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In their attempts to communicate with managers and other interested readers, marketing researchers frequently present complex findings in various sorts of visual displays. These diagrams, charts, maps, pictures, and other figures help elucidate the nature of the relationships and structural patterns involved. However, their ability to communicate is partially limited by their typical restriction to the two-dimensional plane of the printed page. As an aid to overcoming such problems, stereographic techniques permit the construction of three-dimensional representations whose vividness and depth provide greater clarity and enhance interpretability to strengthen the reader's grasp of key concepts. The author illustrates the stereographic approach to three-dimensional communication using general examples closely analogous to relevant applications in marketing research.

Stereographic Visual Displays and the Three-Dimensional Communication of Findings in Marketing Research

> All the history of information displays and statistical graphics—indeed of any communication device—is entirely a progress of methods for enhancing density, complexity, dimensionality, and even sometimes beauty.
>
> —Edward Tufte, *Envisioning Information*

In many kinds of marketing research, the formulation of concepts, design of methods, and analysis of data constitute only part—sometimes just a small part—of the challenge faced by those who try to communicate the results of their studies to marketing managers or other interested readers. Often, findings that could in principle be presented as tables of means, regression coefficients, factor loadings, or spatial coordinates provide little insight to readers seeking meanings behind the numbers. In such cases, the communication of findings can benefit greatly from the inclusion of revelatory visual displays (cf. Batsell 1980b, p. 102; Novak 1995, p. 361). Thus, various procedures have evolved for showing the results of statistically sophisticated analyses in vivid and intuitively compelling forms that lend themselves to interpretation and understanding by people who might not grasp all of the underlying mathematical subtleties but who must comprehend the essence of their implications regarding such issues as the structure of competitive offerings, patterns of customer preferences, or interrelationships among market-related variables.

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Existing Approaches to Creating Visual Displays

Conspicuous examples of approaches that produce visual displays to communicate more effectively include both those intended to represent multidimensional spatial (MDS) positions and those that depict functional relationships between some dependent variable and one or more independent variables.

Multidimensional spatial positions, such as those derived from multidimensional scaling or plots of product characteristics, provide an easily understood picture of the proximities among brands or product categories. Usually—in resolving the trade-off between parsimonious interpretability and improvements in fit from including additional dimensions (Green 1975)—such a representation appears in two dimensions on horizontal and vertical axes (Batsell 1980b; Shepard 1972). If more than two dimensions are required, they are usually presented as a series of two-axis subspaces.

Functional relationships appear in pictorial form, for example, when representing preference as a surface that lies above a horizontal plane that is based on two product attributes (Batsell 1980a, b; Batsell and Lodish 1981). In other cases, similar graphical techniques produce XYZ scatter diagrams in which data points are plotted with a dependent variable (Z) on the vertical axis and one or two independent variables (X, Y) on the horizontal axis or axes.

Problems With Existing Approaches: The Missing Dimension

The approaches mentioned thus far capitalize on the reader's essentially right-brained ability to make sense of gestalt-like visual displays that simultaneously capture aspects of data less accessible to a sequential left-brained presentation through words or numbers (Beaton 1985). In other words, a picture is worth a thousand words. It follows that the design of pictorial displays takes on great importance in the communication of quantitative results (Tufte 1983). Hence, like others concerned with communicating complex material, marketing researchers have long sought more effective ways to enhance the vividness, clarity, realism, and interpretability of such presentations.

One remaining problem results from the fact that, thus far, all known attempts presented on the inherently flat printed pages of the marketing research literature use only two visual dimensions (left/right, up/down) to portray the relationships of interest, even if those relationships explicitly involve the consideration of a third conceptual axis (e.g., the aforementioned MDS spaces, preference surfaces, and other types of $Z = f(X, Y)$ relationships). Thus, such approaches neglect the eyes' ability to apprehend another dimension of experience, namely, the third dimension of everyday reality, which is familiar in the sense of depth with which people ordinarily perceive the world around them but is lost in the customary presentation of figures, charts, and graphs in flat planes on the printed page. As Riemschneider (1994, p. 4) notes with special relevance to conventional marketing research studies, "When it comes to exchanging information, images and ideas, it is a painful fact that we are still trapped in a predominantly two-dimensional world." A similar point appears in the influential work *Envisioning Information* by Tufte (1990, p. 12), who comments that "the world portrayed on our information displays is caught up in ... two-dimensionality" and concludes that "*escaping this flatland is the essential task of envisioning information.*"

In short, as the central problem motivating the present article, marketing researchers seek maximally effective visual representations of their findings and employ spatial models that in principle can provide such compelling displays on up to three axes, but the third dimension virtually always fails to appear in the flat-surface, two-dimensional diagrams that find their way into print. The traditional style and format of presentation thereby sacrifice a dimension of experience that might enhance the vividness, clarity, depth, and interpretability of such visual displays and thereby increase their usefulness for communicating with readers in general or with marketing managers in particular.

Purpose

Toward the goal of overcoming this problem, I propose and illustrate some approaches to presenting results from marketing research in a stereographic format that provides a true three-dimensional viewing experience. Researchers in other branches of the physical and social sciences often use such stereographic visual displays in their searches for structure in multidimensional data (Bastide 1990; Cleveland and McGill 1988; Fisherkeller, Friedman, and Tukey 1975; Lorenz 1987; McAllister 1993; Wegman and DePriest 1986). However, marketing researchers have generally neglected the opportunities offered by stereography. I therefore propose that they take advantage of stereographic visual displays to add an extra dimension of vividness, clarity, depth, and understanding in ways that strengthen the communication of research findings.

TYPES OF STEREOGRAPHIC VISUAL DISPLAYS

Background

The need to provide visually compelling representations in three dimensions has been recognized for a long time. Thus, early multidimensional scalers talked about the construction of physical models in which vertical stems rising above a horizontal plane were topped by balls depicting the objects of interest—unfortunately, with unwieldy and fragile results. The technology needed to overcome such inefficiencies in the use of space and materials has existed for 150 years and has manifested itself in a household device common in the nineteenth century and still popular as late as the 1950s. The gadget in question is called a *stereoscope* and was designed to view double photographs mounted side by side with an optical instrument that used prisms to cause the two images to fuse in the field of vision. Although the psychophysiology of stereoptical perception and its connection with brain research is a formidably complex topic (Frisby 1980; Gregory 1990; Julesz 1971, 1995), and though such applications as those involving computational models of visual perception (Marr 1982), three-dimensional computer vision (Faugeras 1993), or higher-order dimensionalities (Cleveland and McGill 1988) range beyond the scope of this article, the basic principle involved in such stereoscopic viewing is straightforward, familiar, and well understood (Dyckman 1994; Ferwerda 1990; Girling 1990; Gregory 1970; Lorenz 1987; McAllister 1993).

