PSIHOLOGIJA, 2002, Vol. 35, br. 3-4, 245-260 UDC 159.937.522.075

OBJECTIVE CONSTRAINTS OF FIGURAL GOODNESS

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The effects of uniformity, compactness and symmetry on pattern goodness estimates were evaluated in three experiments. Ss were asked to choose the pattern which looks the best in respect to other patterns from given set. Patterns within sets differed from each other in uniformity (Experiment 1), compactness (Experiment 2) and symmetry (Experiment 3). Regression analyses indicated that symmetry was a single good predictor of the frequency of good pattern choice. This result is connected with Koffka's concept of perceptual economy: uniformity and compactness have perceptual advantages in the restricted situations (low energy disposal), while symmetry prevails in unrestricted conditions (high energy disposal).

Key words: *figural goodness, uniformity, compactness, symmetry*

This study addresses the question why some visual patterns, configurations and figures look better or have more perceptual "goodness" than others. Generally speaking, this question cam be approached from two aspects, external and internal. The external aspect is related to objective stimulus features, which form a pattern more or less perceptually good. For example, from this point of view one could say that pattern A (**: :**) looks better than pattern B (**<*. '**) because A possesses some objective advantages over B, such as greater uniformity, greater symmetry etc.

The internal aspect is related to the subjective evaluation of perceived patterns, i.e. to the question of how much a certain pattern satisfies some basic tendencies in perceptual processing. From this aspect one could say that a pattern A (**: :**) is better than the pattern B (**<*. '**) because A enables better realization of a natural tendency toward the fastest, the most precise, the most stable, etc. perception.

It should be emphasized that considerations of pattern goodness from the external or from the internal aspect does not require any theoretical presuppositions, such as the acceptance of either externalistic (e.g. gibsonian) or internalistic (e.g. constructivistic, information processing etc.) approaches to perception. The distinction between the external and internal aspects is descriptive in nature. The

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former deals with the psychophysical description of the phenomenon, and the latter, is oriented toward modeling of inner perceptual processes and states.

This study will mainly be concerned with the external aspect of goodness, i.e. the specification of stimulus goodness features. However, since such features are necessarily connected with certain inner states or perceptual evaluators (e.g. nutrition is related to certain needs of organisms), the internal aspect of goodness will be also taken into account.

Referring to the inner aspect of goodness, we in principle accept the classic Gestaltistic idea of perceptual economy. In the following text, this idea will be briefly outlined.

INTERNAL ASPECT OF GOODNESS: ECONOMY OF PROCESSING

Prägnanz. The notion of perceptual goodness was originally introduced by Gestalt psychologists. According to Wertheimer's concept of Prägnanz (or Prägnanzqualität) and the similar notion of von Ehrenfels' concept of Gestaltqualität, the perceptual goodness can be defined as the presence of some global structural qualities or forces which spontaneously integrate elements of the perceptual experience into the unique phenomenological configurations (Gestalten). Hence, pattern goodness increases with the increase of Prägnanz or the Gestalt quality (cf. Wertheimer, 1922).

Perceptual organization. In addition to such, rather intuitive and vague definition of perceptual goodness, Gestaltists made attempts of offering a more detailed concept of Gestalt integration. This concept described several specific laws of perceptual organization (or laws of element grouping) such as similarity, proximity, continuation, symmetry etc. (cf. Wertheimer, 1923). These laws predict that the similar, proximal, continual (or arranged along consistent path), symmetrically connected elements etc., will always be perceived as an integrated entity, as opposed to an agglomeration of independent or free parts.

Isomorphism. Gestalt psycholostists asserted that the phenomenological aspect of perceptual organization is closely related to its neural basis by the principle of isomorphism. This principle holds that each configuration, which is immediately given in perceptual experience, indicates an isomorphic configuration of electric charges in the brain (i.e. the physical Gestalt, cf. Köhler, 1920). According to this idea, one could say that the better organized or more “pragnant” the percept, the better or more “pragnant” is the structure of certain biophysical states and processes in the nervous system.

