Some Preliminary Data on a New Theory of Complexity of Three-Dimensional Objects

An Honors Thesis

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Running Head: COMPLEXITY

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Many measures of stimulus complexity have been used in visual perception experiments, and there are many hypotheses which attempt to predict perceived complexity of stimuli. For two-dimensional random polygons, Attneave (1957) found that about 90% of the variance of his subjects' complexity judgments was accounted for by three factors: (a) the number of independent turns (the total number of turns for an asymmetrical shape and about half of the total number for a symmetrical shape), (b) symmetry (with symmetrical shapes judged more complex than asymmetrical shapes when the number of *independent* turns was held constant, but vice versa when the *total* number of turns was held constant), and (c) angular variability (where more variability resulted in higher complexity judgments). Attneave also noted that curvature (as opposed to angularity) had no effect on judgments.

In a study yielding similar results, Arnoult (1960) found that about 85% of the variance among subjects' judgments of complexity was explained by symmetry, angular variability, perimeter squared over area, and the number of independent sides of polygons. Curvature was found to have no effect on complexity judgments here, either.

Alexander and Carey (1968) investigated horizontal linear arrangements of seven squares that were either black or white. The investigators found that subjects´ rank-orderings of the patterns for simplicity were "almost perfectly accounted for by the relative number of subsymmetries in the different patterns" (p. 73). A subsymmetry of a pattern was defined as a "bilateral symmetry of a segment within that pattern" (p. 77). In essence, then, the number of symmetrical segments in a pattern was the number of subsymmetries in the pattern, with more subsymmetries corresponding to more simplicity (less complexity).

Zusne (1970), in his review of complexity scaling research, points to Stenson´s 1966 factor analysis of complexity ratings for two-dimensional forms. Investigating many of the variables used in previous complexity research, Stenson attempted to discover if some of the variables traditionally discussed were measuring different factors, or if they were essentially getting at the same thing. He found that four physical measures described the one factor that accounted for most of the variance in his subjects' complexity judgments: length of the perimeter, perimeter squared over area, number of turns, and the variety of internal angles.

Researchers have attempted to use this two-dimensional complexity approach to predict complexity judgments of two-dimensional representations of three-dimensional objects (Hochberg and Brooks, 1960; Butler, 1982). Hochberg and Brooks (1960) studied reversible-perspective line drawings of objects. They found complexity to be best measured by the number of continuous line segments (ignoring intersections), the number of interior angles, and the variety of internal angles (total number of different angles over total number of internal angles).

Although Hochberg and Brooks' (1960) measure is a good measure of complexity, it is not perfect. Hochberg (1964) notes that while this approach explains most of the subjects' responses quite well, several stimuli elicited responses that could not be accounted for, suggesting that the approach may be lacking some important factor. Butler (1982) found that Hochberg and Brooks' (1960) measure could not explain judgments of a variety of new drawings.

One of the first attempts to develop a <u>theory</u> of complexity, as opposed to a data-driven measurement of complexity, was Garner's (1962) information/uncertainty approach. Garner argued that more complex figures are more redundant figures, where redundancy increases "the number of variables on which two or more events in a set can be discriminated" (Garner, 1962, p. 184). He explains that increasing redundancy "has the effect of increasing complexity and discriminability between the patterns in a particular set of stimuli because the redundancy provides more distinctive cues than are actually required for discrimination" (p. 195).

Leeuwenberg (1968) developed a new theory of complexity based in part on Garner's approach. Leeuwenberg combined the information approach of Garner and the law of Pragnanz (the "minimum principle") from gestalt psychology to form a perceptual coding system. He contends that the preferred interpretation of a drawing will be the simplest one, the one whose code contains the fewest units of structural information. The more units of structural information in a pattern's code, the more complex the pattern is.

Butler (1982) attempted to use Leeuwenberg's (1968) measure to predict complexity of line drawings of objects which could be seen as two-dimensional or as three-dimensional. Finding that

Leeuwenberg's approach did not work well, he proposed another measure of complexity for two-dimensional drawings of three-dimensional objects. He integrated Leeuwenberg's approach to complexity (the information load in a drawing) with a traditional measure of complexity, the number of lines. Combining these two measures, Butler provided a reasonably good account of both how organized the drawing is and how much is in the drawing.