Normally, the eyes see the world from two slightly different perspectives. The images presented to the left and right eyes vary slightly—exhibiting binocular disparity—because the two eyes are located approximately two and one-half inches apart. The brain synthesizes this information regarding left–right parallax to produce the impression of depth. We take this third dimension involving distance from the viewer for granted as an ordinary aspect of our everyday experience. But, however unconsciously, we use this valuable gift every time we hit a tennis ball, drive a car, or reach for the salt shaker (Grossman and Cooper 1995). It therefore contributes greatly to our sense of verisimilitude in visual perception (Frisby 1980).

From this, it follows that stereoscopic imaging tends to promote enhanced vividness, clarity, realism, depth, interpretability, and even survival value. Styles of presentation that capitalize on these benefits of three-dimensional viewing therefore should communicate more effectively. Hence, the marketing research that appears on the printed pages of the literature should be presented in a manner designed to achieve such advantages.

Typology of Presentation Modes for Stereographic Visual Displays

I propose that the relevant types of stereographic presentation modes can be distinguished on the basis of three key aspects. (For earlier but generally less systematic typologies, see Bolt 1992; Love 1993; McAllister 1993; Wegman and DePriest 1986.)

(1) *Number of Separate Images.* Many stereographic displays present two images located side by side and designed to be viewed separately by the left and right eyes. By contrast, some three-dimensional representations appear as one image with all the relevant stereographic information embedded in a manner that can be extracted independently by each eye.
(2) *Imaging Device.* Many stereographic images are captured by a camera or some other technique that uses film. Others are drawn or plotted by a computer or sometimes by hand in a manner that could be emulated by a computer.
(3) *Viewing Approach.* Some stereo images are designed for free-viewing without the assistance of mechanical aids. Others rely on optical devices of some sort to facilitate aided viewing.

Combining these three aspects produces the typology shown in Table 1. In this table, the eight logically possible combinations suggest the major types of three-dimensional representations potentially available for application by marketing researchers.

Stereo pairs. Perhaps the simplest type of stereographic display, stereo pairs consist of two photographs taken by side-by-side exposures or by a special twin-lensed camera. When appropriately cropped, mounted, and viewed, such paired stereographic photos provide a true three-dimensional effect with a vividly compelling sense of clarity and depth (Burder and Whitehouse 1992; Ferwerda 1990; Johnstone 1995; Waack 1987).

Rotated plots, double projections, and random dot stereograms (RDS). Just as stereo pairs of photographs can recreate the visual images seen by the left and right eyes, paired computer drawings of data points can be rotated spatially from left to right on their central axes to produce rotated plots. These plots simulate the visual effect of moving a short distance around the periphery of the display and approximate what a viewer would see through his or her different eyes to facilitate the interpretation of three-dimensional data with the in-depth visualization of graphic displays (Cleveland and McGill 1988; Fisherkeller, Friedman, and Tukey 1975). Although such rotated plots must be used with restraint because of possible visual distortions (McAllister 1993), this theoretical problem does not appear to cause practical difficulties for small rotations of no more than, say, three or four degrees (Cleveland and McGill 1988; Ferwerda 1990; Girling 1990; Julesz 1971; Smith 1996; Waack 1987; Wegman and DePriest 1986). Alternatively, in double projections the computer shifts images to mimic the displacement that would result from a left-to-right movement of the eye in a direction parallel to the plane of the display (McAllister 1993). Meanwhile, an RDS achieves a similar effect in a manner developed and described by Julesz (1971, 1995; Frisby 1980; Marr 1982) and easily implemented on a personal computer (Kinsman 1992; Richardson 1994). However, the RDS lends itself to the representation of only fairly simple configurations and is therefore not well suited to the display of complex marketing research findings.

Stereoscopes and stereoviewers. By employing prismatic lenses that enlarge and shift paired pictorial images to aid their fusion, the stereoscope gained great popularity in American households during the late nineteenth century and rapidly became the mass medium for the dissemination of visual information (Burder and Whitehouse 1992; Ferwerda 1990; Gregory 1970; van Keulen 1986; Rheingold 1994; Waack 1987). Beginning in the 1940s and 1950s, more contemporary versions of the same approach emerged in the form of stereoviewers, such as the Stereo Realist for adults or the View-Master for children (Dennis 1984; van Keulen 1986; Sell and Sell 1994). By forcing each eye to see one and only one photographic slide, such stereoviewing aids produce not only compelling but also easily accessible three-dimensional experiences. As an alternative approach that lends itself to print media, the old double-image slides

Table 1
TYPOLOGY OF PRESENTATION MODES FOR STEREOGRAPHIC VISUAL DISPLAYS

Viewing Approach	*Imaging Device*	*Number of Separate Images*: *Two Images*	*One Image*
Free-Viewing	Camera	Stereo Pairs	Lenticular Prints; Holograms
	Computer	Rotated Plots; Double Projections; Random Dot Stereograms (RDS)	Motion Parallax; Single-Image Random Dot Stereograms (SIRDS)
Aided Viewing	Camera	Stereoscopes (Stereoview Prints); Stereoviewers (Stereo Realist, View-Master, etc.); Prismatic Lorgnettes (Added Dimension, etc.)	Anaglyphs (Comics, etc.); Polarization (Slides, Three-Dimensional Movies, etc.); Shutter Glasses (Sony Imax, etc.)
	Computer	Virtual Reality (VR) (Games or Simulations With Goggles, Helmets, Head-Mounted Displays, etc.)	Stereo Computer Graphics (Computer-Assisted Design or Data Displays With Shutter Glasses, etc.)

can be presented side by side on a page and then viewed with the aid of a *prismatic lorgnette* (Hayes 1992; McAllister 1993; Schwartzman 1981). This type of hand-held apparatus is the device of choice for the aided viewing of printed stereo pairs, as I recommend and describe at greater length subsequently.

Virtual reality (VR). Moving the two-image approach into the contemporary computer-assisted age of aided viewing, various VR applications and related electronic marvels have pushed the principle of the stereoscope to its logical conclusion and have even put "3-D" on the cover of *Business Week* (Coy and Hof 1995). By wearing special goggles or helmets that direct a separate light-emitting diode (LED), liquid crystal display (LCD), cathode ray tube (CRT), or television image to each eye, participants experience a lifelike feeling of three-dimensional depth or presence that adds greatly to the dynamic excitement of action-oriented video games or the realism of computer-driven simulations (Biocca 1992; Rheingold 1994; Richardson 1994). Various types of head-mounted displays (HMDs) have been developed for use by serious students and professional practitioners in the technology of "immersive" VR (Biocca 1992; Clark 1995; Wildstrom 1995). In the long run, especially as the marketing research profession moves into the age of electronic publishing, such applications of VR hold great promise for the in-depth presentation of research findings. Currently, however, publications such as *JMR* appear primarily in print formats. I therefore focus mostly on the latter form of presentation.