Economy. Gestalt psychologists believed that the physical aspect of Prägnanz is identifiable with the economy of perceptual processing (cf. Köhler, 1927; Koffka, 1935). They hypothesized that the perceptual (nervous) system is a dynamic and sophisticated natural system which permanently tends to economize its energy engagement, i.e. to maintain an optimal balance between a tendency toward minimizing the general distribution of energy with the tendency toward maximizing the effective use of available energy. In other words, the Gestaltists held that the perceptual system works by the principle: "with the least investments reach the greatest gains". When such an economic principle is taken into account, the idea of phenomenological tendency toward Gestalt integration will be clearer: for a perceptual system, it is more economic (easier and more effective) to deal with unique, simple, regular etc. entities, than with several independent parts and elements. Therefore, one can say that perceptual system tends to reduce the degrees of freedom of the stimulus pattern description. For instance, one group of dots (**: :**) will rather be seen and described as a single entity with a simple and symmetric structure, than as an agglomeration of four independent entities.

Informational interpretation of economy. The concept of perceptual economy was widely accepted and developed in the informational approach to perception (cf. Attneave, 1954; Garner, 1962; Leeuwenberg, 1971). Here, the economy was not defined as optimization of the neural energy engagement, but rather as an optimization of information processing. Thus, the informational approaches hold that a perceptual-cognitive system always tends to code the outer world in the simplest and most precise manner. The tendency toward simplicity enables the minimization of processing load (it is easier to process a smaller, than a greater amount of information), while the tendency toward precise description enables the maximizing of processing efficiency (the more structured information decreases the noise and the uncertainty and yields more accurate perceptual output).

OBJECTIVE FEATURES OF PATTERN GOODNESS

Although Gestalt psychologists were mainly oriented toward the inner (phenomenological and neural) aspects of perception, they were also aware of the importance of external stimulus constraints. Thus, Koffka (1935) pointed out that the perceptual system is not always able to overcome the "local forces" and restrict the freedom of perceptual "particles", because the efficiency of global integrational Gestalt forces, or the Prägnanz, necessarily depends on the prevailing stimulus conditions. For example, pattern A (**: :**) will be seen easily and unambiguously as a unique entity or a good Gestalten, because it is objectively well structured. On the other hand, pattern B (**<*. '**) will be seen as a group of independent entities, because it is objectively poor organized.

Nevertheless, Gestalt psychologists did not build a theory, which would strongly include a stimulus aspect of the Prägnanz and perceptual organization. Moreover, Köhler strictly stated that the notion of Gestalt could be applied only to the inner phenomenological and neural configurations, and not to the external stimulus (pattern) structures (Köhler, 1947). Not only the Gestalt psychologists, but even some later authors (cf. Hatfield & Epstein, 1985; Perkins, 1982) held that the description of stimulus constraints is not crucial for an explanation of the perceptual goodness and the economy of processing. They presumed that the description of inner coding (i.e. perceptual interpretation) of the stimulus is much more theoretically important. However, we believe that the question of how perceptual system organizes and transforms the agglomerations of stimuli into meaningful informational structures, must be connected to the question of what the objective constraints of such activities are, or what the external sources of information permit the perceptual system to do with the information.

Many authors tried to pay more attention to the external aspect of pattern goodness. Such an orientation resulted in several attempts toward specifying and quantifying the stimulus constraints of a "good Gestalt". Of course, it is not easy to identify these constraints and to find completely satisfying metrics and techniques for their quantitative description. Namely, the goodness is not a dimension, such as size, shape, brightness, color and other elementary features of pattern, which clearly can be seen (by naive perceivers) and detected (by perception scientists). Rather it belongs to some more abstract organizational level of pattern structure.

The attempts made to specify objective dimensions of pattern goodness can be reduced to three groups of models, that is, to the models of (1) uniformity, (2) compactness and (3) symmetry.

