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In support of hierarchy in object representations

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Abstract The descriptive minimum principle states that the preferred interpretation of a pattern is reflected by the simplest representation of that pattern. Such a simplest representation generally has a hierarchical structure. The pattern component represented at the highest hierarchical level is said to constitute the "superstructure" of the pattern, and pattern components represented at lower levels are said to constitute the "subordinate" structure. The primed-matching paradigm has been employed in two experiments to test whether superstructures of three-dimensional objects are perceptually more dominant than subordinate structures. In the first experiment, the test pairs consisted of two-dimensional line drawings of three-dimensional objects; each prime was a two-dimensional face of such an object, corresponding to either the superstructure or the subordinate structure. Two priming conditions were employed. In the "literal" condition, the object face was presented as it appeared in the drawing of the object (physical similarity). In the "frontal" condition, the object face was presented in the frontal-parallel plane (representational similarity). Object matching was found to be facilitated more by priming superstructures than by priming subordinate structures. In the second experiment, the order was reversed: the test pairs were composed of the object faces and the object drawings were taken as primes. Again, there were facilitating effects for both superstructures and subordinate structures, but this time without differentiation between superstructures and subordinate structures.

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Introduction

This paper deals with the model of object representation that has been developed within the Structural Information Theory (SIT) (Leeuwenberg, 1969, 1971; Leeuwenberg & van der Helm, 1991). A key assumption of SIT is the global-minimum principle (Hochberg & McAlister, 1953). According to this principle, the simplest of all possible representations of an object is the preferred one. With respect to object representation, this implies that relevant object features cannot be assessed a priori but are the result of the simplest representation of that object. Leeuwenberg and van der Helm (1991) and Leeuwenberg, van der Helm, and van Lier (1994) demonstrated that these features may have a hierarchical relationship with respect to each other. The topic, however, is not without controversy. For example, Biederman's (1987) RBC model starts from predefined features, such as specific types of axes and cross sections, in the classification of its elementary volumetric components (called "geons"). These predefined features do not have a hierarchical relationship. In previous papers, Leeuwenberg and van der Helm (1991) and Leeuwenberg et al. (1994) discussed differences between the SIT approach and other approaches such as RBC. In the present study, we focus on the hierarchical relationship between the relevant object features as specified within SIT, and we empirically test its role in object representation. We will not go into the formal details of SIT (for such details, see Leeuwenberg & van der Helm, 1991; van der Helm & Leeuwenberg, 1991; van der Helm, van Lier, & Leeuwenberg, 1992; van Lier, van der Helm, & Leeuwenberg, 1994, 1995). For the relatively simple stimulus objects to be considered in the present paper, the following demonstrations suffice.

The tube-like object in Fig. 1A has a global S-shaped form and a constant circular cross section. In fact, the exterior shape of this object can be mimicked exactly by moving a circle orthogonally along an S-shaped curve (see Fig. 1B). Now, SIT's resulting representation of this tube-like object precisely comprises the S-curve and the circle as separately represented object components, plus the relation between these components. This relation, analogous to "moving one along the other," is a hierarchical relation: the S-curve specifies the positions and orientations of the circles, not the other way around. Therefore, the S-curve is called the "superstructure" of the object, and the circle is called its "subordinate" structure. Figure 1B′ shows a visualization of SIT's representation of the tube-like object, indicating the relation between the separately represented components by depicting the subordinate-structure component below the superstructure component. The hierarchical character of the super/subordinate relation may be illustrated further by Fig. 2. SIT's resulting representation of the vase-like object in Fig. 2A again comprises an S-curve and a circle as separately represented object components, but this time their relation is analogous to moving the S-curve along the circle (see Fig. 2B). Therefore, for this object, the circle is the superstructure and the S-curve is the subordinate structure (see Fig. 2B′), which is the reverse of the hierarchy in Fig. 1B′. This illustrates the impact of the hierarchical relation between components: two representations comprising the same separately represented object components may, due to differences in hierarchy, represent completely different objects.

Obviously, many other representations are possible for the objects in Figs. 1 and 2. As mentioned, an important assumption within SIT is the global-minimum principle, which prescribes that the simplest of all possible interpretations of a shape is preferred. SIT's demand for simplicity may be illustrated by Figs. 1C and 2C, showing visualizations of alternative interpretations of the tube-like object and the vase-like object. The representations (Figs. 1C′ and 2C′) of these alternative interpretations comprise the specification of many different components and many different relations between components. Compare, for example, the difference between the S-shapes that are needed to describe the left side and the right side of the tube in Fig. 1C. These alternative interpretations contrast with the earlier discussed interpretations (Figs. 1B and 2B) for which the representations (Figs. 1B′ and 2B′) comprise the specification of only two components and one relation between these two components. Clearly, the latter representations are much simpler. In fact, they are the simplest representations of these objects and, therefore, determine the superstructure and the subordinate structure of those objects.

