general, when visualizations include both textual and graphic information, the graphic information is likely to receive greater weight. Thus, visualizations using color to show day-to-day changes in stock prices or market share may lead decision makers to act on information that is simply random noise (Barber and Odean 2001, 2002; Gilovich, Vallone, and Tversky 1985). Similarly, providing airline passengers with maps of alternative routes rather than text-based city pairs may enhance Soman and Shi's (2003) finding that consumers prefer trips with only forward progress to those with backward progress but shorter trip times. In particular, map-based visual representations may lead users to focus on direction of travel rather than overall trip times.

Although, in general, graphic information may be more vivid than text information, certain types of visual representations are likely to be more vivid than others. In particular, shapes and colors that "pop out" from the background by being unique, by contrasting sharply, by having the greatest variation in size, or by having the greatest salience to human information processors (Benbasat and Dexter 1985; Jarvenpaa 1990; Simkin and Hastie 1987; Treisman 1988) will be more vivid and therefore more heavily used in decision making. For example, MacGregor and Slovic (1986) find that when facial characteristics are used to represent different features, greater weight is given to attributes represented by eyes and mouths, regardless of the predictive validity of the information represented by these more salient features. Similarly, by using color to make the direction of price changes more vivid, SmartMoney.com's MarketMap (Fidelity Investments 2006) may increase attention to this attribute. Other research suggests that in judgments of proportion, angles of 0 degrees, 90 degrees, and 180 degrees "jump-out" more than other angles (Simkin and Hastie 1987, p. 463). Therefore, if a manager is using a series of pie charts to evaluate salespeople in terms of meeting sales quotas, he or she will be more likely to attend to the performance of salespeople for whom these charts show right angles and to use their performance as a reference for evaluating their colleagues.

Even subtle changes in vividness can affect judgments and decision making. Cleveland and McGill (1984, 1985) find that changing the saturation level of colors in a two-color chart (from both high to both low) affects judgments of size of the two areas. In addition, less frequently occurring shapes and colors are more vivid and are more likely to receive attention because they provide more information and discrimination (West 1996). Furthermore, by focusing attention on particular observations, vividness tends to enhance attention to presented data relative to other information, such as information from memory. In general, decision makers may overestimate the relative frequency or probability of more vivid information (Sherman et al. 1985). For example, a pharmaceutical company using Spotfire's DecisionSite, showing sales by region, might overestimate demand for a drug when sales information is presented as frequency points on a map overlay because of the vividness of this information.

This suggests the following propositions regarding vividness:

P_6: Decision makers using graphic versus text-based presentations of the same information
- a. place greater weight on this information when it is presented graphically,
- b. are more likely to change their choices in response to changes in attributes, and
- c. are more likely to overestimate this information when making judgments.

P_7: Decision makers using visual representations that include graphic as well as text-based information
- a. place greater weight on the graphic information,
- b. are more likely to change their choices in response to changes in attribute values that are shown graphically, and
- c. overestimate the graphic information and underestimate the textual information.

P_8: Decision makers using visual representations for which some information shows greater variance in shape, size, or color
- a. place greater weight on information that shows more variance,
- b. are more likely to change their choices in response to changes in attribute values that show more variance, and
- c. overestimate high variance information and underestimate low variance information.

P_9: Decision makers using visual representations that vary in their presentation of features that are salient in human perception
- a. place greater weight on the more salient features,
- b. are more likely to change their choices in response to changes in attribute values that are shown by salient features, and
- c. overestimate information shown by salient features and underestimate information shown by nonsalient features.

Evaluability

Evaluability (Hsee 1996) refers to the ease with which information can be assessed and compared. By making it easier to compare information, visualization tools enable decision makers to notice changes, recognize outliers, and see patterns more quickly. Making information easier to compare is likely to lead to increased acquisition, weighting, and processing of this information (Ariely and Lynch 2000; Bettman and Kakkar 1977; Bettman and Zins 1979; Hsee 1996; Jarvenpaa 1989, 1990; Kleinmuntz and Schkade 1993; MacGregor and Slovic 1986; Russo 1977; Schkade and Kleinmuntz 1994).