1) ***Uniformity.*** Uniformity is quantified by the amount of different elements in the pattern, e.g. by the number of different line segments, intersections and angles in the pattern (Hochberg & McAlister, 1953; Hochberg & Brooks, 1960). Leeuwenberg proposed a more abstract and more general coding model of uniformity which describes the informational complexity or the pattern informational load (Leeuwenberg, 1971). The informational load is related to the number of different primitive elements (codes) of a pattern and the number of relations among primitives. Of course, goodness is directly related to the uniformity or to the informational simplicity because the patterns which contain the less informational load will be more economically (easier and more precise) specified by the perceptual system.

2) ***Compactness.*** While the previous models may be connected to the Gestalt law of similarity (uniformity of pattern elements), the second group includes the quantitative models, which are comparable with the Gestalt laws of proximity, continuation, compactness and the like. There were several models which used measures of goodness such as the degree of the random figure dispersion (Attneave & Arnoult, 1956), a number of the same coloured adjacent areas (Royer & Weitzel, 1977), the proximity of line segments (Palmer, 1977), etc. These models are primarily related to the spatial cohesiveness and the unity of a form, or to the integration of pattern elements into compact entity. Naturally, more compact patterns will be perceived as perceptually better because it is easier and more accurate to identify them as entities.

3) ***Symmetry.*** The third group of objective goodness measures includes several models of pattern symmetry (Alexander & Carey, 1968; Zusne, 1971; Szilagyi & Baird, 1977; Yodogawa, 1982; Marković, 1995). Many experimental studies have strongly confirmed that symmetrically structured patterns and figures (especially with bilateral mirror reflections) have greater perceptual advantages (Fitts et al., 1956; Chipman, 1977; Corballis & Roldan, 1974, 1975; Marković, 1993; Palmer & Hemenway, 1978; Pashler, 1990; Rock & Leaman,

1963; Royer, 1981; Wagemans et al., 1991). In addition, there is the Garner's model of figural goodness, which claims that more symmetric patterns are perceptually better because they have fewer alternatives, or smaller sets of equivalents than the less symmetric patterns (Garner, 1962; Garner & Clement, 1963). Garner defined a set of pattern equivalents as a set obtained by vertical and horizontal reflection and\or consecutive 90^0 rotation of a single pattern. For instance, the set size of letter O is E=1, because every reflectional-rotational transformation of it yields the same orientation and position, the set size of letter H is E=2, the set size of letter T is E=4, while the set size of letter F is maximum E=8, because each reflection (vertical or horizontal) and 90^0 rotations of it result in the eight different oriented patterns. According to Garner, patterns with smaller set sizes are better because they are more redundant: the fewer the alternatives of a pattern, the less amount of information for its specification in the equivalent set will be needed. Many experimental studies showed that equivalent set size is inversely related to several pattern goodness variables: goodness is the greatest when a pattern is unique or invariant under reflection-rotation, while it is the least when a pattern has the maximum of the possible number of equivalents or changes under each reflection-rotation (Garner & Clement, 1963; Clement, 1964; Bell & Hendel, 1976; Bear, 1973; Royer, 1971; Checkosky & Whitlock, 1973; Garner & Sutliff, 1974).

All of the models of pattern goodness (models of uniformity, compactness and symmetry) converge to the similar concept of perceptual economy. The main assertion of this concept is that the perceptual system "prefers" situations in which the stimuli arrangements are set up in more economic (simpler and more regular) ways. However, each group of models deals with some specific aspect of pattern economy, such as (a) reduction of the different primitives of pattern (models of uniformity), (b) reduction of the spatial variation, i.e. the dispersion of form or the spatial independence of primitives (models of compactness), and (c) reduction of the irregularity of pattern (models of symmetry). From an intuitive point of view, each of these dimensions can be taken as a good constraint of the processing economy: patterns which are more uniform, more compact or more symmetric will be more easily and more effectively detected by the perceptual system, while patterns with several specific, unconnected or asymmetrically arranged elements will require the greater perceptual engagement and yield a poorly organized percept.