In a series of experiments, Butler (1982) found that this proposed complexity measure was better than other measures but still had some weaknesses. He suggested extending the approach by developing a three-dimensional coding theory, one describing the three-dimensional complexities of depicted objects instead of two-dimensional complexities of drawings of three-dimensional objects. But he and others have been unsuccessful in extending two-dimensional measures to handle three-dimensional complexities.

A more direct attempt to specify three-dimensional complexity of objects has recently been made by Biederman (1987) in his Recognition-by-Components theory of human image understanding. Instead of extending two-dimensional perception theories to objects, Biederman uses three-dimensional objects as a starting point. The crux of his theory is that in object recognition, the image of input is parsed into segments at areas of deep concavity, resulting in an arrangement of simple geometric components (called geons) such as wedges, blocks, and cylinders. Biederman has argued that complex objects require more components to look complete than do simple objects.

Recognition-by-Components presents a novel approach to three-dimensional complexity, clearly involving new units of analysis. While the theories discussed above are attempts to quantify object complexity using two-dimensional measures such as the number of lines, number of angles, perimeter lengths, etc., Biederman's theory posits actual three-dimensional geons as the basic level of analysis, with more geons indicating more complexity.

Biederman's approach represents a giant leap from using two-dimensional notions to understand three-dimensional complexity. However, there may be ways of manipulating object complexity other than, as Biederman proposes, simply varying the number of geons involved.

In previous complexity research (e.g., Butler, 1982), it has been shown that simply counting components of stimuli (e.g., number of lines, number of angles) is not enough to successfully predict complexity. There may be other factors influencing object complexity, such as the arrangement of geons and the individual complexities of the geons comprising the object. The arrangement of the geons would seem to matter, based on gestalt and information approach research (with more organized arrangements judged less complex). And from complexity research showing that two-dimensional forms have differing complexities, it is logical to assume that three-dimensional objects also differ in complexity. The following experiment involves perceived complexities of three-dimensional objects.

Method

Subjects

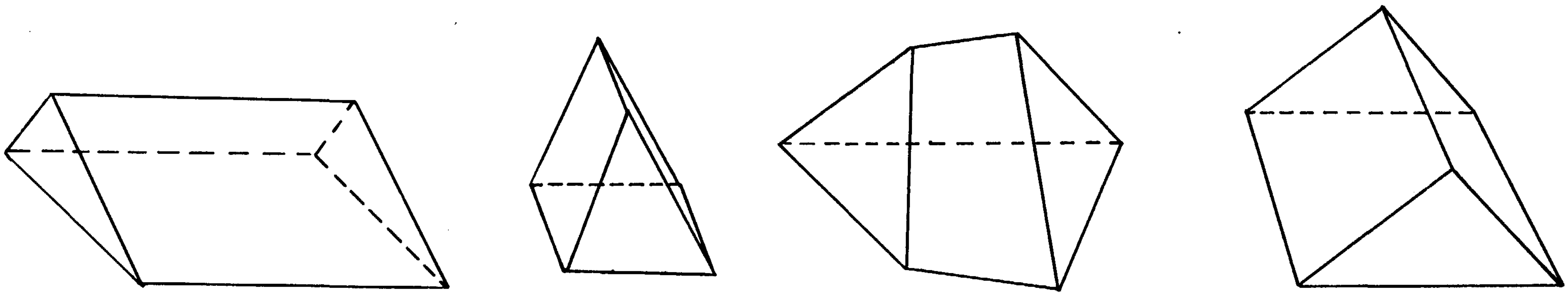
The subjects were 24 male and female undergraduates from the psychological science subject pool at Ball State University. Students can participate in psychology experiments as part of the subject pool to fulfill the out-of-class activity requirement for introductory psychology courses.