Although practitioners often claim that information visualization leads to better, faster, and more confident decisions (Brath and Peters 2005), whether graphic or textual (tabular) presentations are superior likely depends on the fit between these alternative representations and the nature of the task (DeSanctis 1984; Vessey 1991). Tasks that are predominately spatial in nature include comparisons and assessments of trends, associations, and other relationships in the data. Primarily symbolic tasks include those that focus on discrete data values. Although the same information is presented, graphic presentations enhance the evaluability of spatial information, whereas tables (of numbers) enhance the evaluability of symbolic information (Vessey 1991). Graphic representations are likely to be superior for detecting trends, comparing patterns, and interpolating values. For example, a manager may be more likely to identify a competitor's product as a threat when viewing a visual representation that shows sales of his or her product and the competitor's product over time than when viewing the same information in a table. In contrast, tabular representations are superior for retrieving specific data values (Benbasat 1986; Benbasat and Dexter 1985; Jarvenpaa and Dickson 1988; Vessey 1991). Displays that combine both tabular and graphic information may lead to better performance than either graphic or tabular displays alone (Benbasat 1986).

Relative to tabular data, graphic presentations can lead to biased interpretations (Cleveland and McGill 1984, 1985; Krider, Raghubir, and Krishna 2001; Raghubir and Krishna 1996, 1999). Cleveland and McGill (1984, 1985) find that length judgments are more accurate than area judgments, which in turn are more accurate than volume judgments. Thus, in assessing differences between values, greater accuracy is expected when the information is presented in table form than when it is indicated by object size. Other research has found that the accuracy with which bar height is judged is lower for taller bars and when other bars are present (Zacks et al. 1998). This suggests that, in general, judgments of absolute values are less accurate for extreme values and when graphic information is provided on nontarget and target objects.

Among the most difficult graphs to interpret are those that require estimations of area. Figure 3, Panel A, shows an example of the familiar General Electric/McKinsey matrix used for business portfolio analysis, in which circles represent business units and the areas of the circles are proportional to market size. A similar approach is used to represent segment sizes on perceptual maps. The "size effect" (Teghtsoonian 1965) suggests that decision makers underestimate the magnitude of the difference between larger and smaller circles. This suggests caution when using area to illustrate relative quantities because such figures are likely to be misinterpreted.

Visual representations may enhance decision makers' ability to evaluate information on multiple attributes. In particular, visual representations support simultaneous processing and are likely to lead to more intuitive and holistic, rather than piecemeal, processing (Holbrook and Moore 1981; Sloman 1996). For example, an investor using Table-Lens to evaluate mutual funds (see Figure 3, Panel B) may develop more of a gestalt assessment of a mutual fund than an investor presented with the same data in text form. In addition, research on cognitive capacity shows that humans can process more information when it is presented graphically than when it is presented in text form (Miller 1956; Tegarden 1999). This suggests that in evaluating and choosing products, decision makers will use more attributes and engage in more compensatory decision processes when information is presented graphically. In addition, because interactions between features are more readily detected in graphic displays than in verbal descriptions, the relative strength of such interactions is likely to be stronger for graphic than for text information (Holbrook and Moore 1981). This also implies that decision makers who use visualization tools may be less able to explain their choices than those who use text-based tools, for which particularly desirable or undesirable aspects are more easily identified. Similarly, managers who use visualization tools may be less able to explain their decisions to top management than those who can point to specific (textual) data.