The S-shaped superstructure of the object in Fig. 1A can be characterized as a global structure, as might be expected in the context of Navon's (1977) global-precedence approach (see also Leeuwenberg & van der Helm, 1991). Notice, however, that this is not always the case. For example, the global structure of the vase-like object in Fig. 2A is determined mainly by the two symmetric outer S-curves, whereas SIT's superstructure is given by a circle.

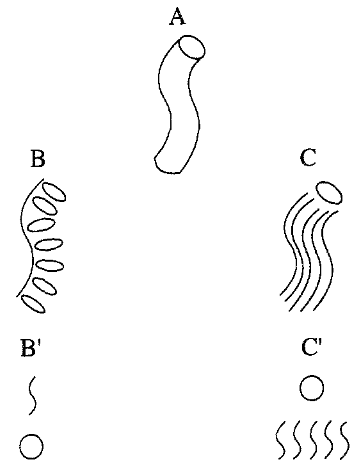


Fig. 1 A tube-like object represented in different ways B and C show two possible ways to mimic the exterior shape of the object, reflecting the meaning of the hierarchical representations in B′ and C′, respectively. The representation in B' comprises only two components (an S-curve and a circle), and is the simplest representation of the object. Therefore, the higher-hierarchical component in B′ (the S-curve) is the superstructure of the object, and the lower-hierarchical component in B′ (the circle) is its subordinate structure.

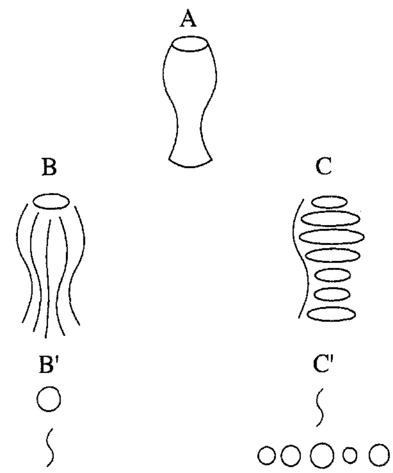


Fig. 2 A vase-like object represented in different ways. The representation in B' comprises only two components (a circle and an S-curve), and is the simplest representation of the object. Therefore, the higher-hierarchical component in B' (the circle) is the superstructure of the object, and the lower-hierarchical component in B' (the S-curve) is its subordinate structure. This hierarchy is the reverse of the hierarchy in Figure 1B'.

SIT's hierarchical approach shares some aspects with Biederman's (1987) RBC model, but there are also essential differences. The RBC model integrates ideas of many other scientists (e.g., Barrow & Tenenbaum, 1982; Binford, 1981; Garner, 1962; Navon, 1977; Marr, 1982; Hoffman & Richards, 1985) and, despite the opposition against it (e.g., Leeuwenberg & van der Helm, 1991; Leeuwenberg, van der Helm, & van Lier, 1994; Kurbat, 1994), it can be seen as a prototypical approach within current theorizing on object recognition. RBC allows only geon axes that are straight or monotonously curved (i.e., without points of inflection). Because of this, RBC would decompose the tube-like object in Fig. 1A into two geons: the upper half and the lower half of the object. The combined curved axes of these two geons form an S-curve corresponding to the S-curve which, according to SIT, constitutes the superstructure of the object. SIT's superstructure, however, does not necessarily correspond to RBC's axis. For the vase-like object in Fig. 2A, the situation is different. As RBC allows only geon cross sections that either expand or contract, or first expand and then contract, this object also consists of two geons: the part above and the part below the smallest cross section of the object. These parts each have a straight axis and a varying circular cross section. Thus, this time, SIT's superstructure (a circle) corresponds to the geon cross section. Within RBC there is no representational difference between the cross section of the object in Fig. 1A and the cross section of the object in Fig. 2A, whereas within SIT the circular component is represented once as a subordinate structure (Fig. 1A) and once as a superstructure (Fig. 2A).

Superstructure-dominance hypothesis

An important aspect of SIT's model of object representations is the hierarchical dependency relation between the separately represented object components. As indicated, the superstructure determines the positions and orientations of the subordinate structures, not the other way around. We therefore hypothesize that the superstructure is perceptually more dominant than its subordinate structures. SIT's hierarchical approach and the superstructure-dominance hypothesis have already gained some support. As illustrated above, SIT's approach allows any pattern component to emerge as a superstructure, provided it yields maximal representational simplicity. Leeuwenberg et al. (1994) demonstrated that this approach accounts for object classification better than does the RBC approach, which allows only a few types of axes and cross sections. Furthermore, Leeuwenberg and van der Helm (1991) demonstrated how the super/subordinate hierarchy can be related to perceived unity and variety of patterns. An experiment (van Bakel, 1989) supported this hypothesis for three-dimensional objects. In this experiment subjects were asked to judge whether a presented pair of objects was perceived as unitary or as dual. For the specific stimulus set used, it appeared that a pair of objects with the same superstructure was more likely perceived as unitary than was a pair of objects with the same subordinate structure (see Leeuwenberg & van der Helm, 1991, for a synopsis of van Bakel's study). We view that experiment, however, as a rather indirect test of the superstructure-dominance hypothesis, as it uses the intermediate concepts of unity and variety. The purpose of this paper is to present a more direct testing of the relative strengths of superstructures and subordinate structures. The employed method is the so-called "primed-matching paradigm."