Stimuli

The stimuli were 12 polyhedra varying in number of surfaces and in regularity of surfaces. They are shown in Figures

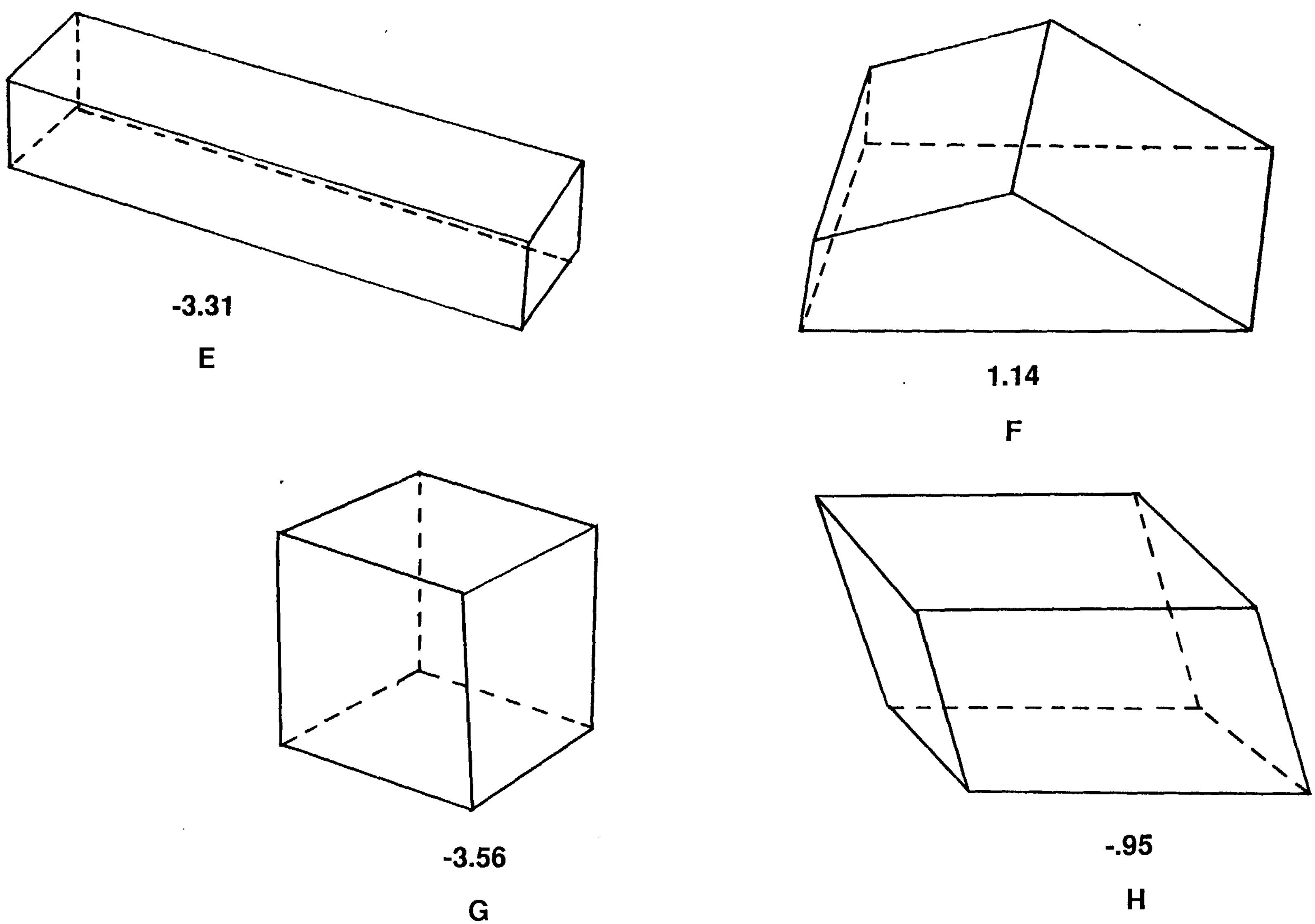
1a, 1b, and 1c. Three groups of stimuli were constructed: four wedges (five-surfaced objects, shown in Figure 1a), four boxes (six-surfaced objects, shown in Figure 1b), and four polyhedra with more than six surfaces, shown in Figure 1c. In keeping with the purpose of varying complexity, each of the wedges had a different shape for a base. One had a square base (object B), one had a rectangle base (object D), one had a parallelogram base (object A), and one had an irregular trapezoid base (object C). As can be seen in Figure 1a, the wedges also varied in several other ways. The shape of the base (and cross section) of each box was either a square (object G), a rectangle (object E), a parallelogram (object H), or an irregular trapezoid (object F). The size of the cross-section was constant along the entire object, following the terminology of Biederman (1987). Three of the polyhedra with more than six surfaces were formed with the size and shape of the cross section constant along the object. One had an irregular pentagon base, creating seven surfaces (object I), one had an irregular seven-sided base, creating nine surfaces (object K), and one had a regular hexagon base, creating eight surfaces (object J). The remaining polyhedron had an irregular pentagon base, creating seven surfaces (object L), but the top surface was made nonparallel to the base.