Lenticular prints and holograms. Some photographic three-dimensional images are designed to be viewed as single pictures by the unaided eye. These include the lenticular prints that often adorn the covers of musical recordings or books and sometimes appear in commercial advertising or on greeting cards. Because lenticulars require special multilensed cameras and printing of the photo images in an interlaced format on a single flat sheet covered by a prismatic screen that directs a different exposure to each eye, they do not lend themselves to use in conventional cost-conscious print media such as marketing journals (Burder and Whitehouse 1992; Ferwerda 1990; Love 1993; Richardson 1994; Waack 1987). Similar results—at vastly greater costs in terms of effort and expense but with even less flexibility of subject matter, location, or media—result from the use of laser technology to produce holograms (Unterseher, Hansen, and Schlesinger 1992). The relevant literature clearly indicates that—because of the currently exorbitant costs, cumbersome implementation, and restricted range of appropriate subject matter—practical applications of holography to the presentation of marketing research must await further developments in the twenty-first century or beyond (Love 1993).

Motion parallax and single-image random dot stereograms. As one technique for presenting images on a CRT screen, motion parallax simply provides small displacements, rapid alterations, or continuous movement of a visual display in a way that permits a viewer to extract depth information (Cleveland and McGill 1988; Fisherkeller, Friedman, and Tukey 1975; McAllister 1993; Wegman and DePriest 1986). Here, in contrast with true stereopsis, the comparison of different viewpoints occurs sequentially rather than synchronously and is inherently incompatible with the goal of presentation through print media (Frisby 1980; Julesz 1971; Marr 1982). Meanwhile, extending the principles that govern the two-image RDS already discussed, Tyler (1994; Tyler and Clarke 1990) and others (Dyckman 1994) have developed a comparable type of stereo effect that presents the relevant pattern with one computer-generated display known as a *single-image random dot stereogram* (SIRDS). As described by Dyckman (1994), Kinsman (1992), Richardson (1994), and Tyler (1994), a key advantage of the SIRDS is that it lends itself to conventional print formats (Tyler and Clarke 1990, p. 196). Toward this end, various computer scientists have supplied software to permit SIRDS construction on personal computers (Kinsman 1992; Richardson 1994). However, none of the SIRDS applications achieved thus far has attained a level of fine-grained detail sufficient to present research findings in anything beyond their crudest form.

Anaglyphs, polarization, and shutter glasses. If left and right images are superimposed and printed as anaglyphs in green or blue and red, respectively, and are then viewed through special eyeglasses with red and green/blue filters on the left and right, each eye sees only the appropriate image, and a dramatic stereographic effect results (Dyckman 1994; Frisby 1980; Girling 1990; Richardson 1994; Sales 1994; Waack 1987). Such anaglyphs appear widely in children's books or in adult-oriented applications to science and technology (Frisby 1980; Gregory 1970; Julesz 1971; Lorenz 1987; Sales 1994; Wegman and DePriest 1986). One major problem with anaglyphs, which discourages their use for the presentation of marketing research in print media, is that they require expensive color printing but, after red and green/blue filtering, appear essentially monochromatic (black and white). This loss of color may be overcome by polarizing the left and right pictures at a ninety-degree angle to each other, projecting them onto a silver screen, and viewing them through glasses with lenses that impart complementary orthogonal directions of polarization so that each eye sees only the appropriate left or right rendering. This apparatus-aided technique has been adopted widely for the viewing of stereoscopic slides and films but cannot in principle be applied to the printed page (Ferwerda 1990; Waack 1987). A still more sophisticated cinematic application has appeared in the remarkable stereo realism of the Sony Imax movie theaters (Aronowitz 1995; Marren 1994). Here, double movie projectors flash left- and right-eye images on a giant screen in rapid succession for viewing with special *shutter glasses* synchronized to open and close on the left and right in such a way that each eye sees only the appropriate visual information. Although this approach produces a seamless stereographic three-dimensional impression, it again falls outside the range of applications suitable for print media.

Stereo computer graphics. Finally, several advanced techniques exist for the mechanically aided viewing of stereographic images on computer screens using "field-sequential" electronics. Like the other single-picture approaches, these stereo computer graphics rely on the basic principle of presenting different left and right images to the two eyes by using liquid crystal shutter systems, parallactiscopic moving slits, oscillating mirrors, rotating multiplanar volumetric displays, lenticular screens, or other mechanical devices (Cleveland and McGill 1988; McAllister 1993; Wegman and DePriest 1986). However, such computer graphics methods are prohibitively expensive for most academic marketing researchers and are, in any case, well beyond the scope of the present focus on approaches that are potentially applicable to printed material.

Preview

Drawing on the preceding introduction to the various types of stereographic visual displays, I focus primarily on an approach that seems to offer the greatest promise for applications to the presentation of marketing research in the print media. True, the day may come when marketing research is more generally disseminated electronically and when computer-assisted aids therefore will assume greater importance in our ability to communicate visually with our audience. At present, however, I believe that greatest usefulness attaches to those stereographic techniques that lend themselves to the black and white printed page. In that spirit, the method and illustrations that follow present computer-generated double projections and pairs of rotated plots that may be free-viewed or experienced by aided viewing with the help of a prismatic lorgnette. I first describe techniques for constructing and viewing such images and then offer three illustrative applications of the proposed approach.

METHOD

Stimuli

The illustrations shown subsequently present two-dimensional plots of three-dimensional spatial positions in both the conventional and the proposed stereographic formats. The latter projections of three-dimensional spaces onto a two-dimensional plane could be constructed by hand, but a more efficient approach employs a graphics package, such as SAS (1988). The method pursued here presents displays of the type described by McAllister (1993). Specifically, rotated plots simply use the graphics package to portray the data twice (side by side) on X-, Y-, and Z-axes tilted forward, say, 20 degrees and rotated to the right, say, approximately 22 versus 18 degrees (i.e., approximately three or four more degrees in the left- than in the right-hand plot). Meanwhile, the method of double projections begins by converting the coordinates of points in a three-dimensional space to a left-right pair of two-dimensional transformations in which (1) the vertical coordinate of each three-dimensional point from bottom to top of both transformed two-dimensional spaces is shifted down (up)—for those points lying above (below) the center of the vertical axis—by a factor proportional to the point's distance from the front to the back of the original three-dimensional space, and (2) the horizontal coordinate of each three-dimensional point for the left (right) two-dimensional plot is shifted toward the left (right) by a factor proportional to the point's distance from the front to the back of the original three-dimensional space. The two-dimensional coordinates that result from these remappings through rotated plots or double projections are then displayed for the left and right members of a stereo pair.

