CRITIQUE

Objects and Mappings: Incompatible Principles of Display Design – A Critique of Marino and Mahan

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Marino and Mahan (2005, this issue) designed a graphical nutrition label and evaluated it in three experiments. The article is technically sound and it possesses a number of admirable qualities: a high degree of "real-world" relevance, a representative set of experimental stimuli, the involvement of domain experts, and sophisticated techniques for the measurement of performance. The authors are to be commended for this relatively unusual combination. As the title of their article suggests, the authors rely upon the proximity compatibility principle (PCP; e.g., Wickens & Carswell, 1995) as the primary source of inspiration for their work. Marino and Mahan also utilize concepts and principles from an alternative perspective: the "representation aiding" (RA) approach (e.g., Bennett & Flach, 1992; Bennett, Nagy, & Flach, 1997). Despite the positive aspects of this article, we have some fairly serious reservations regarding the authors' interpretation and application of these display design principles, as well as the conclusions that are drawn.

Mappings in Support of Integration Tasks

Representation aiding is a "problem-driven" or an "ecological" approach to display design with a general orientation that is consistent with cognitive systems engineering (Rasmussen, Pejtersen, & Goodstein, 1994). Effective decision support depends upon three system components: the domain (the work to be done), the agents (the humans or machines doing the work), and the interface between them (usually, but not necessarily, computerized). Each of these components contributes a set of constraints; the effectiveness of graphical decision support will ultimately depend upon the quality of *very specific sets of mappings* between these constraints (e.g., Bennett & Flach, 1992).

PCP is an alternative approach to display design with a distinctly different emphasis (Wickens & Carswell, 1995). Marino and Mahan's (2005) interpretation of PCP places a central role on perceptual "objects" (all italics added): "In *object* configural displays, multiple pieces of information are mapped to a single perceptual *object*" (p. 122). Objects are the primary consideration in the authors' definition of the core principle of display proximity: high display proximity occurs "[w]hen different features of the same *object* represent multiple pieces of information" (p. 122); low display proximity occurs "[w]hen separate perceptual *objects*...represent multiple pieces of information" (p. 122). For tasks in which multiple pieces of information must be considered to reach a decision (*high-proximity tasks*), Marino and Mahan predict that high-proximity displays will facilitate performance: "high-proximity tasks should be best supported by high-proximity displays" (p. 122).

Over a decade ago Bennett and Flach (1992) reviewed the visual attention, object perception, and display design literatures with regard to the role that a perceptual object should play as a display design principle. They urged designers to reconsider the prominent role that was often conferred. Bennett and Flach (1992, p. 528) provided reasonably compelling evidence that "improved performance at integrated tasks is more closely tied to configural properties of visual forms...than to objectness per se." (Note that the terms *integrated tasks* and *high-proximity tasks* are interchangeable for the purposes of this critique.) For example, it has been demonstrated that a nonobject display can produce significantly better performance at integrated tasks

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than an object display can (Sanderson, Flach, Buttigieg, & Casey, 1989). The critical considerations are configurality (i.e., emergent features) and the degree to which the emergent features map into domain properties. Configural display formats will provide effective decision support for integrated tasks if "the display produces highly salient emergent features and these emergent features directly reflect the critical data relationships and inherent constraints in the domain" (Bennett & Flach, 1992, p. 530).

Marino and Mahan (2005) describe their working premise with regard to the critical data relationships in the domain of nutritional quality: "[T]here was general consensus among the subject-matter experts that nutritional quality reflects the balance between nutrients that need to be *limited* in the diet and those that need to be consumed in *adequate* amounts" (p. 126, italics added). The authors assume no interactions between nutrients and therefore adopt the design goal of developing a display that illustrates the difference in the overall quality of the nutrients between the two categories (i.e., limited and adequate).

For the moment this working premise will be accepted and the focus will be on the extent to which the design goal was achieved. Marino and Mahan (2005) evaluated performance for integrated tasks in Experiments 1 and 2 and obtained results favoring the polar coordinate display, relative to the traditional label (an alphanumeric display). Despite the emphasis on PCP (and objects), the interpretation of these results called upon concepts central to the RA approach: "[T]he configural display possessed the emergent feature of area of a polygon that *corresponded directly* to the task requirement.... [T]he configural format *creates visual forms that correspond to that task*"(p. 128, italics added). We believe that the mapping is, in fact, not direct and that the graphical nutrition label suffers from several additional flaws in design. The observations in support of these beliefs will follow; they are organized around the specific mappings between system components described earlier.