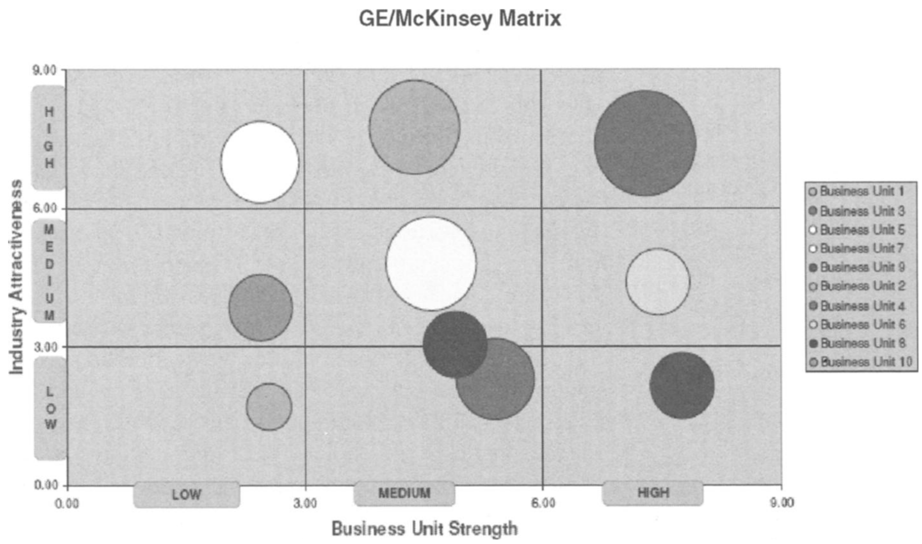
Differences in evaluability may also affect how decision makers acquire and evaluate visual information. Jarvenpaa (1989) finds that decision makers are more likely to acquire information by attribute when using bar charts organized by attributes but are more likely to acquire information by alternative when using bar charts organized by alternatives. Jarvenpaa (1989) also finds that information displays enhance by-attribute and by-alternative processing when the displays are congruent with attribute- or alternative-based choice rules. Similarly, Simkin and Hastie (1987) find that viewing bar charts leads to comparison judgments, whereas viewing pie charts leads to proportion judgments. In addition, alternative visual representations may affect the speed and accuracy of different decision processes. In Simkin and Hastie's studies, discrimination was faster and comparison judgments were more accurate when bar charts were used, whereas proportion judgments were more accurate when pie charts were used.

Similarly, the compatibility hypothesis (Slovic, Griffin, and Tversky 2002) suggests that information that is compatible with a given task will be given more weight. Thus, if a marketing manager's task is to rank-order salespeople and if a visual representation shows each salesperson's performance in dollar and unit sales and one of these is presented as a bar graph, which enables easy comparisons, and the other is presented as an area graph (circles), which makes comparisons more difficult, the manager is more likely to use the more compatible bar-graph information.

Finally, the evaluability of alternative visual representations is likely to affect the extent of compensatory versus noncompensatory decision making. Visualization tools that enable simultaneous viewing of multiple attributes can lead to more compensatory decision making than those that provide information on only a few attributes at a time (Jarvenpaa 1989). However, these effects may be tempered by the user's cognitive limitations and whether the visualization provides different visual cues and combinations of visual cues that can be holistically processed. For example, research using facial features to present financial information on multiple variables simultaneously to both skilled and naive users found that the schematic faces were processed more quickly with no loss in accuracy than when the same information was presented in financial ratios or accounting statements (Smith and Taffler 1996). Related research found that when predictive cues were represented

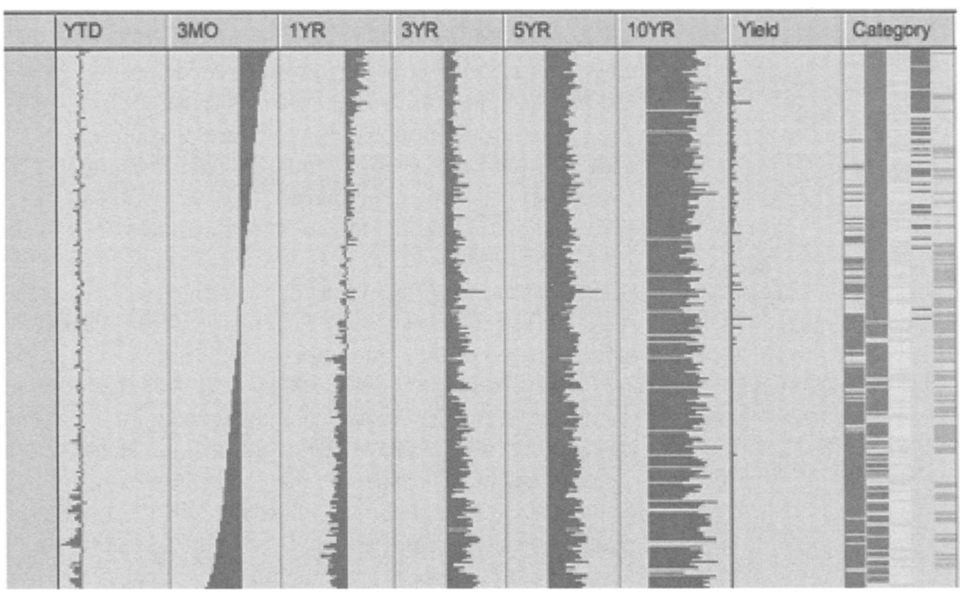
FIGURE 3
Information Context: Evaluability and Framing