Presentation

After obtaining satisfactory left and right visual images with a suitable parallax displacement, they must be shrunk to a size that permits them to be mounted side by side with no more than approximately two and one-half inches separating their common elements. Too small a width will restrict their size unnecessarily, but too great a width will place them farther apart than the eyes and will thereby thwart the viewer's efforts to fuse them in free-viewing. Note that an alternative manner of presentation that is based on cross-eyed viewing does allow the images to be placed farther apart (Saburi 1993, p. 22) but is not recommended because of its tendency to cause extreme eye fatigue (Gregory 1970, p. 125).

Free-Viewing

Sufficiently motivated readers may learn to free-view stereographic paired displays, such as those shown subsequently, as follows: Begin by holding the page close to the face while looking straight ahead and past the two pictures presented in the relevant figure. Then move the page slowly away from the eyes while continuing to look through the two pictures until they seem to float together and fuse into one clearly focused three-dimensional image. This stereo three-dimensional image will appear in a position between the left and right pictures, which will remain two-dimensional and should be ignored when experiencing the central three-dimensional effect. When properly free-viewed in this way, the stereographic image will possess striking vividness, clarity, and three-dimensional depth. (For helpful tutorials on free-viewing, see Alderson 1988; Ferwerda 1990; Girling 1990; Grossman and Cooper 1995; Johnstone 1995; McAllister 1993; Pratt 1995; Richardson 1994.)

Before attempting to attain such three-dimensional depth perception on the basis of stereo pairs shown in a flat plane, readers who have not had previous experience with this free-viewing technique should note that its successful accomplishment may require some investment of time and effort. In normal sight, convergence and accommodation are coupled together, so that as an object comes closer, the eyes automatically follow and focus. The trick to three-dimensional free-viewing is that accommodation and convergence must be *decoupled*; specifically, the eyes must focus without converging so that each eye looks straight ahead and sees a different image with clarity (Alderson 1988; Ferwerda 1990; Frisby 1980; Kinsman 1992; McAllister 1993; Richardson 1994). At best, this ability to gaze in parallel while keeping objects in focus requires practice, patience, and perseverance.

Aided Viewing

Despite the consensus among the authors just cited that unaided stereoscopic free-viewing experiences generally prove to be the most rewarding, some readers may prefer or even require optical assistance in seeing the three-dimensional images shown here and elsewhere. Such potential assistance comes in a variety of forms, which range from simple cardboard dividers (Alderson 1988; Burder and Whitehouse 1992; Johnstone 1995; McAllister 1993; Pratt 1995) to magnifying glasses held over the images and slowly pulled apart (Dyckman 1994; Ferwerda 1990; Girling 1990; Kinsman 1992) to binoculars with their eyepieces removed (Brown 1994). However, for those needing assistance, the single most effective aid that I have found is the prismatic lorgnette viewer. This type of viewer uses two prismatic magnifying lenses spaced approximately two and one-half inches apart and fitted with a handle.[1]

ILLUSTRATIONS

I present three illustrations that revisit the types of visual displays reviewed previously, namely, MDS positions, preference surfaces, and scatterplots of a dependent variable (Z) against two independent variables (X, Y). The relevant three-dimensional representations were constructed using the stereographic methods discussed previously and should be observed by the reader through either free-viewing techniques or the approach to aided viewing that employs the prismatic lorgnette.

Illustration 1: MDS Positions

The first illustration (Figure 1) plots the randomly generated positions of 200 objects on three axes: X, Y, and Z. This diagram resembles the output that might be obtained from the coordinates in an MDS solution or from a plot of factor loadings for a large number of variables. However, in this case, the random generator constrained the sum of X^2, Y^2, and Z^2 to equal a constant, thereby placing the objects on the surface of a three-dimensional circumplex of the sort that might be found, for example, by a principal components analysis in which 100% of the variance was explained by three underlying dimensions.

The top row of Figure 1 shows such positions as they would normally appear in a pair of two-by-two plots with Dimension Z on the vertical axis and with first Dimension X and then Dimension Y on the horizontal axis. Clearly, such displays reveal that the general shape of the points in a three-dimensional space is round. However, a viewer would be hard pressed to infer the hollow sphericity of the data points from even the most painstaking examination of the top row in Figure 1.

By contrast, stereoviewing of the three-dimensional pair in the bottom row of Figure 1 clearly shows that the configuration of points lies on the surface of an empty globe. Thus, the complex pattern of spatial positions emerges vividly only when seen as part of a three-dimensional experience by viewing them in three-dimensional depth to gain insights that escape the more limited two-dimensional perspective.

Illustration 2: Preference Surfaces

The second illustration constructs a preference surface comparable to those described by Batsell (1980a, b; Batsell and Lodish 1981). In general, such a spatial representation might appear if liking for a brand (Affect = Z) depends on the brand's levels of two product characteristics (Attribute X and Attribute Y). In this case, Z was programmed to increase with both X and Y, with the addition of a randomly generated residual component. Hence, the overall shape follows a gradually ascending terrain composed of jagged peaks and valleys.

The preference surface appears in two-dimensional renderings at the top of Figure 2, with the vertical axis representing Z (Affect) and the horizontal axis representing either Attribute X (left-hand image) or Attribute Y (right-hand image). These two-dimensional diagrams clearly indicate the manner in which Affect rises with increases in X or Y (on the left-hand and right-hand sides, respectively). However, they give only the vaguest sense of how the various peaks and valleys are arrayed in three-dimensional space.

A slightly greater apprehension of the relative positions among the various peaks and valleys emerges from a close examination of either XYZ plot at the bottom of Figure 2. These XYZ surfaces resemble the way in which such representations are usually drawn; in this case, Affect (Z) increases from bottom to top, one characteristic (X) increases from left to right, and the other characteristic (Y) increases from front to back. However, given the jumble of lines that appear in such a diagram, a viewer would be hard pressed to visualize the jagged contour of the preference surface in detail.

A better grasp of the true shape of the preference surface, with its contour of sharp peaks and deep valleys, results from viewing the two pictures at the bottom of Figure 2 as a stereo pair. Here, when fusing the left and right images into one stereoscopic representation, the detailed contour of the complex terrain that rises along the Z-axis above the horizontal X and Y dimensions is clearly seen. The three-dimensional stereo effect greatly clarifies the relative positions of the peaks and valleys, which now stand out in bold relief through the experience of true three-dimensional depth.

Illustration 3: Scatterplots of a Dependent Variable Against Two Independent Variables

The third example portrays illustrative data collected from a class of 31 Master of Business Administration (MBA) students and represented by scatterplots showing their grades on the final exam (Final) as a function of grades on the midterm (Midterm) and class participation (CP). Here, the scatterplots appear as they would be displayed by the interactive data analysis options available in recent versions of the SAS/ASSIST routine. This approach quickly generates two-way XY or three-way XYZ plots and permits the researcher to rotate the latter to any desired angle or spin the configuration of data points from left to right at a wide range of speeds. The rotate-or-spin feature can be used to take advantage of the motion parallax described previously or to present duplicate plots side by side, with the left-hand plot rotated slightly to the right for stereoviewing.