Figure 1a. Wedges and their complexity ratings in mean z-scores.

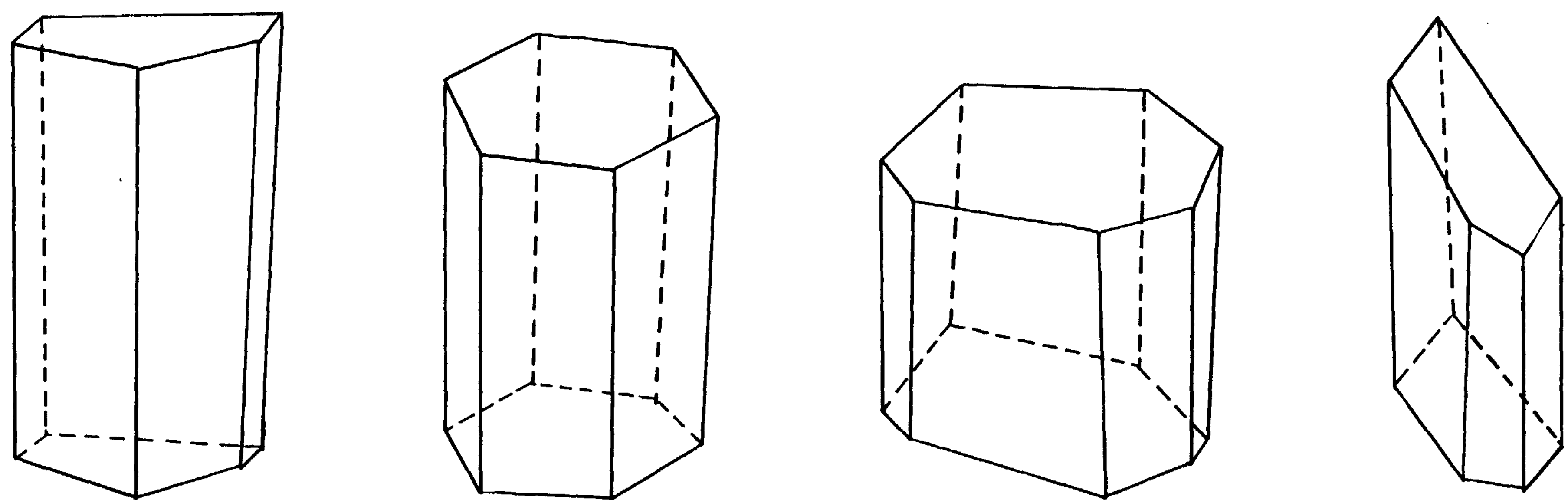


.17 A   -3.21 B   2.19 C   -2.79 D

Figure 1b. Boxes and their complexity ratings in mean z-scores.



<u>Figure 1c</u>. **Polyhedra with more than six surfaces and their complexity ratings in mean z-scores.**



2.66	**1.04**	**3.17**	**3.46**
I	**J**	**K**	**L**

The objects were constructed from layers of extruded polystyrene insulation. They were coated with canvas primer and then painted medium blue. The longest axes of the objects varied from 5.5 cm (for object B) to 16.2 cm (for object E).