Primed-matching paradigm

In the primed-matching paradigm, the effect of a prime on matching a pair of shapes is tested. Beller (1971) found that, in the case of a matching test pair (two identical shapes), the responses are facilitated by representational similarity of prime and test shapes. For example, matching the letters in the pair "aa" is facilitated not only by the physically similar prime "a," but also by the representationally similar prime "A." The primed-matching paradigm has recently gained renewed attention by its application in the domain of visual occlusion and completion. Sekuler and Palmer (1992) used partly occluded two-dimensional shapes as primes and unoccluded two-dimensional shapes in the test pairs. When both test shapes corresponded to the preferred completion of the occluded shape in the prime, they found a higher facilitating effect than when both test shapes corresponded to the literal "mosaic" interpretation. This result suggests that the facilitation can be explained better by the representational similarity of the activated interpretations of prime and test shapes than by the physical similarity of prime and test shapes. Other studies confirmed these findings for a broader range of occlusion patterns (Sekuler, Palmer, & Flynn, 1994; Sekuler, 1994; van Lier, Leeuwenberg, & van der Helm, 1995). In the present study, the distinction between physical similarity and representational similarity is taken into account as well.

In the following, the impact of hierarchy in object representations is investigated in two different experiments based on the primed matching paradigm. In the first experiment, the components are presented before the objects, i.e., the components are the primes and the objects are the test shapes. By means of this presentation order, the priming effects on either a superstructure or a subordinate structure within an object is examined. In the second experiment, the components are presented after the objects, i.e., the objects are the primes and the components are the test shapes. By means of this presentation order, the priming effects of a complete object on one of its descriptive components is examined.

Experiment 1: From components to objects

Method

Subjects. Thirty-one subjects participated in the experiment. All subjects received a small payment.

Stimuli. In Fig. 3, all the stimulus objects are shown, together with a visualization of SIT's representation of each object. The objects were constructed in the way indicated in Figs. 1B and 2B. Objects A, B, C, and D (Set 1) were constructed by means of a circle plus a C-shaped or an S-shaped curve. The circle corresponds with the superstructure in objects A and B, and with the subordinate structure in objects C and D. Objects E, F, G and H (Set 2) were constructed by means of a square plus a C-shaped or an S-shaped curve. The square corresponds with the superstructure in objects E

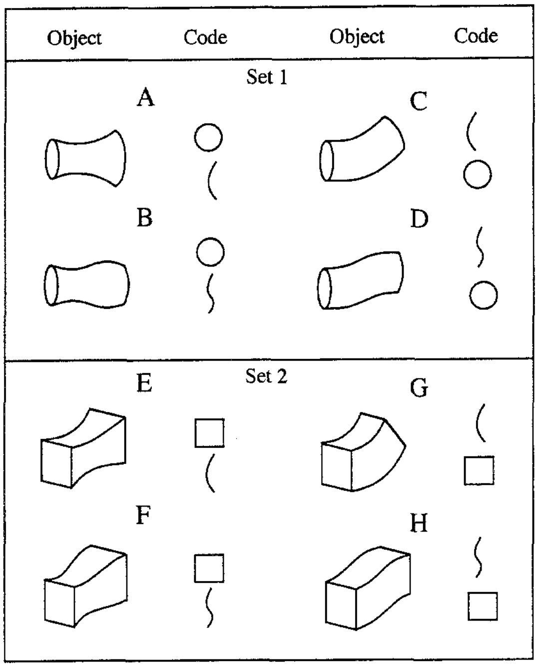


Fig. 3 All objects that were used in the experiments, together with the representation of each object. The objects were constructed by means of a C-shaped or an S-shaped curve, plus a circle (set 1) or a square (set 2). In the drawings, the physical appearance of all circles in set 1 and of all squares in set 2, is the same. In the left-hand column the circles and the squares are the superstructures of the objects; in the right-hand column they are the subordinate structures of the objects

and F, and with the subordinate structure in objects G and H. With these objects, eight matching test pairs (comprising identical objects) were composed. To balance the amount of correct same/different answers, eight nonmatching test pairs were included as well. These nonmatching test pairs were composed such that all objects were presented an equal number of times.