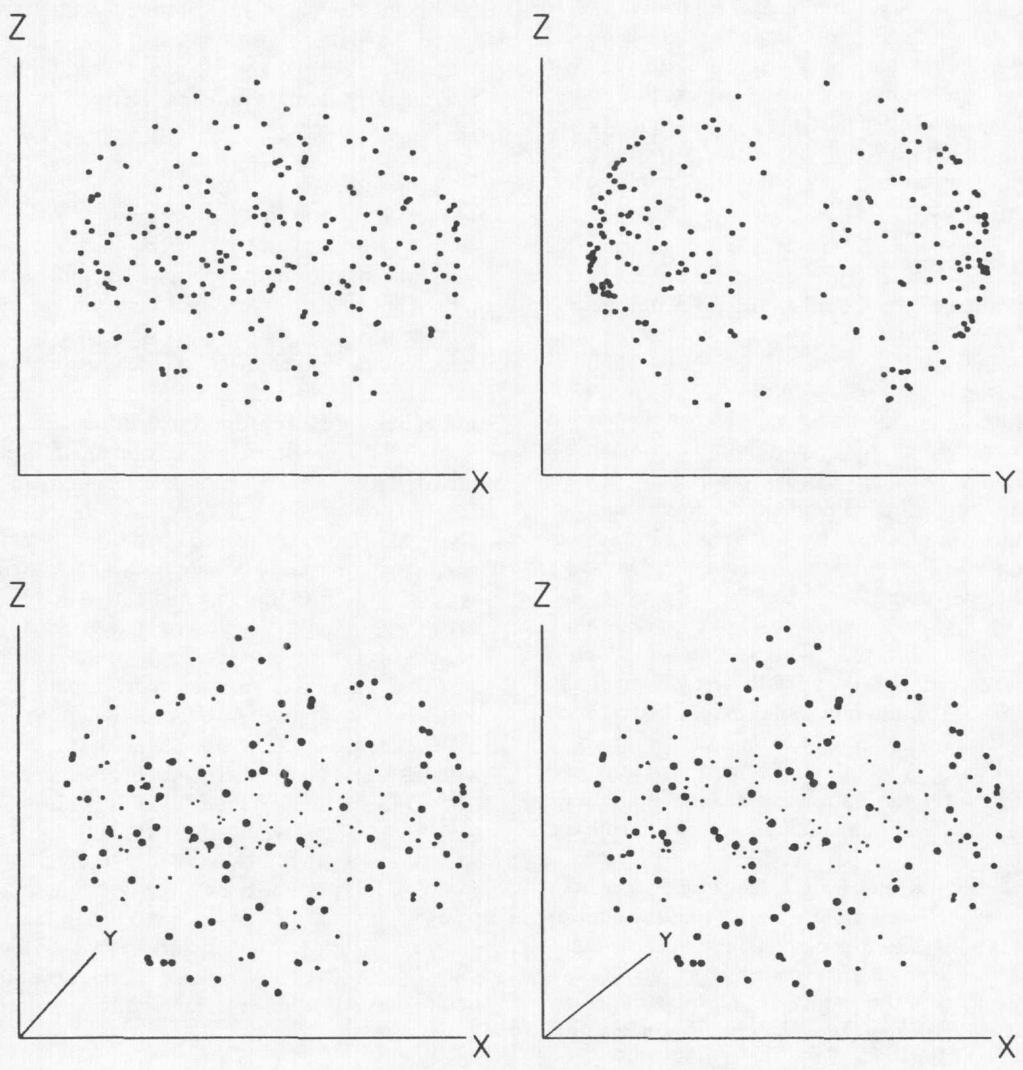
The top row of Figure 3 shows two-way XY plots exactly as they appear on the ASSIST screen, with Final plotted

[1]These can be ordered from the original manufacturer at a modest cost of under five dollars (The Added Dimension, P.O. Box 15325, Clearwater, FL 34629, 813-446-9106); from Reel 3-D Enterprises, which takes credit card orders over the phone (P.O. Box 2368, Culver City, CA 90231; 310-837-2368); or by sending five dollars to Cygnus Graphic (P.O. Box 32461, Phoenix, AZ 85064, 602-277-9253). Alternatively, readers who do not feel prepared to invest five dollars in the three-dimensional viewing experience may send me a self-addressed envelope, and I shall be happy to lend them one of my own viewers for as long as they need it.

Readers who feel impatient with the applications to print media emphasized here may prefer to view the stereographic illustrations in the form of anaglyphs suitable for experiencing with the aid of red and green/blue glasses. Toward this end, I have put the relevant displays plus a brief description on my Web site (http://www.columbia.edu/~mbh3). Additional examples appear on the home page of my colleague Professor Takeo Kuwahara (http://www.sfc.keio.ac.jp/~kuwahara/ or by a link found on my Web site). Readers who need to obtain the appropriate red and green/blue glasses should use http://www.tisco.com/3d-web or http://www.insight.com/web/founders.html, contact Cygnus or Reel 3-D, or send me a self-addressed envelope with a request to borrow such an aid for the duration needed.

Figure 1

THREE-DIMENSIONAL SPATIAL POSITIONS OF 200 OBJECTS WHOSE RANDOMLY GENERATED X, Y, AND Z COORDINATES LIE ON THE SURFACE OF A SPHERE



against Midterm on the left (r = .57, $p < .001$) and against CP on the right (r = .56, $p < .001$). Viewed in two dimensions through the left- and right-hand panels at the top of Figure 3, the XY plots clearly indicate that performance on the Final increases with both Midterm (left) and CP (right).

However, one advantage of ASSIST is that it permits quick mapping of a dependent variable against two independent variables through an XYZ plot. Such plots appear at the bottom of Figure 3. Looking at either three-way plot monocularly, the viewer derives some sense of how Final increases with both Midterm (left to right) and CP (front to back) ($R^2 = .53$, $p < .0001$). However, in two-dimensional viewing, the impression consists mostly of a cluster of points with an indistinct shape.