Ineffective mapping: Agent constraints ↔ display constraints. The polar coordinate display format requires an agent to estimate the area of a polygon. There is evidence that agents are not particularly effective at this basic perceptual task. For example, Cleveland (1985) found numerous graphical features that provided more effective mappings (i.e., that resulted in a more effective decoding of quantitative information) than area.

Ineffective mapping: Domain constraints ↔ display constraints (1). The authors focus on the emergent feature of area and its relationship to nutritional quality. However, graphical forms often possess a "hierarchy of nested structures, with local elements combining to produce more global patterns or symmetries" (Bennett et al., 1997, p. 681). This is clearly the case for the polar coordinate display. Each line that connects the daily required values (DRVs) for two nutrients produces a local emergent feature: orientation. Each pair of lines that connect three DRVs produces contours with intermediate-level emergent features, including orientation, shape (e.g., "spike" vs. "flat"), and symmetry. Finally, the contours combine to form a closed polygon that produces higher level, global emergent features related to its shape (including, but by no means limited to, area).

The design flaw is that there is a poor mapping between the numerous emergent features produced by the polar coordinate display and the domain property they are intended to represent (i.e., nutritional quality within one of the two categories). The numerous, salient, and hierarchically nested emergent features described in the previous paragraph specify relationships and interactions between variables. Recall, however, that these interactions are not important under the current working premise. Therefore, all of the emergent features other than area need to be ignored. This is a feat that will be difficult, if not impossible, for agents to accomplish. In summary, the strong configural properties make the polar coordinate display a poor design choice in this particular instance.

Ineffective mapping: Domain constraints ↔ display constraints (2). The emergent feature of area and nutritional quality within a category of nutrients is correlated. It is, however, by no means a direct mapping. Consider Figure 1, which illustrates two alternative mappings of the same four nutrients and their DRVs. The only difference is that the physical locations of the sodium and total fat nutrients have been