The primes were constituted by the circle and the square. Two priming conditions were employed: a "literal" priming condition and a "frontal" priming condition (see Fig. 4). In the literal priming condition, the object component was presented exactly as it appears in the drawing of the object (an ellipse or a parallelogram). This implies that there is physical similarity between the prime component and the corresponding object component in the test shapes. In the frontal priming condition, the object component was presented as it would appear in the frontal-parallel plane (circle or square). This time the prime corresponds to the representation of that object component, so that there is representational similarity between the prime component and the corresponding object component in the test shapes. In principle, one could use both the superstructure and the subordinate structure of each object as a prime. However, this would create several control problems. For

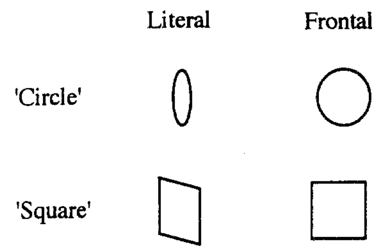
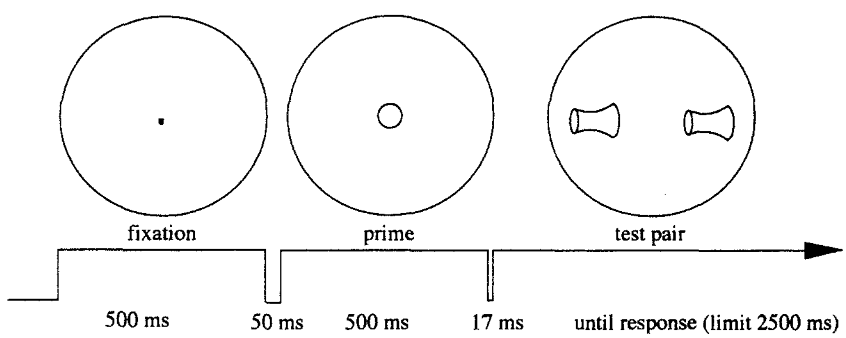


Fig. 4 The circular and square-like object components used in the experiments. The literal version is the object component as it appears in the drawing of the objects (see Fig. 3). The frontal version is the object component as it appears in the frontal-parallel plane

instance, the circle and the square are two-dimensional object faces, whereas the C-curve and the S-curve are not, which would undermine the comparability of the primes. Moreover, the literal appearances of the C-curves and S-curves in the object drawings all differ. Since such problems do not arise for the circle and the square, the literal and frontal versions of only these two-dimensional object faces were taken as primes. As a control, a no-prime was also included (represented by the letter "X,"), so that there were five different primes. The choice of the primes implies that one cannot test the relative strength of the superstructure and the subordinate structure within one object. However, these strengths can be tested by comparing the priming effect of a component on matching objects in which it is the superstructure with the priming effect on matching objects in which it is the subordinate structure.

Procedure. In Fig. 5 the sequence of events in one experimental trial is shown. First, a fixation dot was presented for 500 ms (at the same position on a computer screen in all trials). Then, after a blank of 50 ms, the prime was presented at the same position as the fixation dot. The presentation time of the prime was 500 ms, which is long enough to ensure a strong activation of the representation of the prime shape (see, e.g., Sekuler & Palmer, 1992). The test pair was presented 17 ms after the prime had disappeared. The visual angle of the prime was about 2°, and the visual angle of the test pair was about 7°. The subjects were instructed to respond to the question of whether the objects in the test pair were the same or different. The subjects were asked to respond as quickly as possible; as a maximum, a response time of 2500 ms was allowed. The response was given by pressing one of two buttons. To encourage the subjects to respond quickly, the subjects received visual feedback on their response time after each trial (in concordance with Sekuler & Palmer, 1992, and van Lier et al., 1995). Wrong answers were also reported to the subjects, and those trials were presented once more in a later stage of the series of trials. To control for possible orientation effects, each combination of prime and test pair was presented twice: once in the orientation as given in Figs. 3 and 4, and once rotated in a clockwise direction 90°. All stimuli were given in complete random order. Each subject was instructed with a series of 15 trials.

Fig. 5 The spatial and temporal lay-out of the experimental procedure in Exp. 1



Predictions. According to SIT, the matching of objects is based on their simplest representations. We reason that if the search for the simplest object representation depends on the prior exposure of object components, it will also effect the matching of the objects. More specifically, we expect superstructure primes to enhance the search for the simplest representation more than subordinate-structure primes, as they suggest the correct hierarchical order within an object representation. Because of this, we expect the superstructure primes to facilitate the matching of objects more than the subordinate-structure primes.