A: Evaluability



In this example of the General Electric/McKinsey matrix, the circles represent business units, and the area of the circles is proportional market size. The size effect (Teghtsoonian 1965) suggests that decision makers will underestimate the magnitude of the differences between larger and smaller circles.

B: Framing



TableLens (Pirolli and Rao 1996; Rao and Card 1994) is a graphical spreadsheet that turns numerical data into columns of bar graphs that can be sorted and compared.

by different facial features, decision makers were more likely to use all the cues than when each cue was represented by the same visual features, such as bar graphs, deviation bar graphs, or spoke displays (MacGregor and Slovic 1986). These findings may have resulted from using a different facial feature (shape) for each cue or from decision makers' greater familiarity with making facial than symbolic assessments. This suggests two, though not necessarily conflicting, predictions: (1) Tools using different representations of cues (attributes) lead to more compensatory processing than tools using a single representation (shape) for each attribute, and (2) tools using familiar (to human) objects (e.g., faces, animals, houses) in which each cue is represented by a different feature (e.g., eyes and mouth, spots and tail length, house size and number of windows) lead to more compensatory processing than tools using different symbolic (nonmeaningful) shapes and colors for each attribute.

On the basis of this discussion of evaluability, we offer the following testable propositions:

P_{10}: Decision makers using graphic versus text-based (tabular) presentations of the same information

a. more quickly identify outliers, trends, and patterns of covariation between variables;

b. make less accurate assessments of differences between values;

c. use more attributes in judgment and choice; and

d. are less likely to attribute their judgments and choices to any single product feature.

P_{11}: Decision makers using visual representations that include graphic and tabular information show higher performance in terms of decision accuracy and speed than decision makers using either graphic or tabular formats alone.

P_{12}: Compared with decision makers who use visual representations that make it easy to compare alternatives on multiple attributes, decision makers who use visual representations that make it easier to compare alternatives on a particular attribute

a. place greater weight on that attribute,

b. are more likely to choose the alternative that is superior on that attribute, and

c. are less likely to choose compromise alternatives.

P_{13}: Decision makers using visual representations that allow attributes (versus alternatives) to be more easily compared show greater processing by attributes than by alternatives.

P_{14}: Decision makers using visual representations that highlight the similarity among alternatives on a given attribute weigh other attributes more heavily in their decision making.

P_{15}: Decision makers using visual representations that are congruent with particular decision rules (processes) rather than visual representations that are incongruent with particular decision rules

a. are more likely to use those decision rules and

b. make faster and/or more accurate decisions.

P_{16}: Decision makers using visual representations with different visual representations of each cue (attribute) engage in more compensatory processing than those using visual representations with the same representation for all cues.

P_{17}: Decision makers using visual representations that represent different cues (attributes) using different aspects of objects that are familiar to human decision makers (e.g., facial features) engage in more compensatory processing than those using visual representations that use different aspects of unfamiliar objects.

Framing

By changing the presentation of a given problem, visual representations may accentuate biases and heuristics in decision making (Gilovich, Griffin, and Kahneman 2002; Hutchinson, Alba, and Einstein 2004; Kahneman, Slovic, and Tversky 1982). This could occur by changing the reference point against which data are compared, thus framing data alternatively as a loss or a gain. For example, SmartMoney.com's MarketMap (Fidelity Investments 2006) presents daily gains and losses. Because daily losses are more frequent and dramatic than losses over longer periods, a daily presentation is more likely to show losses than a longer-term presentation. Because decision makers are often risk seeking for losses but risk averse for gains (Kahneman and Tversky 1979), a visualization with a more recent reference point may lead investors to riskier behavior.