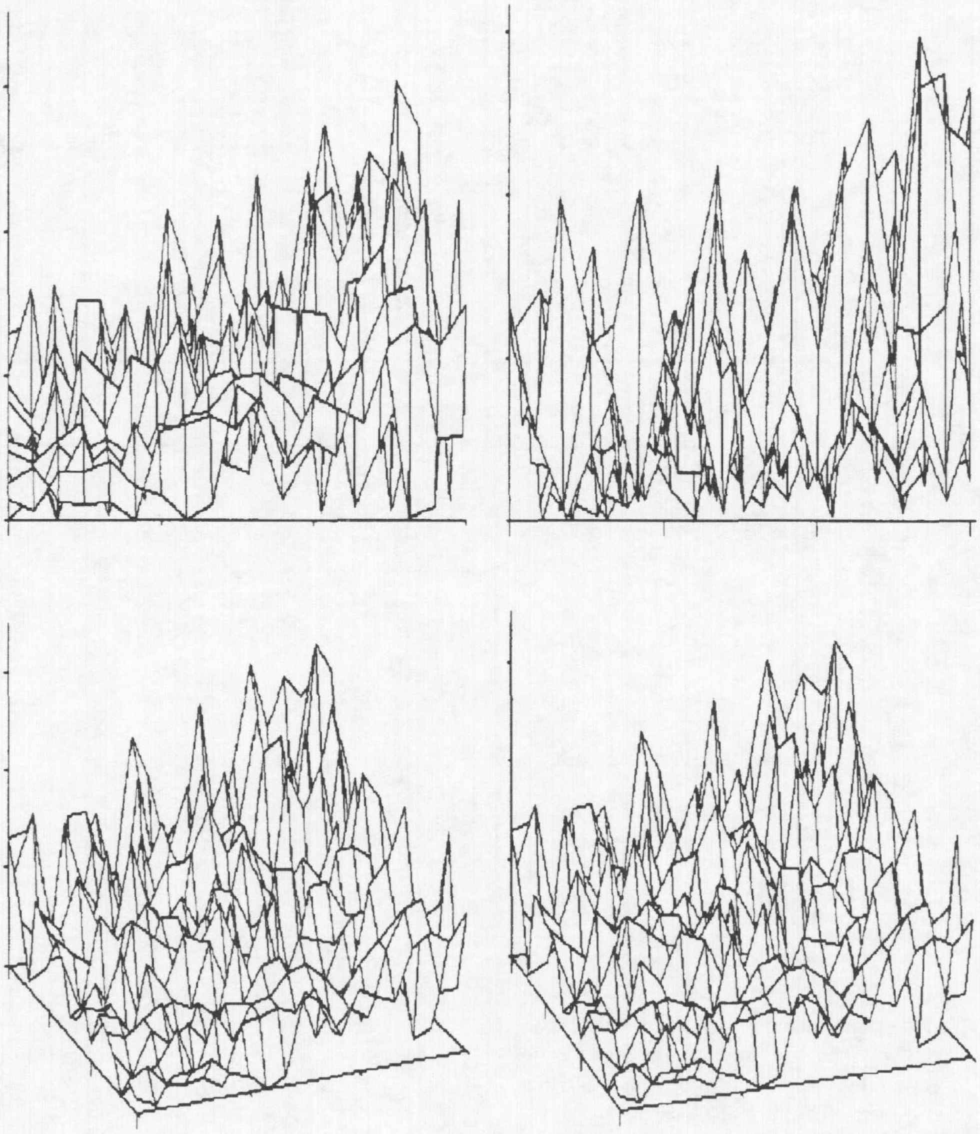
In contrast, the nature of the relationships emerges more clearly when the stereo pair on the bottom of Figure 3 is viewed stereoscopically to form a true three-dimensional representation. The depth provided by such a three-dimensional experience makes the relative positions of the observations more salient in general and greatly facilitates a grasp of the manner in which Final increases with Midterm from left to right (t = 3.64, $p < .001$) and with CP from the front to the back of the space (t = 3.56, $p < .001$). Hence, the stereographic effect enhances a reader's understanding of the meaning in a three-dimensional representation.

DISCUSSION

Limitations and Directions for Further Research

As any technique in marketing research, the power of three-dimensional viewing can be used or abused. In many cases, the results of an analysis will be sufficiently clear in a simple two-dimensional representation (e.g., a two-way scatterplot) or in a verbal form (e.g., a table), and no further benefit would result from the laborious project of converting the findings to a stereographic visual display. However, in

Figure 2
RANDOMLY GENERATED THREE-DIMENSIONAL PREFERENCE SURFACE WITH AFFECT (BOTTOM TO TOP) SHOWN AS A FUNCTION OF ATTRIBUTE X (LEFT TO RIGHT AT THE TOP LEFT AND IN THE BOTTOM ROW) AND ATTRIBUTE Y (LEFT TO RIGHT AT THE TOP RIGHT AND FRONT TO BACK IN THE BOTTOM ROW)



other cases, including the examples just given, additional insights result from the stereographic three-dimensional experience. In such cases, further benefits should reward refinements of the basic approach illustrated here.

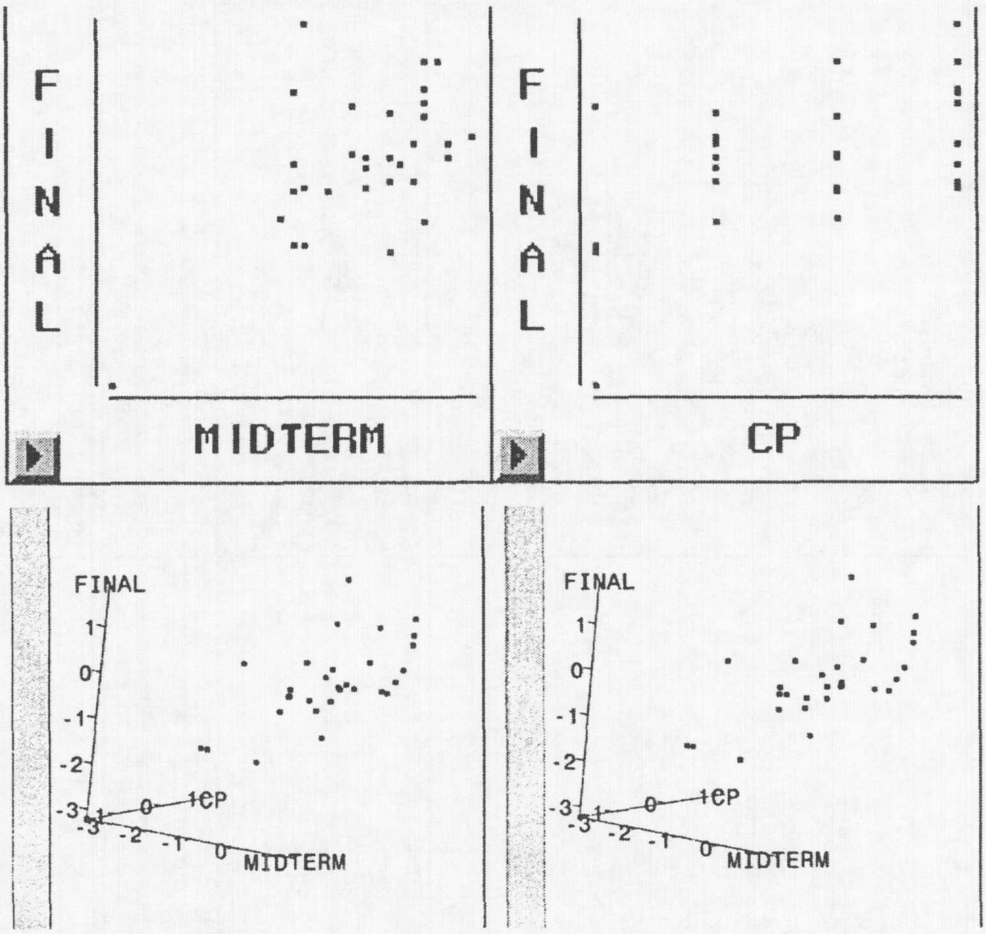
One such potential refinement involves the size of the feasible stereographic image. Using normal vision in free-viewing, the maximum comfortable width corresponds to the interocular distance of roughly two and one-half inches for most readers. Wider angled stereoscopic vision can be attained only by the use of special lenses, mirror-based devices, or projection systems. As one possibility, each issue of a marketing journal containing three-dimensional stereo pairs might come equipped with special glasses for viewing the figures contained therein. However, whether the marketing research community is prepared to accept the extra cost needed to achieve such an enhancement of the reading experience remains a topic for further investigation.