Results

In line with previous findings on the primed-matching paradigm (e.g., Beller, 1971; Sekuler and Palmer, 1992; van Lier et al., 1995), differential effects are to be expected only on those trials in which the objects within a test pair are identical. We shall therefore restrict the analysis to the trials with identical test shapes. In the analysis, the response times on the test pairs after the no-prime are taken as baseline values. That is, for a specific prime, its priming effect (PE) on a matching test pair is defined by the response time on this test pair after the no-prime minus the response time on this test pair after that specific prime. In this way, possible differences in processing speed between test objects are accounted for. As we are interested in facilitation, we shall consider all trials in which the objects of the test pair are identical and, moreover, in which the prime corresponds to a (literal or frontal) face of those objects. In Table 1 the mean response times and the priming effects are given. In the literal priming condition, the priming effects of both the superstructure primes and the subordinate-structure primes are significant, whereas in the frontal priming condition only the superstructure primes yield a significant priming effect. (The t-values are given in Table 1.)

An ANOVA with PE as the dependent variable was performed on the following factors: Structure (super vs. subordinate), Projection (literal vs. frontal), and Set (circle vs. square). Both the main effect on Structure, $F(1,30) = 5.43$, $p < 0.05$, and the main effect on Projection, $F(1,30) = 10.01$, $p < 0.01$, were significant. The main effect on Set was not significant, $F(1,30) = 1.30$. There were no significant interaction effects on Structure × Set, $F(1,30) = 0.00$, Structure × Projection, $F(1,30) = 0.74$, and Set × Projection, $F(1,30) = 1.41$. The three-way interaction Structure × Set × Projection was not significant either, $F(1,30) = 0.01$. In Fig. 6, the mean PE values are shown for the literal primes and the frontal primes.

Discussion

In both the frontal priming condition and the literal priming condition, the priming effects were higher for the superstructures than for the subordinate structures. The main effect on Structure supports the notion of structural hierarchy. The main effect on Projection calls for further discussion. It appears that the priming effects for both the superstructures and the subordinate structures are higher in the literal priming condition than in the frontal priming condition. In our view this can be understood by distinguishing between physical and

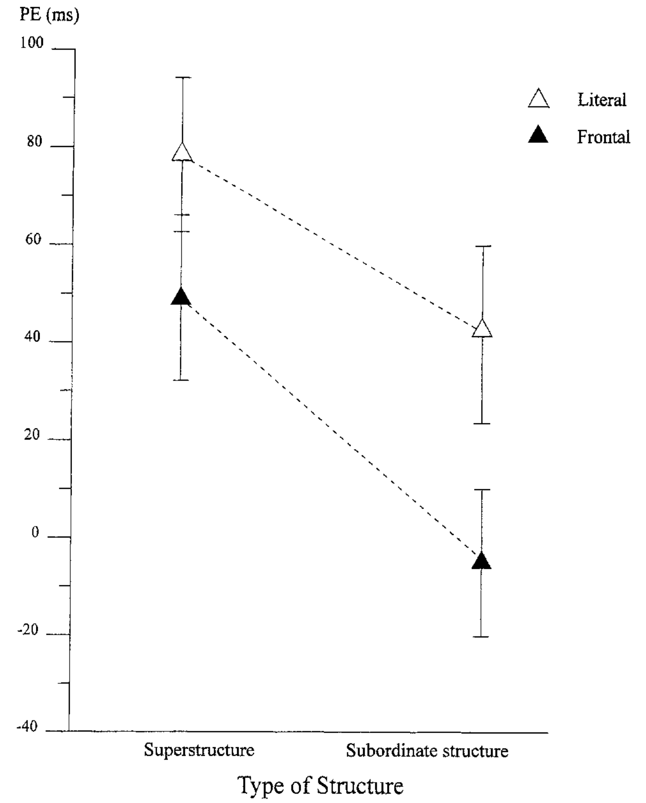


Fig. 6 Results of Exp. 1. The mean priming effects (PE) and corresponding error bars (+/−1SE) of the literal and frontal prime components on matching test objects in which either the superstructure or the subordinate structure corresponded to the prime

Table 1 Results of Exp. 1. PE = $RT_{No\text{-}prime}$ minus RT_{Prime}

	RT_{Prime} (ms)	$RT_{No\text{-}prime}$ (ms)	PE (ms)	$t(30)$
	Literal			
Superstructure	714.4	792.6	78.2	5.00, $p < 0.001$
Subordinate structure	735.4	777.7	42.3	2.30, $p < 0.05$
	Frontal			
Superstructure	742.5	792.6	50.1	2.86, $p < 0.01$
Subordinate structure	782.7	777.7	−5.0	0.33, n.s.

representational similarity (e.g., Beller 1971; Roediger & Blaxton, 1987), as follows. In the frontal priming condition, the physical similarity between the prime component and the corresponding components in the test objects is obviously very small, whereas the representational similarity is large. Consequently, in the frontal priming condition, the representational similarity is the decisive facilitation factor, and the hierarchy in the representations assigns a dominant role to the superstructures. In the literal priming condition, the physical similarity between the prime component and the corresponding components in the test objects is large for both the superstructures and the subordinate structures. In addition, there is also substantial representational similarity, since in the present 3-D context the literal primes (ellipse and parallelogram) are readily perceived as their prototypes (circle and square, respectively). Thus, in the literal priming condition, there are two relevant facilitation factors: first, the physical similarity, which has roughly an equal effect for superstructures and subordinate structures, and second, the representational similarity, which differentiates (though not as strongly as in the frontal priming condition) between superstructures and subordinate structures.