Procedure

Each session lasted approximately 15 minutes. Each subject was run individually and was given the following instructions:

> In this experiment, you will be making complexity judgments about the 12 objects in front of you. Please judge the complexity of the OVERALL objects, ignoring imperfections such as lines and brushstrokes. I would like you to move the objects around until they are in order from simplest to most complex.
>
> Now I would like for you to assign numeric ratings to the objects. Use a scale from 1 to 10, like the scale used in the Olympics, where 1=simplest, and 10=most complex. You may use decimals in your judgments. For example, you may assign an object a rating of 3.7. You may also decide that two or more objects are the same and

should receive the same rating. This is fine.

There are no correct answers; these are simply YOUR judgments.

Do you have any questions?

After the subject finished reading the instructions, the experimenter paraphrased the instructions and answered questions. The subject ordered the objects and then gave complexity ratings, with the experimenter typing the numeric values into a nearby computer terminal. When the subject was satisfied with the final ratings, he or she was asked to describe the criteria he or she used to judge complexity. The subject was thanked and dismissed.

Results

The mean complexity judgments of the objects varied substantially. For each subject, z-scores were computed for each of the 12 stimuli using the mean and standard deviation of each subject's response distribution. Then, for each stimulus, the z-scores were averaged across subjects, yielding a mean z-score for each stimulus. The means are shown in Figures 1a, 1b, and 1c. The differences in the mean z-scores were so large that an analysis of variance was not needed to verify the significance of the differences.

A stepwise multiple regression was performed to determine the best predictors of judged complexity. The predictors tested included the following: number of surfaces, regularity of the designated base (all angles and sides equal), whether or not the base had parallel sides, whether or not the object had a constant cross section, reflective symmetry of the base, rotational symmetry of the base, and a ratio of number of different surface angles to total number of surface angles. This data analysis revealed that the most important predictor was whether or not the designated base had parallel sides [$R^2 = .69$, $p < .001$, $df(1,10)$]. The next most important predictor was the number of surfaces [$R^2 = .76$, $p = .13$, $df(2,9)$]. Although the addition of this second predictor did not produce a significant increase in prediction power, it should be noted that the degrees of freedom were extremely small, and these results are at least suggestive of the importance of number of surfaces in predicting complexity. Using these two variables produces the following regression equation:

complexity in z-score = -3.76 (parallel sides in base)

+ .60 (number of surfaces) - 1.58

Discussion

In general, the best predictor of judged complexity was whether or not the designated base had parallel sides (with parallel sides indicating less complexity). The next most important factor was the number of surfaces. Adding the second predictor did not lead to a statistically significant increase in prediction power, but this preliminary analysis suggests that it could be important. In general, complexity judgments appear to be higher for objects with more surfaces.

An important step in this research was rescaling the complexity judgments. In order to eliminate the effects of subjects' using the 1 to 10 scale differently, a z-score transformation was performed before attempting the regression analysis. Even with rescaling, the differences in the mean z-scores were highly significant. Future investigations should also include some kind of rescaling procedure.

This study involved perceived complexity of only a subset of Biederman's (1987) proposed geon types. While these results were informative, an appropriate extension of this research would be to investigate complexity using all 36 of Biederman's proposed geons.

The first of the two factors found to be important in predicting object complexity is a measure of regularity (how organized the object is), while the second is a quantity measure (how much is in the object). In this study and others (e.g., Butler, 1982), both organization and quantity have been shown to predict perceived complexity. In this light, it may be safe to speculate that Biederman's (1987) notion of object complexity, determined simply by the number of components (geons) in an object, may be incomplete, lacking any organizational measure.

The hypothesis driving this investigation is that complexity judgments for objects are influenced not only by the number of geons (components) involved (Biederman, 1987), but also by the arrangement of geons (a measure of organization) and the individual complexities of the geons. While the number of geons may be the most important predictor of complexity, the data from this pilot study of individual geons' complexities has verified the assumption that geons themselves do vary substantially in perceived complexity.

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