Figure 1 shows three situations related to the three dimensions of pattern goodness: (a) uniformity, (b) compactness and (c) symmetry. Each situation is represented with the pair of patterns, which are distinguished by only one dimension, while the other two are constant.

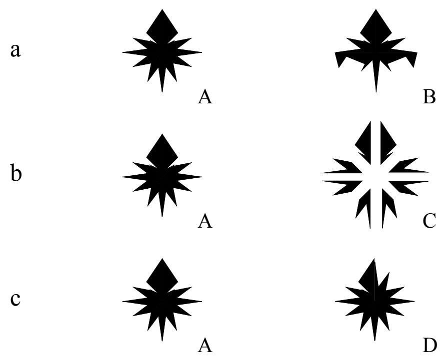

Figure 1: In situation a, pattern A is more uniform than B (has smaller number of different turns), in situation b A is more compact than C (has unique form), and in situation c A is more symmetric than D (has reflection).

(a) According to the uniformity models, it can be predicted that pattern A will be better perceived than the pattern B, because A is more uniform, i.e. has less different turns than B. Note that both patterns have similar compactness (both have unique uninterrupted areas) and equal symmetry (both have a single reflection axis).

(b) According to the models of compactness it can be predicted that pattern A will be better perceived than the pattern C, because A is integrated into a unique figure, while D consists of eight separate elements. Note that both patterns consist of the same elements (both have identical uniformity) and are equalized by the level of symmetry (both have single reflection axis).

(c) According to the symmetry models it can be predicted that the pattern A will be better perceived than the pattern D, because A is more symmetrical than D (A has one reflection axis, while D is completely asymmetrical). Note that A and D have similar compactness and same uniformity (both consist of two different elements).

One of the most important, but still unresolved problems is the question whether all of the three predictors mentioned above are equally good. In other words, does each of the three features (uniformity, compactness and symmetry) contribute the perceptual economy and the goodness of pattern perception with equal strength. Let us now articulate this question as a concrete empirical problem. Look for a moment at Figure 1 and ask yourself whether the objective differences between pattern A and the other patterns (A-B, A-C and A-D) have the same effects on perceivers' preference, or inversely, whether some of the features (uniformity, compactness or symmetry) determine more consistently and more strongly than others the perceivers' estimates of goodness.

In order to resolve this question we investigated empirically the effects of uniformity (Experiment 1), compactness (Experiment 2) and symmetry (Experiment 3) on pattern goodness estimates.

EXPERIMENT 1

In the present experiment the effect of uniformity on pattern goodness estimates was investigated. Uniformity was defined and quantified as the number of different primitives in a pattern: the smaller the number of different primitives, the greater the uniformity.

Method

Subjects: Ss were 36 undergraduates from the Department of Psychology, University of Belgrade.

Stimuli: The patterns with different level of uniformity, i.e. number of different primitives, were used as stimuli. There were three levels of uniformity (U): (1) the first (highest) level included patterns consisting of one type of primitives, (2) the second level included patterns consisted of one type of differently coloured (black and white) primitives, (3) the third level included two different types of primitives (elements with different form), and finally, (4) the fourth (lowest) level includes patterns consisting of four types of primitives. There were four groups of patterns: A, B, C and D. The primitives from each group are presented in Figure 2. These primitives were obtained using Attneave's method of the construction of random polygons (Attneave & Arnoult, 1956).

Figure 2: The primitives from groups A, B, C and D.

Each group included the four sets of patterns: x1 (asymmetrical compact patterns), x2 (compact patterns with single vertical reflection), x3 (asymmetrical discrete patterns), and x4 (discrete patterns with single reflection). The sets of patterns from group A are presented in Figure 3.