Visual representations may also aggravate biases by changing how decision makers process and evaluate information. Hutchinson, Alba, and Einstein (2004) find that compared with tabular and bar-graph presentations of the same data, line graphs lead to increased use of an "adjacent-differences heuristic," in which correlations are assessed by comparing differences on adjacent values of an independent variable with differences on adjacent values of the dependent variable. Hutchinson, Alba, and Einstein show that this bias can lead to greater spending on particular media in an advertising context or greater investments in a particular stock in a financial setting, even if both types of media (stock) are equally correlated with sales (financial returns). This suggests that compared with frequency-based representations (e.g., bar graphs, scatter plots), line-based representations increase biases such that decision makers infer greater levels of correlation between variables and make decisions that reflect this bias. Following Hutchinson, Alba, and Einstein's example, marketing managers who are given line-based representations of media spending versus sales are more likely to be biased in their interpretation of these data than those given the same information in bar-graph format.

Similarly, alternative visual representations may change the framing and, therefore, judgments about products. For example, Levin and Gaeth's (1988) finding that impressions of ground beef are higher when framed as 75% lean than when framed as 25% fat is likely to be replicated by visualizations that present a positive versus negative framing of the same information. Alternative visual representations may also moderate these framing effects. For example, if foods marked as green are perceived as healthful and foods marked as red are perceived as unhealthful (Synovate 2005), the perceived difference between nutritional pie charts that are 75% green and 25% red versus 25% green and 75% red may be greater than that between black-and-white versions of the same information.

Relatively subtle visual cues, such as the orientation of the object (e.g., whether a square is aligned with horizontal and vertical axes or rotated 45 degrees), can change which dimension is most heavily weighted in estimates of size and volume (Krider, Raghubir, and Krishna 2001). Likewise, by changing whether information is presented in absolute or relative terms, visual representations may change decision makers' preferences for integrating or segregating losses and gains (Heath, Chatterjee, and France 1995). In particular, visualization tools that make it easier to see changes in percentage terms (e.g., multiple pie charts) may lead to greater segregation of losses and gains than visualizations that facilitate absolute comparisons (e.g., line graphs). In general, visual representations are likely to change the anchors that decision makers use (Chapman and Johnson 2002; Tversky and Kahneman 1974). For example, a visual display of sales from highest to lowest may lead to higher overall sales estimates than a display from lowest to highest because of the tendency to place greater weight on initial information (Chapman and Johnson 2002; Tversky and Kahneman 1974). Figure 3, Panel B, shows a TableLens example that uses financial data in which eight dimensions (year-to-date, three-month, one-year, three-year, five-year, and ten-year performance; yield; and category) are displayed. Whether these columns are sorted from highest to lowest or vice versa is likely to affect investors' estimates of overall stock returns.

Finally, alternative visual representations may lead to context effects, such as violations of regularity (i.e., the attraction effect) in which the share of an alternative increases when alternatives that it dominates are added to a consideration set (Huber, Payne, and Puto 1982; Simonson 1989). Hamilton, Hong, and Chernev (2007) find that changing the perceptual organization of a choice set (e.g., by changing the display order of alternatives in a product-by-attribute matrix) can draw attention to unique attribute values in such a way as to moderate the strength of the attraction effect. This suggests that judgments and choices could vary depending on the order of alternatives in a visual representation. In particular, because order affects the ease with which alternatives can be compared on a given attribute, this may lead to an attraction effect for alternatives that are dominant on the easy-to-compare attribute. Because the attraction effect seems to depend on how readily alternatives can be compared on a given attribute (Hamilton, Hong, and Chernev 2007), it is more likely to occur with visual representations that display information by attribute than by alternative. Likewise, the compromise effect (Simonson 1989), in which the addition of a non-dominated alternative leads to increased choice of a compromise alternative, may depend on the extent to which a visualization enables easy comparisons of alternatives across attributes. If comparison is easiest for a single attribute, choice proportions are likely to increase for the alternative that is highest on that attribute; however, if comparisons on multiple attributes are easy, this should increase the choice of compromise alternatives. Thus, if a marketing manager is evaluating three new products on the basis of market share potential and profitability, his or her decision to go with a product that represents a compromise between these objectives may depend on whether the visual representation makes it easy to compare the products on both attributes simultaneously.