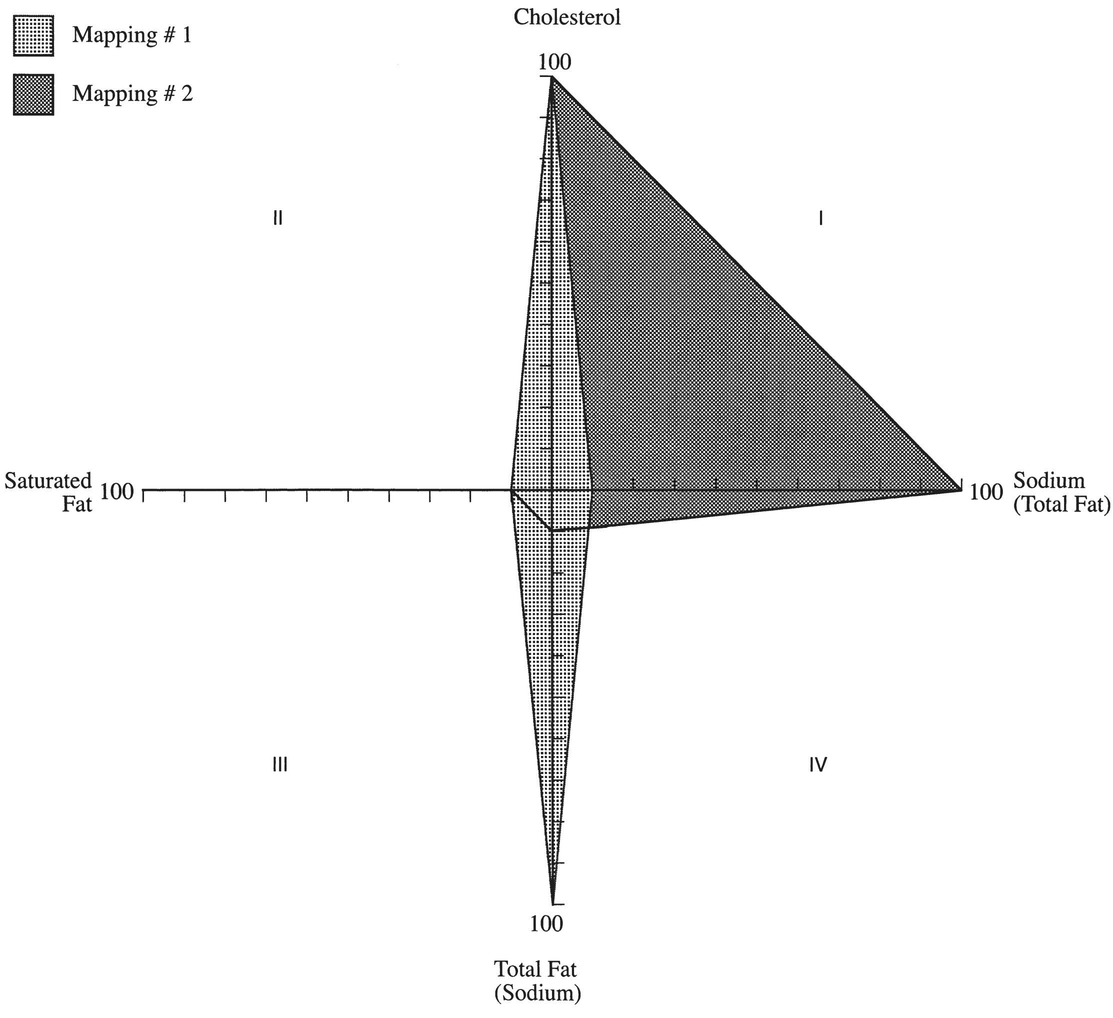

Figure 1. Graphical illustration of indirect mapping between nutritional quality and area.

switched. As demonstrated in Table 1, the area of the polygon in Mapping #1 is 2000 square units; the area in Mapping #2 is 6050 square units. Obviously, the nutritional quality remains exactly the same. The variations in area are caused by quantitative differences between DRVs and their specific placements in the graphic. The example is not an isolated case: These conditions will exist when the DRVs are not exactly equal (i.e., almost always). Thus the mapping between area and nutritional quality is far from direct, despite the authors' claim to the contrary.

Ineffective mapping: Domain constraints ↔ display constraints (3). An additional design flaw is that the pair of polar coordinate displays does not support the agent in making the critical comparison between categories of nutrients. The nutritional quality of each category (adequate, limited) must be determined independently from two separate displays that are located at two different points in space. A direct visual comparison between these two graphical features is impossible. Placing the two polygons in the same coordinate system would have improved the design somewhat (see Figure 1). However, a far better design choice would have been to incorporate a single visual feature that specifies the critical higher level domain property (i.e., the difference between the two categories of nutrients) directly.

Alternative design. Figure 2 illustrates an alternative design: a "contribution" graphic utilizing

TABLE 1: Mathematical Proof of Indirect Mapping Between Nutritional Quality and Area

Nutrient	DRV	Right Triangle (Quadrant)	Base (Unit)	Height (Unit)	Area: ½ B×H (Sq. Unit)
		Mapping #1			
Cholesterol	100%	I	10	100	500
Saturated fat	10%	II	10	100	500
Total fat	100%	III	10	100	500
Sodium	10%	IV	10	100	500
				Total area of the polygon =	2000
		Mapping # 2			
Cholesterol	100%	I	100	100	5000
Saturated Fat	10%	II	10	100	500
Sodium	10%	III	10	10	50
Total Fat	100%	IV	10	100	500
				Total area of the polygon =	6050

stacked bar graphs. This design improves the quality of specific mappings in several ways. Agents are required to determine position along a common scale (i.e., vertical extent), the most effective basic perceptual task that Cleveland (1985) identified. Also, there is a truly direct, one-to-one relationship between the domain constraints (i.e., nutritional value within a category) and the graphical constraints (i.e., vertical extent of the bar graph). Note that switching the physical location of the total fat and sodium nutrients would not modify vertical extent. The critical higher level property of nutritional quality between the two categories is specified redundantly: by the relative heights of the two bar graphs and by the orientation of the line connecting them. Finally, all emergent features produced by the display are meaningful and do not need to be ignored.

The fact that Marino and Mahan (2005) obtained significant results favoring the polar coordinate displays in Experiments 1 and 2 appears to be a far greater testament to the power of perceptual systems than to effective design. It is likely that the agents were using area to perform the task, as Marino and Mahan suggest. What is so impressive is that the agents were able to do so despite the number of irrelevant emergent features that had to be ignored, the independent and spatially separated representations of nutritional value for the two categories, and the indirect mapping between area and nutritional quality (see Figure 1).

Domain semantics revisited. There are several problems with Marino and Mahan's (2005) treatment of nutrition. First, it is important to note that protein is an essential part of a diet and therefore needs to be present in a nutrition label. The authors' rationale for not including protein is invalid: The DRV for protein can be determined if one assumes a target for caloric intake (e.g., 2000 calories). In fact, the authors have made similar assumptions for carbohydrates and fat. Second, the working premise was that there were no interactions between nutrients. This is incorrect. The presence of one nutrient can either increase or decrease the digestibility (i.e., the capability of the body to absorb) of other nutrients. These interactions include the following: Vitamin C promotes the digestibility of iron; fiber inhibits the digestibility of iron, fat, and cholesterol; and sodium inhibits the digestibility of calcium (Whitney, Cataldo, & Rolfes, 2002). Also, fiber inhibits the digestibility of calcium (Mahan & Arlin, 1992).