Considering the overall results of Experiment 1, the priming effects on the superstructures and the subordinate structures within objects clearly differ from each other. The higher priming effects on the superstructures support the notion that the generation of an object representation is enhanced by priming the superstructures. This "internal relevance" of hierarchy does not imply that, given a certain object, the superstructure would be more salient than the subordinate structure. Such an "external relevance" of hierarchy is examined in the next experiment, in which the presentation order of components and objects is reversed. After Exp. 2, some alternative explanations of the difference in the priming effects are discussed.

Experiment 2: From objects to components

Method

Subjects. The subjects who participated in the previous experiment participated again in this experiment. They received a small payment.

Stimuli. The eight test objects of Exp. 1 were now used as primes, yielding, together with a no-prime, nine different primes. The prime components of Exp. 1 were now used to compose the test pairs. Analogous to Exp. 1, two test conditions were employed: a literal test condition with the literal versions of the components, and a frontal test condition with the frontal versions of the components. This yielded four different matching pairs. To balance the amount of correct same/different answers, four nonmatching test pairs were included as well. These nonmatching test pairs were composed such that all test components were presented an equal number of times.

Procedure. The procedure was the same as in Exp. 1. See Fig. 7 for an example of the reversed presentation order of objects and components.

Predictions. We reason that if the structural hierarchy of object representations causes one of the structures to be more salient than the other, it induces differential matchings of the subsequently presented components as well. For example, if superstructures are more salient than subordinate structures, they are expected to facilitate the matching of subsequently presented similar components most.

Results

Again, the response times on the test pairs after the no-prime will be taken as baseline values (see Exp. 1), and we will consider those trials with matching test components that correspond to either the superstructure or the subordinate structure of the prime object. In Table 2 the mean response times and the priming effects are given. All priming effects are significant (the t-values are given in Table 2), i.e., in both the literal test condition and the frontal test condition, the prime objects facilitate the matching of the test components, no matter whether the test components correspond to the superstructure or to the subordinate structure of the prime object.

An ANOVA with priming effect PE as a dependent variable was performed on the same factors as in Exp. 1: Structure (super vs. subordinate), Projection (literal vs. frontal), and Set (circle vs. square). There were no main effects on Structure, $F(1,30) = 0.39$, Projection, $F(1,30) = 1.50$, and Set, $F(1,30) = 0.10$. There were no significant interaction effects on Structure × Set, $F(1,30) = 0.49$, Structure × Projection, $F(1,30) = 1.54$, and Set × Projection, $F(1,30) = 0.04$. The three-way interaction Structure × Set × Projection was not signifi-

Fig. 7 The spatial and temporal lay-out of the experimental procedure in Exp. 2

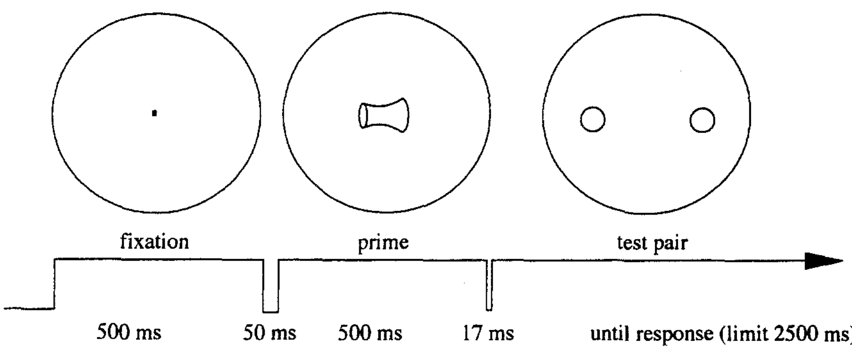


Table 2 Results of Exp. 2. PE = $RT_{No\text{-}prime}$ minus RT_{Prime}

	RT_{Prime} (ms)	$RT_{No\text{-}prime}$ (ms)	PE (ms)	$t(30)$
	Literal			
Superstructure	503.8	564.6	60.8	3.69, $p < 0.01$
Subordinate structure	519.0	564.6	45.6	2.71, $p < 0.05$
	Frontal			
Superstructure	485.8	515.4	29.6	3.30, $p < 0.01$
Subordinate structure	481.5	515.4	33.9	4.33, $p < 0.001$

cant, either, $F(1,30) = 1.22$. Figure 8 shows the mean priming effects in the literal and the frontal test conditions.