A related question is whether the typical reader of marketing research is both able and willing to employ free-viewing or aided-viewing techniques.[2] With respect to ability, Julesz (1971, 1995) repeatedly insists that at least 98% of the general population are functionally capable of seeing the sorts of stereoscopic effects represented by his RDS (which are actually more difficult to observe than the stereographic displays illustrated here). However, with respect to willingness, it is uncertain whether the typical reader of marketing research reports will invest the time and effort needed to master the relevant free-viewing techniques. This

[2]This issue was raised by reviewers.

Figure 3

SCATTERPLOTS SHOWING RELATIONSHIPS FOR 31 MBA STUDENTS OF GRADES ON THE FINAL EXAM (FINAL) TO THOSE ON THE MIDTERM EXAM (MIDTERM) AND CLASS PARTICIPATION (CP)



is where the prismatic lorgnette viewer and other forms of optical assistance play their potentially important role. In an informal study, I asked 54 MBA students whether they were able to observe three-dimensional depth effects in three stereographic representations similar to those shown previously—first, by free-viewing (without the help of optical assistance, without prior practice, and without training in how to do it) and second, by aided viewing (with the help of a prismatic lorgnette). Even without practice or training, 31 respondents (57.4%) successfully free-viewed at least one of the three stereographic displays, 18 respondents (33.3%) succeeded on at least two displays, and 9 respondents (16.7%) succeeded on all three. With the help of the prismatic lorgnette (but with neither practice nor training), 44 respondents (81.5%) succeeded in aided viewing of all three stereographic displays, 51 respondents (94.4%) succeeded on at least two displays, and 52 respondents (96.3%) succeeded on at least one. The latter estimate that 96.3% of viewers are functionally capable of achieving stereopsis corresponds roughly to the figure of 98% reported by Julesz (1971, 1995). Indeed, the two respondents who could not achieve stereopsis indicated that they suffered from ophthalmological problems (self-described as a "lazy eye"). All this strongly suggests that—for an expenditure of under five dollars or the trouble of borrowing a viewer for free—any interested *JMR* reader with normal sight can participate readily in the three-dimensional experience. However, the issue of how many *JMR* readers will want to make this modest financial commitment to stereography remains a question suitable for further research.

Other key questions for further research should involve refinements of the methods for presenting stereographic representations of marketing research results and the potential extension of stereopsis to other marketing-related applications. With respect to the refinement of methods, I envision useful research to determine which of the various presentation modes shown by the typology in Table 1 provide the greatest effectiveness in enhancing vividness, clarity, depth, or understanding, and which modes achieve the most efficient effectiveness–cost ratios. With respect to marketing-related extensions, work has already begun toward investigating applications of stereo photography to the collection and presentation of qualitative data in consumer research, studying possible benefits of stereography in advertising, using three-dimensional stereographic imaging in the computer-assisted design of consumer products, and applying similar stereo computer-assisted design methods to the design of three-dimensional retail spaces or other realistic three-dimensional environments. These and other possible extensions suggest the basis for a rewarding research agenda to address issues raised by opportunities for the use of stereographic visual displays.

Conclusion

Subject to these limitations and needs for further study, I have demonstrated the potential usefulness of stereographic visual displays to enhance the communication of marketing research results. The discussion has reviewed basic procedures for creating such three-dimensional images. Three illustrations indicate that these stereo three-dimensional representations can be constructed from such data as are normally offered in reports of marketing research to portray MDS positions, preference surfaces, or other functional relationships. These illustrations also demonstrate the power of stereographic visual displays to deepen the reader's understanding of the underlying associations or structural patterns in the data presented. Such associations or patterns spring to life when they are seen three-dimensionally in ways that enhance their vividness, clarity, depth, and interpretability. Furthermore, besides strengthening the reader's ability to understand visual representations, the three-dimensional experience should also bolster the reader's motivation to gain such insights by making the interpretive task more compelling and enjoyable. Any device that can facilitate communication between marketing researchers and those who use their findings in this way deserves serious consideration as a potential benefit to the overall marketing research enterprise. Hence, the power of stereographic visual displays and the three-dimensional communication of findings seem ripe for harvesting in the field of marketing research.

REFERENCES

Alderson, Tony (1988), "Everyone's Guide to Freevision," *Stereo World*, 15 (November/December), 12–17.

Aronowitz, Sheldon (1995), "Across the Sea of Time: Vintage Stereos on the IMAX Screen," *Stereo World*, 22 (September/October), 4–7.

Bastide, Françoise (1990), "The Iconography of Scientific Texts: Principles of Analysis," in *Representation in Scientific Practice*, Michael Lynch and Steve Woolgar, eds. Cambridge, MA: MIT Press, 187–229.

Batsell, Richard R. (1980a), "Consumer Resource Allocation Models at the Individual Level," *Journal of Consumer Research*, 7 (June), 78–87.

——— (1980b), "On the Use of Hidden Surface Routines in the Analysis of Marketing Data," *Journal of Marketing*, 44 (July), 102–106.

——— and Leonard M. Lodish (1981), "A Model and Measurement Methodology for Predicting Individual Consumer Choice," *Journal of Marketing Research*, 18 (February), 1–12.

Beaton, Alan (1985), *Left Side, Right Side: A Review of the Laterality Research*. New Haven, CT: Yale University Press.

Biocca, Frank (1992), "Virtual Reality Technology: A Tutorial," *Journal of Communication*, 42 (Autumn), 23–72.

Bolt, Raymond (1992), "3-D Video for the '90s," *Stereo World*, 19 (November/December), 12–13.