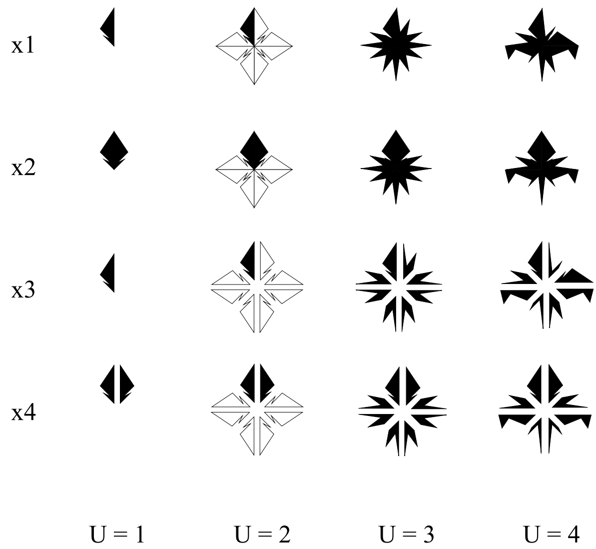

Figure 3: Four sets (x1, x2, x3 and x4 from group A) which include patterns with different levels of uniformity (from U=1 to U=4).

Thus, there were 64 patterns all together: 4 groups (A, B, C and D) x 4 sets (x1, x2, x3 and x4) x 4 patterns with different level of uniformity (U=1 U=2, U=3 and U=4).

Procedure. The preference task was used. Ss were asked to point out the pattern, which looked "visually the best" with respect to the other patterns from the presented set. The order of group (A, B, C and D) and sets was balanced. There were 16 sets to estimate.

Results

The regression analysis performed over entire population of patterns indicated that the degree of pattern uniformity was not a good predictor of pattern preference (measured by the frequency of pattern choice): $r^2 = .020$, $F(1, 62) = 1.28$, $p > .05$. Figure 4 shows the averaged distribution of choice frequency of 64 patterns in respect to the level of uniformity.

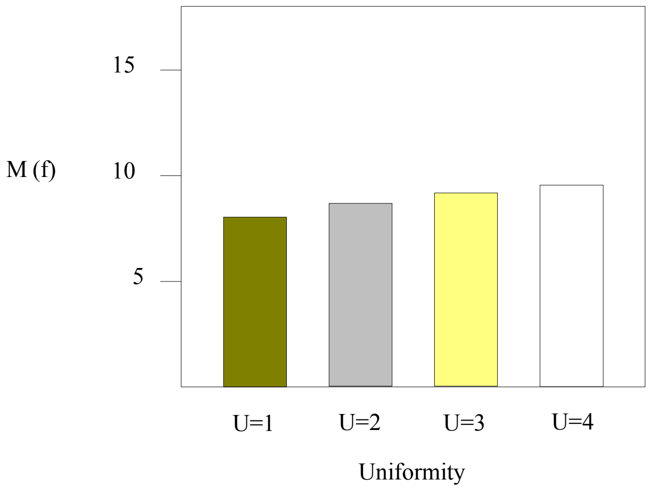

Figure 4: The distribution of averaged frequencies of the choice of patterns from the 16 sets (sets x1, x2, x3 and x4 from groups A, B, C and D). Mean frequencies, M(f), of patterns with different level of uniformity (U) are represented by columns with different levels of gray.

The results of this experiment suggest that the uniformity can not be taken as a systematic objective constraint of pattern goodness estimates.

EXPERIMENT 2

In the present experiment the effect of compactness on pattern goodness estimates was investigated. Compactness was defined as the unity of pattern form and quantified by the number of separate parts of a pattern: the smaller the number of separate parts, the greater the compactness.

Method

Subjects. Ss were 36 undergraduates from the Department of Psychology, University of Belgrade.