Discussion

For each Structure × Projection combination the priming effect was significant. However, this time, there were no significant differences in priming effects between superstructures and subordinate structures, neither in the literal test condition nor in the frontal test condition. We conclude that structural hierarchy does not differentially effect the saliency of superstructures and subordinate structures.

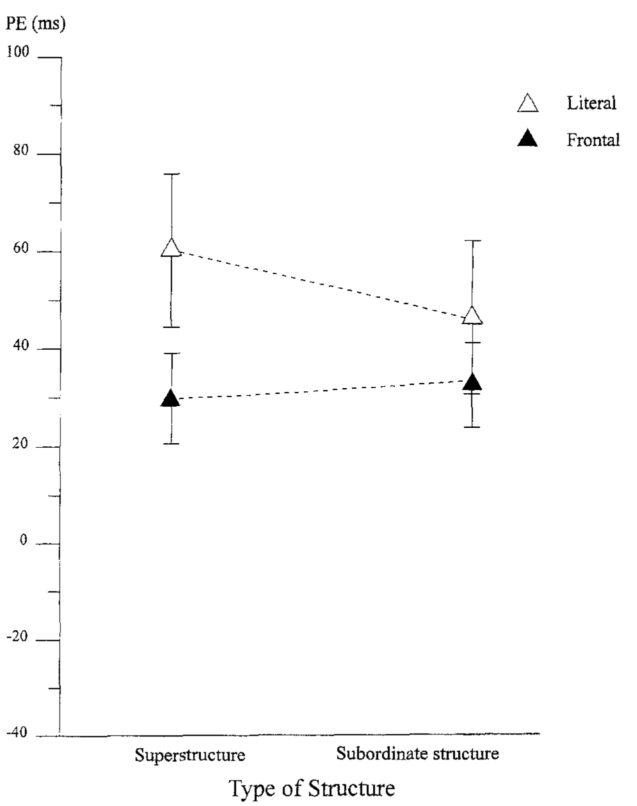


Fig. 8 Results of Exp. 2. The mean priming effects (PE), and corresponding error bars, on matching literal or frontal test components, of the prime objects in which either the superstructure or the subordinate structure corresponded to the test components

General discussion

Before elaborating further on the hierarchy explanation for the present experimental results we first discuss alternative explanations for the difference in priming effect between SIT's superstructures and subordinate structures.

Some alternative explanations

The tested objects may also be differentially classified by other approaches, such as RBC. Indeed, according to the RBC approach, also, there are systematic differences between the objects used in our experiments. For instance, objects A, B, E, and F in Fig. 3 (the objects in which the test component is a superstructure) are constituted by geons with a straight axis and a varying cross section, whereas objects C, D, G, and H in Fig. 3 (the objects in which the test component is a subordinate structure) are constituted by geons with a curved axis and a constant cross section. However, as RBC does not assume an hierarchical relationship between the constituting components, the different RBC classifications do not imply an a priory dominance of one of them.

Let us take a closer look at a few object properties. As the cross section has a constant size in the objects in which it is a subordinate structure, that specific cross section is far more redundantly present in those objects than it is in the objects in which it is a superstructure. On this basis, a dominant role of the cross section would even seem to be more likely in the objects in which it is a subordinate structure. Yet, according to the results of Exp. 2, there is no differential effect at all, whereas according to Exp. 1, just the opposite is the case. Thus, the priming effects, also, cannot be explained by differences in cross section alone. Further, as the difference in curvature of the axis leaves the angle between axis and cross section constant, all objects in Fig. 3 are symmetrical with respect to their axis. We therefore conclude that the higher priming effects in Exp. 1 for the objects in which the cross sections are the superstructure cannot be caused by differences in axis-related symmetry. Notice that, because of the constant cross section in objects C, D, G, and H, the axis-related symmetry is even greater in the objects in which the cross section is a subordinate structure. Still, it could be maintained that, in Exp. 1, objects with a straight axis of symmetry somehow fit best to prior-perceived cross sections. Such relationships between cross sections and axis shape, however, cannot be deduced a priory from RBC. Furthermore, on the basis of this symmetry account alone, the different results in Exps. 1 and 2 remain to be accounted for.