Brown, Theodore (1994), *Stereoscopic Phenomena of Light & Sight*. Culver City, CA: Reel 3-D Enterprises.

Burder, David and Pat Whitehouse (1992), *Photographing in 3-D*, 3d ed. Surrey, UK: The Stereoscopic Society.

Clark, Ken (1995), "Virtual Reality: From Doom to Mars to Your Garage," *Stereo World*, 21 (January/February), 12–15.

Cleveland, William S. and Marylyn E. McGill, eds. (1988), *Dynamic Graphics for Statistics*. Belmont, CA: Wadsworth & Brooks.

Coy, Peter and Robert D. Hof (1995), "3-D Computing," *Business Week*, (September 4), 70–77.

Dennis, John (1984), "Seven Billion Windows on the World—View-Master Then and Now," *Stereo World*, 11 (March/April), 4–16.

Dyckman, Dan (1994), *Hidden Dimensions*. New York: Harmony Books.

Faugeras, Olivier (1993), *Three-Dimensional Computer Vision: A Geometric Viewpoint*. Cambridge, MA: MIT Press.

Ferwerda, Jac. G. (1990), *The World of 3-D: A Practical Guide to Stereo Photography*, 2d ed. Borger, Holland: 3-D Book Productions.

Fisherkeller, Mary Anne, Jerome H. Friedman, and John W. Tukey (1975), "PRIM9: An Interactive Multidimensional Data Display and Analysis System," in *Data: Its Use, Organization, and Management*. New York: Association for Computing Machinery, 91–109.

Frisby, John P. (1980), *Seeing: Illusion, Brain and Mind*. Oxford: Oxford University Press.

Girling, Arthur N. (1990), *Stereoscopic Drawing: A Theory of 3-D Vision and Its Application to Stereoscopic Drawing*. London: Arthur N. Girling.

Green, Paul E. (1975), "Marketing Applications of MDS: Assessment and Outlook," *Journal of Marketing*, 39 (January), 24–31.

Gregory, Richard L. (1970), *The Intelligent Eye*. New York: McGraw-Hill.

——— (1990), *Eye and Brain: The Psychology of Seeing*, 4th ed. Princeton, NJ: Princeton University Press.

Grossman, Marc and Rachel Cooper (1995), *Magic Eye: How to See 3D*. Kansas City, MO: Andrews and McMeel.

Hayes, Suzanne Lloyd (1992), *3-D Hollywood: Photographs by Harold Lloyd*. New York: Simon & Schuster.

Johnstone, Tom (1995), *Magic 3D: Discover the Revolutionary World of Photographic Free-Viewing*. London: Stanley Paul.

Julesz, Bela (1971), *Foundations of Cyclopean Perception*. Chicago: University of Chicago Press.

——— (1995), *Dialogues On Perception*. Cambridge, MA: MIT Press.

Kinsman, Andrew (1992), *Random Dot Stereograms*. Rochester, NY: Kinsman Physics.

Lorenz, Dieter (1987), *The Stereo Image in Science and Technology*, 2d ed. Cologne, Germany: German Aerospace Research Establishment.

Love, Shaun (1993), "3D Hardcopy," in *Stereo Computer Graphics and Other True 3D Technologies*, David F. McAllister, ed. Princeton, NJ: Princeton University Press, 26–49.

Marr, David (1982), *Vision: A Computational Investigation into the Human Representation and Processing of Visual Information*. New York: W. H. Freeman.

Marren, Don (1994), "Sony and Imax Go Into the Deep," *Stereo World*, 21 (November/December), 18–24.

McAllister, David F., ed. (1993), *Stereo Computer Graphics and Other True 3D Technologies*. Princeton, NJ: Princeton University Press.

Novak, Thomas P. (1995), "MANOVAMAP: Graphical Representation of MANOVA in Marketing Research," *Journal of Marketing Research*, 22 (August), 357–74.

Pratt, H. Lee (1995), "Free Vision Stereo Viewing," *PSA Journal*, 61 (April), 30.

Rheingold, Howard (1994), Foreword to *Stereogram*. San Francisco: Cadence Books, 6–9.

Richardson, Dan (1994), *Create Stereograms on Your PC: Discover the World of 3D Illusion*. Corte Madera, CA: Waite Group Press.

Riemschneider, Burkhard (1994), *Interactive Pictures*, Karen Williams, trans. Cologne, Germany: Benedikt Taschen.
Saburi, Eugene H., ed. (1993), *3D Wonderland*. Bellevue, WA: Tokuma Shoten Publishing.
Sales, Jerry Haines (1994), *Constructing Anaglyph Images*. West Covina, CA: J. H. Sales.
SAS (1988), *SAS/Graph User's Guide*, Release 6.03 ed. Cary, NC: SAS Institute.
Schwartzman, Steven (1981), *Bodies of Light*. Austin, TX: SunShine.
Sell, Mary Ann and Wolfgang Sell (1994), *View-Master Viewers: An Illustrated History*. Borger, Holland: 3-D Book Productions.
Shepard, Roger N. (1972), "A Taxonomy of Some Principal Types of Data and Multidimensional Methods for Their Analysis," in *Multidimensional Scaling*, Vol. 1, R. N. Shepard, A. K. Romney, and S. B. Nerlove, eds. New York,: Seminar Press.
Smith, Charles W. (1996), "Plain Words About Convergence," *The Stereoscopic Society Journal of 3-D Imaging*, 133 (July), 2–4.
Tufte, Edward R. (1983), *The Visual Display of Quantitative Information*. Cheshire, CT: Graphics Press.
——— (1990), *Envisioning Information*. Cheshire, CT: Graphics Press.
Tyler, Christopher W. (1994), "The Birth of Computer Stereograms for Unaided Stereovision Including a Guide to Creating Random-Dot Stereograms," in *Stereogram*. San Francisco: Cadence Books, 83–89.
——— and Maureen B. Clarke (1990), "The Autostereogram," in *SPIE Proceedings*, Vol. 1256, John O. Merritt and Scott S. Fisher, eds. Bellingham, WA: International Society for Optical Engineers, 182–97.
Unterseher, Fred, Jeannene Hansen, and Bob Schlesinger (1992), *Holography Handbook: Making Holograms the Easy Way*. Berkeley, CA: Ross Books.
van Keulen, Wim (1986), *3-D Past and Present*. Borger, Holland: 3-D Book Productions.
Waack, Fritz G. (1987), *Stereo Photography: An Introduction to Stereo Photo Technology and Practical Suggestions for Stereo Photography*, Lorenz Huelsbergen, trans. Berlin: F. G. Waack.
Wegman, Edward J. and Douglas J. DePriest, eds. (1986), *Statistical Image Processing and Graphics*. New York: Marcel Dekker.
Wildstrom, Stephen H. (1995), "Entering a New Dimension," *Business Week*, (October 30), 18.