Stimuli. Patterns with different level of compactness (C) were used as stimuli. There were four levels of compactness: (1) the first (highest) level includes patterns with unique form (the areas of all primitives are connected in a unique figure), (2) the second level includes patterns with two spatially independent parts, (3) the third level includes patterns with four parts, and finally (4) the fourth (lowest) level includes patterns with eight separate primitives. There were four groups of patterns A, B, C and D. The examples of most compact patterns from each set are presented in Figure 5.

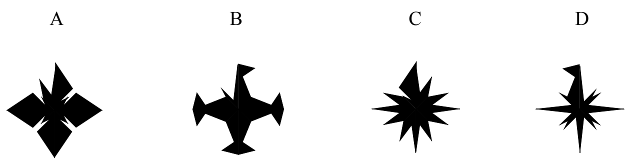

Figure 5. Expamples of the most compact patterns (i.e. patterns whose elements are connected in unigue figure) from groups A, B, C and D.

Each group contained four sets: y1 (asymmetrical patterns with two types of primitives), y2 (asymmetrical black-white patterns), y3 (patterns with single reflection and with two types of primitives), and y4 (black-white patterns with single reflection). The sets of patterns from group A are presented in Figure 6.

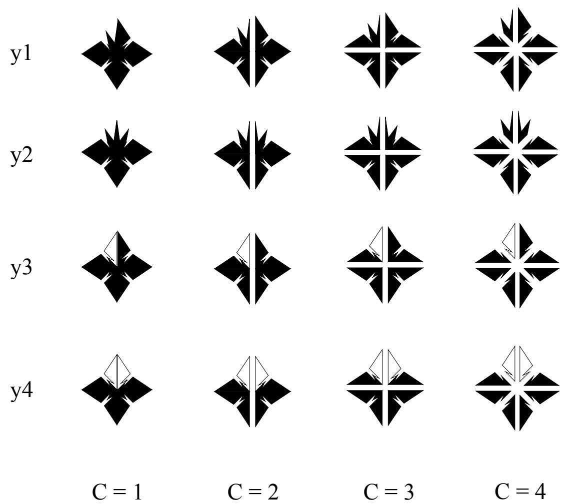

Figure 6: Four sets (y1, y2, y3 and y4 from group A) which include the patterns with different levels of compactness (from C=1 to C=4).

The population of stimuli consists of 64 patterns: 4 groups (A, B, C and D) x 4 sets (y1, y2, y3 and y4) x 4 levels of compactness (C=1, C=2, C=3 and C=4).

Procedure. The preference task was used: Ss were asked to express their preference by choosing one pattern from the presented set. The order of group (A, B, C and D) and sets was balanced. There were 16 sets to estimate.

Results

The regression analysis performed over entire population of patterns indicates that the degree of pattern compactness is not a good predictor of pattern preference (measured by the frequency of pattern choice): r^2=.045, $F(1, 62) = 2,94$, $p > .05$. Figure 7 shows the averaged distribution of choice frequency of 64 patterns in respect to the level of compactness.

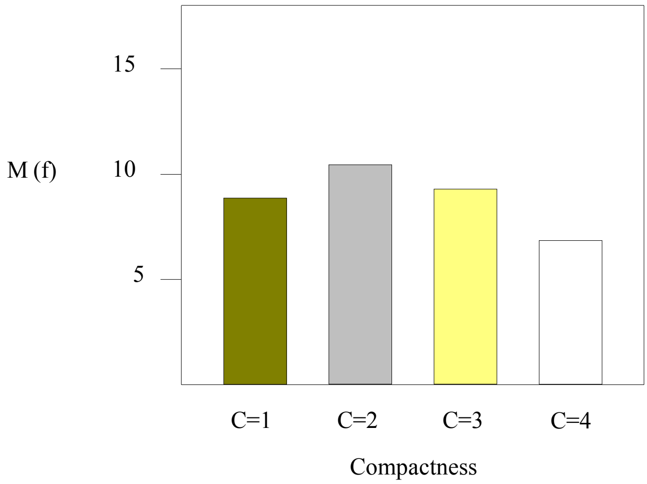

Figure 7: The distribution of averaged frequencies of the pattern choice from the 16 sets (sets y1, y2, y3 and y4 from groups A, B, C and D). Mean frequencies, M(f), of patterns with different level of compactness (C) are represented by columns with different levels of gray.