This suggests the following set of testable propositions regarding framing effects:

P_{18}: Decision makers using visual representations that present data with a more recent reference point engage in more risky decision making than those using visual representations that present data with a less recent reference point.

P_{19}: Decision makers using visual representations that present data in a continuous fashion rather than in frequencies are more biased in their interpretations, such that

a. perceived correlations between variables are higher and

b. their allocation decisions reflect comparisons among adjacent levels of variables.

P_{20}: Decision makers using visual representations are influenced by the vividness of information, such that visual saliency moderates the effect of positive versus negative frames on judgments.

P_{21}: Decision makers using visual representations that present changes in percentage terms (e.g., pie charts) are more likely to segregate gains and losses (mixed gains) than those using visual representations that make it easier to see absolute changes (e.g., line graphs).

P_{22}: Decision makers using visual representations that sort information from highest to lowest make higher estimates than those using visual representations that sort information from lowest to highest.

P_{23}: Decision makers using visual representations that make information easier to compare on an attribute for which one alternative is dominant are more likely to make decisions that are consistent with the attraction effect than those using visual representations that make comparisons on that attribute more difficult.

P_{24}: Decision makers using visual representations that display information by attribute are more likely to make decisions that are consistent with the attraction effect than those using visual representations that display information by alternative.

General Discussion

Summary

Recent advances in information technology have led to expanding capabilities to collect, store, and disseminate data, and there is no sign of this trend abating. However, this explosion of data is a mixed blessing. Although more data can lead to more informed decisions, they can also be overwhelming. To help decision makers cope with the increasing amount of data, an expanding array of visualization tools is available. Although the developers and sellers of these tools promise better, faster, and deeper insights from the use of their product, there has been little investigation into when and how visualization tools affect decision making.

This article draws on theoretical and empirical results in various fields to identify key aspects of visual representations that are likely to affect the visual decoding process. Specifically, we focus on (1) the visual perspective, which includes interactivity and depth of field, and (2) the information context, which includes vividness, evaluability, and framing. These two aspects are not intended to be comprehensive but rather to highlight factors that are common to many situations and tools and to stimulate further research. We draw on theory and prior research findings to posit how these two aspects of visual representation affect decision making.

Potential Moderators

The propositions in this article are largely those of main effects, in which a particular characteristic of visual representation (e.g., interactivity) is posited to affect a particular type of decision-making behavior (e.g., restructuring). However, several proposed effects are likely to be contingent on factors such as expertise, involvement, and need for touch (see Figure 1). We offer some examples of how these factors are likely to moderate the effects of visual representation on decision making.

Expertise is likely to be a moderator for several of our propositions. In particular, how much visual representations change decision-making processes likely depends on users' knowledge of which factors are important and their ability and motivation to change the visual representation to reflect these factors. For example, P_1 proposes that interactive displays lead to more information restructuring, enhanced use of preexisting decision rules, and more compensatory decision making. At the same time, there is evidence that (novice) decision makers tend to use information as it is presented (Bettman and Kakkar 1977; Slovic 1972) and that they often do not know which features are relevant for product evaluations (Sujan 1985). Thus, when novice decision makers are presented with a particular visualization, they may assume that the variables represented are the most relevant and that the default visualization is best. This means that novice users may fail to take advantage of interactivity and will tend to use the default visualization, regardless of its appropriateness for a given task. For example, consumers may be less likely to recognize improvements in reliability for a particular automotive brand if the default view is a scatter plot rather than a sorted table visualization, such as TableLens, because scatter-plot views can make trends more difficult to see (Kobsa 2001).

Other propositions likely to be moderated by expertise include P_6–P_9, for which vivid information is more likely to be overweighted by novices than by experts (who are less likely to use vividness to infer attribute importance), and P_{18}, for which changing reference points is likely to have a greater effect on the riskiness of decisions made by novices than those made by experts, who may be less subject to such visual framing effects. In general, propositions that claim a superiority for visual versus text-based representations, such as P_6, are likely to depend on decision-maker expertise.

Similarly, involvement may play a moderating role because many visualization tools require user effort. Using interactive visual representations to restructure information and explore different options (P_1 and P_2) requires the decision maker to (1) identify which aspects are important and (2) interact with the visualization to display these aspects. Likewise, using visualizations that involve selecting or eliminating alternatives (e.g., P_4) requires the decision maker to play an active role. Unless the decision is sufficiently important, the user may be unwilling to engage in the cognitive and physical effort needed to realize the full benefits.