These interactions should be specified by the visual constraints of the display. Relatively simple modifications of the design in Figure 2 might suffice. For example, spatial positioning might be used to reflect nutrient interactions: Overlapping rectangles could represent inhibition (a decrease in nutrition), and separated rectangles could represent promotion (an increase). However, other considerations (beyond the scope of the present critique) have the capability to compromise the design. It is important to note, however, that

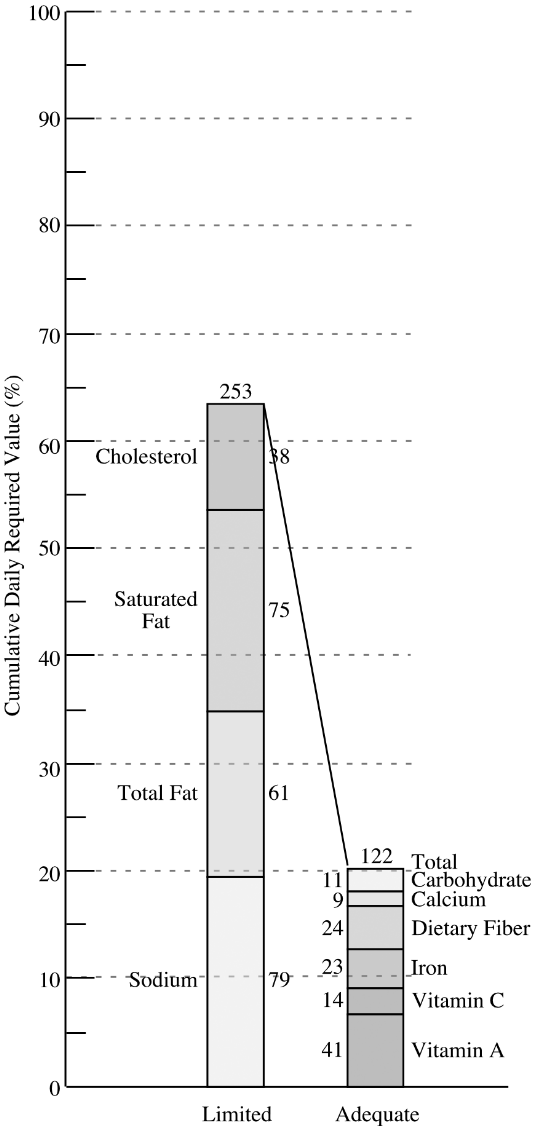

Figure 2. An alternative design using contribution bar graphs.

Marino and Mahan's (2005) displays clearly do not provide effective representations of the nutrient interactions. These interactions are selective (i.e., not all nutrients interact, nor do they interact in the same way), and they occur both within and between categories (Mahan & Arlin, 1992; Whitney et al., 2002). In contrast, all contiguous nutrients within a category interact visually in the same way, and there are no visual interactions between categories with the polar coordinate displays.

Mappings in Support of Focused Tasks

At the opposite end of the continuum from integrated tasks are "focused" tasks, which require an agent to consider the value of a single variable. Marino and Mahan (2005) also believe that the principle of a perceptual object plays a primary role in determining performance at focused tasks. They predict that an object will degrade performance: "Focusing attention on a single dimension is more difficult when it is embedded in a unitary perceptual *object* than when it is represented as one of multiple separate indicators" (p. 122, italics added). Significantly better performance was obtained with the alphanumeric display than with the polar coordinate display in Experiment 3. The authors attribute these performance differences to the presence of an object: "Task performance required focused attention to extract a single piece of nutrient data, and the configural display disrupted the focusing of attention by embedding the nutrient data in a unitary perceptual *object*" (p. 129, italics added).

Bennett and Flach (1992) also urged designers to reconsider the role that perceptual objects had been conferred with respect to focused tasks: "Because emergent features are inherently more salient than are the elemental parts, observers are more likely to pay attention to the emergent features, which may result in apparent performance deficits. This does not mean that observers cannot, at their discretion, focus on the parts of an object when it is necessary to do so" (p. 518). The pattern of results from the display design literature was consistent with this interpretation: "Clearly, these results do not strongly support the existence of an inherent and unavoidable cost for the extraction of low-level data with configural formats" (Bennett & Flach, p. 528).