The results of this experiment suggest that compactness can not be taken as a systematic objective constraint of pattern goodness estimates.

EXPERIMENT 3

In this experiment the effect of symmetry on pattern goodness estimates was investigated. The symmetry of a square structure (fourfold reflection) was used as referent framework: the greater the number of square symmetries (maximally four reflections), the greater the level of pattern symmetry.

Method

Subjects. Ss were 36 undergraduates from the Department of Psychology, University of Belgrade.

Stimuli. The patterns with different level of symmetry were used as stimuli. There were four levels of symmetry (S). (1) The first (highest) level includes patterns with the symmetry of square (quadruple reflection). (2) The second level includes the patterns with one half of square's reflections, i.e. patterns with double reflection. (3) The third level includes the patterns with the quarter of square's reflections, i.e. patterns with single reflection. (4) Finally, the fourth level includes the asymmetrical patterns. There were four groups of patterns: A, B, C and D. The patterns with the maximum symmetry (i.e. patterns which maximally respect the square structure) from each group are presented in Figure 8.

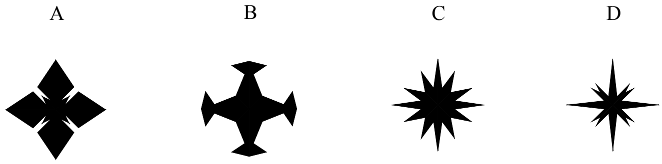

Figure 8: The most symmetric patterns from groups A, B, C and D.

The groups contained four sets of patterns: *z1* (compact patterns with two different types of primitives), *z2* (compact patterns with black-white primitives), *z3* (discrete patterns with two different types of primitives), and *z4* (discrete patterns with black-white primitives). The sets from group A are presented in Figure 9.

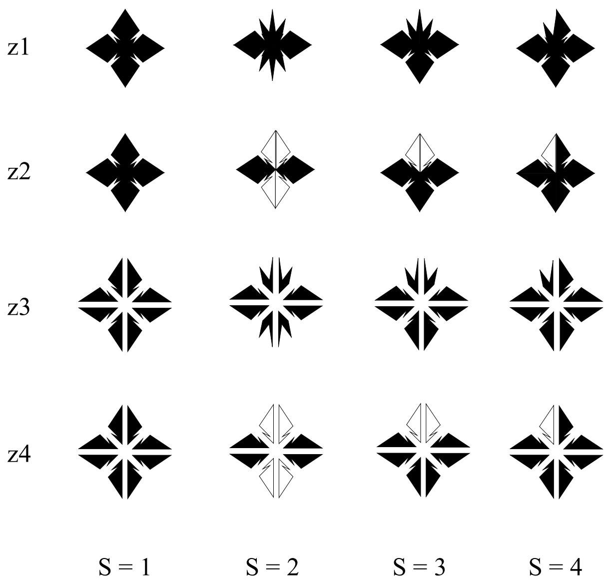

Figure 9. Four sets (z1, z2, z3 and z4 from group A) which include the patterns with different levels of symmetry (from S=1 to S=4).

Thus, the population of stimuli consists of: 4 groups (A, B, C and D) x 4 sets x 4 patterns with different symmetry = 64 patterns.

Procedure. The same preference task, like in previous experiments, was used. Order of groups and sets was balanced. There were 16 sets to estimate.

Results

Regression analysis performed over entire population of patterns indicates that the degree of pattern symmetry is a good predictor of pattern preference (measured by the frequency of pattern choice): r^2=.842 , F(1, 62) = 331,48 , p < .01. Figure 10 shows the averaged distribution of choice frequency of 64 patterns in respect to the level of symmetry.