Need for touch (Peck and Childers 2003) may also be a moderator, particularly for P_2, which suggests that virtual reality representations substitute for real-world information search. However, the direction of this effect is difficult to predict. People who are high in need for touch may believe that there are more benefits to virtual reality because it mimics their preferred search environment. At the same time, people who are high in need for touch may believe that there are fewer benefits because most of these representations do not provide the tactile feedback they seek.

In addition to the decision maker's characteristics, such as expertise, involvement, and need for touch, data characteristics may serve as moderators. These include the number of data points, the extent to which there are lagged effects in the data, and the correlations among attributes. In particular, the proposed effects of P_{10}, in which graphic data enable faster identification of trends but less accurate assessments of differences, are likely to be greater for smaller data sets. For example, Krider and colleagues (2005) find that visual analysis outperforms traditional econometric analysis for inferring causality in data sets with relatively few observations. Similarly, lagged effects may be more accurately identified using visual representations than textual displays or statistical analysis (Diehl and Sterman 1995; Krider et al. 2005). Further research could explore situations in which visual representations may outperform traditional statistical approaches. Finally, the implications of P_{19}, in which perceived correlations between variables are greater for visualizations that present data in a continuous fashion, are likely to depend on whether correlations actually exist in the data. To the extent that such correlations exist in the data, visual representations may be helpful; however, visual representations may also lead decision makers to infer correlations when there are none.

Managerial Implications

As business systems produce ever-increasing amounts of data, the challenge to extract the most value from this growing flood of information increases as well. Visualization tools have the potential to offer managers and consumers ways to improve efficiencies, reduce costs, gain new insights, make data more accessible, and increase satisfaction. At the same time, visualization tools may accentuate biases in decision making. We summarize key implications —both positive and negative—of visual representations.

Efficiencies, cost reductions, and improved productivity. Many visualization tools speed up routine analysis tasks by making it easier to see correlations, outliers, and trends and to make comparisons. By reducing the time required for analysis, firms may require fewer staff or, alternatively, do more with current staffing. A manager for a large European mobile phone retailer estimated that visual representation reduced his time spent analyzing sales data by 20%, freeing time to spend on other tasks (Borzo 2004). Similarly, Smith and Taffler (1996, p. 82) conclude that "by providing a speedy, accurate method of processing information," visual representation of financial information may free up valuable management time. Sales managers, assistant brand or product managers, media buyers, and others who routinely analyze large amounts of data could benefit from increased productivity that visualization tools can offer.

New insights. In addition to improved efficiencies for routine tasks, visualization tools may enable users to uncover new insights that would otherwise have gone unnoticed. Youngworth (1998) reports that a consumer goods manufacturer saved hundreds of thousands of dollars in shipping costs by using visualization software that made exceptions "stand out." Lucent Technologies uses visual representation software to help identify new business opportunities (Borzo 2004). Similarly, visualization tools might help marketing managers uncover formerly undetected patterns that are useful for cross-selling or up-selling. At the same time, because such tools that make exceptions stand out, they may lead marketers to focus too much on outliers rather than data that represent the core of their business.

An area with high potential for using visualization tools for data exploration and ad hoc discovery is clickstream data (Eick 2000). Traditional Web server log tracking and reporting often generate lengthy reports that are ineffective for identifying the trends, outliers, patterns, and connections needed to understand critical questions, such as which vehicles drive the most traffic to a Web site, how visitors navigate the site, and patterns that lead to abandoned shopping carts (Eick 2000). Another area is the use of visualization tools to uncover trends in textual data, such as that found in product blogs and discussion groups. For example, Tilebars (Hearst 1995) could be used to provide a visual representation of text string occurrences in a text file through bar graphs that show the relative length of a document coupled with embedded squares that show the frequency and location of specific terms.