It turns out that effective performance of focused tasks also depends upon the quality of specific mappings among domain, display, and agent constraints. This was demonstrated in a study by Bennett and Walters (2001). They applied four display design techniques (i.e., bar graphs/extenders, scale markers/scale grids, color coding/layering/separation, and digital values) alone, and in combination, to a configural display. Three of the four design techniques (color coding was the exception) were found to improve performance significantly for a focused task (to provide a quantitative estimate for the value of an individual variable). Two of these three techniques provided display constraints (i.e., an analog visual structure: grids, scales, markers, extenders) that allowed estimations to be based on perceptual comparisons as opposed to mental calculations. The third technique, digital values, was particularly effective. The task constraints (i.e., specify a quantitative value) matched the display constraints (a digital representation of that value) perfectly; the need for any form of estimation (and therefore all uncertainty with regard to the value) was simply eliminated.

Our interpretation of the results obtained by Marino and Mahan (2005) in Experiment 3 involves similar considerations of mapping. The experimental task required agents to determine the number of servings required to reach 100% of DRV for a nutrient. Note that this is technically an integrated task, although determining the percentage of DRV contained in a serving (a focused task) does play an important role. The traditional alphanumeric display provided a direct mapping between the constraints of the focused task (i.e., determine the DRV percentage) and the corresponding display constraints (i.e., the digital value specifying the DRV percentage). It is critical to note that the digital values were not included in the polar coordinate display. Therefore the mapping between task and display constraints was far less direct: Agents were forced to estimate the DRV percentage on the basis of the analog visual structure (i.e., the spatial position of the data marker relative to the scale and its markers). This is obviously a more laborious and inexact process than reading a digital value. Note that this mapping-based interpretation is quite parsimonious and totally devoid of any considerations related to a perceptual object.

Mappings in Support of Both Integrated and Focused Tasks

In an earlier analysis of the PCP, Bennett and Flach (1992) stated, "A second problem is that... this principle suggests that configural displays will facilitate performance for integrated tasks, but degrade performance for focused tasks" (p. 528). As the previous discussion indicates, Marino and Mahan's (2005) interpretation of the PCP (and the emphasis on perceptual objects) transforms this suggestion into explicit predictions. In turn, the authors interpret their results as empirical proof that this trade-off is inevitable and unavoidable: "As this study has shown, one label format cannot support all tasks equally well" (p. 129).

We disagree with this conclusion as well. Bennett and Walters (2001) demonstrated the practical reality behind the theoretical reasoning of Bennett and Flach (1992). They required agents to complete both integrated (manual control and fault detection) and focused (quantitative estimates of individual process variables) tasks. A "composite" display (all four of the previously mentioned techniques applied to a configural display) produced very good performance for both task types. Bennett and Walters concluded that "participants could select and use the specific design features in the composite display that were appropriate for tasks at each boundary [focused and integrated]....The results represent progress toward a fundamental display design goal: single graphical displays capable of supporting performance at multiple tasks" (p. 431). The critical design consideration is the annotation of analog graphical formats with digital values. Calcaterra and Bennett (2003) investigated different annotation strategies involving alternative placements of digital values.

Summary

Representation aiding (and similar approaches that share the general orientation) has a great deal of utility, predictive ability, and explanatory power. Marino and Mahan (2005) discuss principles that are critical to the RA approach (configurality, emergent features, and mappings) in a reasonable fashion. However, the application of these principles is far from reasonable. The authors explicitly realize the potential for interactions between nutrients: "The nutritional quality of a food product is a multidimensional concept, and higher order interactions between nutrients may exist" (p. 126). However, they made no effort to discover the nature of these interactions: "No attempt was made to identify contingent interactions between nutrients" (p. 126). Despite not knowing the nature of the interactions between nutrients, they purposely chose a highly configural display that produced numerous emergent features dependent upon these interactions: "A radial spoke display was selected because of the strong configural properties of such display formats (Bennett & Flach, 1992)" (p. 124). Finally, the authors show apparent disdain for the specific mappings among domain, agent, and display that are fundamental to the RA approach: "[O]ther configural display formats could have been used" (p. 124). It is impossible to reconcile these statements and the RA approach to display design.

However, these statements make perfect sense if a perceptual object is a guiding principle in one's approach to display design. Marino and Mahan (2005) draw heavily upon the principle of a perceptual object in their design justifications, experimental predictions, and interpretations of results. As we have indicated here and elsewhere (Bennett & Flach, 1992), we believe that these two sets of organizing principles for display design (i.e., objects and mappings) are incompatible. Display design will never be an exact science; there will always be elements of art and creativity. However, the guiding principles have moved well beyond the simple strategy of throwing variables into a geometric object format and relying upon the human agent's powerful perceptual systems to carry the design.

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