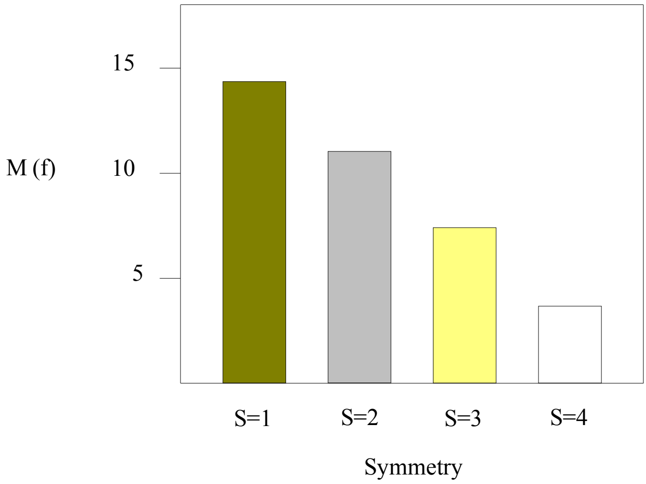

Figure 10: The distribution of averaged frequencies of the pattern choice from the 16 sets (sets z1, z2, z3 and z4 from groups A, B, C and D. Mean frequencies, M(f) of patterns with different level of symmetry (S) are represented by columns with different level of gray.

The results of this experiment suggest that the symmetry can be taken as a systematic constraint of pattern goodness estimates.

GENERAL DISCUSSION

The present study shows that the symmetry is the most significant and most consistent constraint of pattern goodness estimate, while the compactness and uniformity can not account for the distributions of pattern preference. An attempt to explain these outcomes will be based on some of Koffka's ideas of perceptual economy and Prägnanz.

In his considerations related to Prägnanz, Koffka (1935) made a distinction between two situations. The first situation is related to the case when the perceptual system has a smaller amount of disposable energy (e.g. due to the general organic or the specific neural exhaustion). In such situation, the perceptual system tends to minimize the variations in perceptual field, to reduce all differences and details, to homogenize the texture, to decrease the resolution of percept etc. This aspect of Prägnanz Koffka called "minimum simplicity". The second situation is when the perceptual system has a larger reservoir of energy, where it tends to maximize the articulation or to "crystalize" the perceptual field and to reach the most regular, sharpest structured and most sensible percept. This aspect of Prägnanz Koffka called "maximal simplicity". In other words, Koffka supposed that the amount of disposable energy determines the effects of Prägnanz or the economy tendencies. In the case of lower energy states the rough simplification or informational compression will be dominant, while in the case of higher energy states the sophisticated integration of information will prevail.

If we try to connect these ideas with the results of our experiments, we can see the following. Uniformity and compactness of patterns can be taken as features of "minimal simplicity" or of homogeneity of the percept. According to Koffka, these features make the pattern good in situations of low energy states. However, symmetry, being the feature which represents the regular articulation of pattern or "maximal simplicity", induces the pattern goodness in situations when the perceptual system has a larger energy disposal.

We assume that one of the possible reasons why the preference of patterns in our experiments is strongly and consistently determined by symmetry, and not by uniformity and compactness, is that our experimental procedure induced the "maximal simplicity" condition. Hence, because the experiment situations did not include any energy restriction (perceivers were not tired, duration of preference task were not limited etc.), symmetry, as a feature which enables good articulation of patterns, emerged as the most effective and most consistent constraint of goodness estimates. Of course, this explanation does not imply that uniformity and compactness are not relevant constraints of pattern goodness. We believe that they are relevant, but only in more restricted conditions, i.e. in situations in which the economic strategy of the perceptual system leads toward simpler solutions and toward preference of simpler (more uniform and more compact) stimulus pattern. More thorough evaluation of this hypothesis is required, and will be performed in further investigations.

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