Increased information accessibility and decision confidence. Applications such as MarketMap and CreditMap (Fidelity Investments 2006; Panopticon 2003), which make voluminous stock and corporate bond market information more accessible to customers, can lead to greater customer satisfaction and can potentially enhance loyalty and retention. By creating an interactive and more realistic portrayal of alternatives with dynamic imaging and the ability to customize, virtual reality applications have the potential to be a win–win choice for consumers and firms. Online retail sites, including Lands' End, Timberland, and La-Z-Boy, have used virtual reality to increase sales and retain customers (Esfahani 2005).

However, it is also possible that complex visualization tools that require significant learning to master fully may confuse, frustrate, and discourage novice users. For example, MarketMap is a Treemap, a type of tool that novices often have difficulty using (Bederson and Shneiderman 2003). Managers should ensure that users have the ability and motivation to learn how to use such tools before providing them to decision makers.

Potential biases. Although visual representations may enable more data to be processed than a textual presentation, they may also enhance biases in decision making. An awareness of these biases is important for those who use and design visualization tools to aid decision making. For example, visual representations that provide detailed views of alternatives may lead decision makers to make incorrect evaluations by considering only a portion of the data. In addition, the vividness of visual information may lead marketing managers to place inordinate weight on such information, regardless of its diagnosticity. Similarly, by increasing the evaluability of particular attributes, visual representations may lead decision makers to focus on attributes that are easiest to compare rather than those that are most important. Because humans have difficulty comparing graphic portrayals of area and volume, visual representations that use such graphic techniques may lead decision makers to inaccurate assessments. For example, the familiar General Electric/McKinsey matrix uses area to portray market size; this will likely lead to inaccurate perceptions of the actual size differences among markets. People who prepare such visual representations for decision makers should not assume that they will be correctly understood. Likewise, visual representations can lead to biased estimates of correlations and subsequent decisions that reflect this bias (Hutchinson, Alba, and Einstein 2004). In general, even seemingly innocuous decisions about color choice, orientation of shapes, and selection of markers can influence users' judgments and decisions.

Because visual representations draw on the associative rather than the rule-based reasoning system (Sloman 1996), their use may be best suited for situations in which hunches and intuition often lead to the same results as more systematic analysis. When such intuitive approaches are likely to lead to incorrect conclusions (e.g., because of biases in interpretation), traditional data formats may better serve marketing managers. Another approach is to encourage the use of visualization tools for exploration but to subject insights from visual representations to formal analysis.

Because consumers are likely to use the vividness and evaluability of attributes in a visualization to infer importance and are less likely to be able or motivated to change visual representations, default visualizations should be selected with care. This is particularly true when the intent is to aid consumer decision making (e.g., in choosing nutritious foods or a health care plan that meets people's specific needs). If determining a default representation is problematic (e.g., because consumers vary in their preferences), it may be preferable to build visual representations on the fly on the basis of questions that elicit preferences.

Conclusions

When a visual representation is created, information is encoded by aspects such as color, texture, and geometry. When the decision maker sees the representation, these aspects are decoded. The representation "works" only if the visual decoding is accurate and efficient (Cleveland and McGill 1984, 1985). Two ways to further the understanding of this decoding process are to (1) draw on theoretical and empirical findings in relevant areas, such as visual perception, and (2) conduct empirical studies—in particular, controlled experiments—to explore effects or test specific hypotheses.

This article offers a set of theoretically based propositions that are suitable for rigorous empirical investigation. However, current empirical support for our propositions is largely anecdotal. A key next step is empirical research to further the understanding of the posited effects of various visualization tools for decision making. Further research is needed to test these propositions in both controlled and field settings across different types of tasks. One avenue for additional work is to explore potential moderating variables. In particular, studies involving decision makers who vary on key individual difference attributes, such as level of expertise or need for touch, would further the understanding of the implications of visual representations for decision making. Another avenue for research is to examine how decision makers use graphic and textual information together. In particular, many visual representations enable users to see detailed textual information on the individual data points that make up the visualization. For example, SmartMoney.com's MarketMap (Fidelity Investments 2006) allows users to click on individual stocks to reveal earnings, financial ratios, and other text-based information and, in this way, engages decision makers in deliberative and associative information processing. Thus, visual representations offer an interesting setting for examining two systems of reasoning (Sloman 1996) and the potentially sequential, parallel, and interactive nature of these processes. There is no doubt that visual representations will become more prevalent, and we hope that the framework and propositions presented in this article will stimulate further research.

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