Upon inspection of the object drawings it can be noticed that the positional embedding of the superstructures and subordinate structures in the object drawings differ slightly. Although we have tried to reduce such a difference in the stimulus construction, small differences were inevitable. For example, in the drawings of the objects, the ellipse and the parallelogram are connected to the same number of other contour lines at exactly the same positions both for the objects in which they are the superstructure and for the objects in which they are the subordinate structure. However, the angles of connections vary between objects. These differences in embeddedness (caused by the small metric variations) might be the cause for the higher priming effects on the superstructures in Exp. 1. Reed (1974) and Reed and Johnsen (1975), however, convincingly showed that differences in embeddedness would lead to a difference in detectability in the reversed order as well. Actually, Reed and Johnsen (1975) found a significant correlation ($p < 0.01$) between the response times on a part-whole detection task and the response times on a whole-part detection task (with the same wholes and parts). The difference in the main effect on Structure between Exps. 1 and 2 suggests that such a congruence does not hold for the present results. In fact, the Pearson's correlation coefficient for the mean PE values of Exps. 1 and 2 is far from significant for both the literal condition and the frontal condition ($r = 0.16$ and $r = -0.06$, respectively). It is also noticeable that Reed and Johnsen (1975) found that subjects performed better in the part-whole order than in the whole-part order. This finding has been replicated several times (e.g., Ankrum & Palmer, 1991). Now, if we consider the subordinate structures in the frontal conditions of Exps. 1 and 2, the opposite seems to be the case, i.e., in the first experiment (from components to objects) the priming effect is much smaller than in the second experiment (from objects to components).

The hierarchy account

With respect to Exp. 1 we argued that, in the frontal priming condition, representational similarity is the only, or in any case the most dominant, facilitating factor, whereas in the literal priming condition both representational similarity and physical similarity are relevant facilitating factors. The same argument applies to Exp. 2. In our view, the difference between the two experiments is that in Exp. 1 the representational hierarchy differentiates between superstructures and subordinate structures, whereas in Exp. 2 it does not. We shall exemplify this view below.

In Exp. 1, the matching of two test objects occurs on the basis of the simplest representations of the objects. Hierarchy is an important property of these simplest representations. Although any part of an object is represented just as easily as any other part, getting the simplest representation of the whole object means selecting the separate representations of specific object parts in a specific hierarchical order, i.e., the parts and the order that yield maximal simplicity. The superstructure is not only one of those specific parts, but also the first one to be selected to get that specific hierarchical order. Therefore, a superstructure prime facilities the search for the simplest representations of the objects and thereby facilitates the matching of the objects. In contrast, a subordinate-structure prime perhaps corresponds to one of those specific object parts, but it is not facilitating, as it suggests a wrong hierarchical order (like the hierarchical orders in Figs. 1C′ and 2C′). This explains the absence of a priming effect of the subordinate structure primes in the frontal condition in Exp. 1.

In Exp. 2, before two test components are matched, the simplest representation of the prime object is already available. (As indicated, the presentation time of the primes is long enough to ensure this.) Now, note that the structural hierarchy enables representations that are simpler than representations without hierarchy. Thus, the meaning of hierarchy lies in the simplicity of the representation, and once that representation is available, hierarchy has done its job and can be dismissed. What remains is a segmentation of the object into equally accessible parts. In our view, this equality explains that in Exp. 2 hierarchy does not differentially effect the saliency of the structures, so that the priming effects on superstructures and subordinate structures become about equally strong. The above view implies that hierarchy is an internal affair of representations without external implications. As indicated, the hierarchical difference between superstructures and subordinate structures can be assessed during the generation of a representation, but afterwards all parts are equally accessible. As a metaphor, one may consider the internal and external appearance of the walls of a building: inspecting the internal construction of a building, it may appear that only a few of the walls are the supporting walls, yet each brick equally contributes to the shape of the building.

One further indication can be given in support of our hierarchy explanation. As argued, in the literal conditions, both representational similarity and physical similarity are relevant facilitation factors, whereas in the frontal conditions only representational similarity is a relevant facilitation factor. Therefore, it is to be expected that the presence or absence of hierarchy differentiation is relatively more influential in the frontal conditions than it is in the literal conditions. This can be investigated by analyzing the two experiments within one design. To investigate interactions between Exps. 1 and 2, the differences in the priming effects between the two experiments can be determined for each subject and for each of the four Structure × Projection combinations. These differences reflect the differential effect of the presentation order: from components to objects versus from objects to components. In Fig. 9, the mean δPE values, defined by PE(Exp1) − PE(Exp2), were plotted for each of the four Structure × Projection combinations. Obviously, a positive value of δPE indicates that the priming effect in Exp. 1 (from components to objects) is higher than the priming effect in Exp. 2 (from objects to components), whereas a negative value indicates the opposite. The difference between the positive value of δPE in the Frontal/Superstructure condition and the negative value of δPE in the Frontal/Subordinate-structure condition indicates that the generation of an object representation depends not necessarily on the saliency of a component within an object but on its structural representational role. The difference, in δPE , between superstructures and subordinate structures was not significant for the literal conditions $t(30) = 0.82$, whereas it was significant for the frontal conditions, $t(30) = 2.70$, $p < 0.05$. This confirms the above expectation that the presence or absence of hierarchy differentiation is relatively more influential in the frontal conditions than it is in the literal conditions.

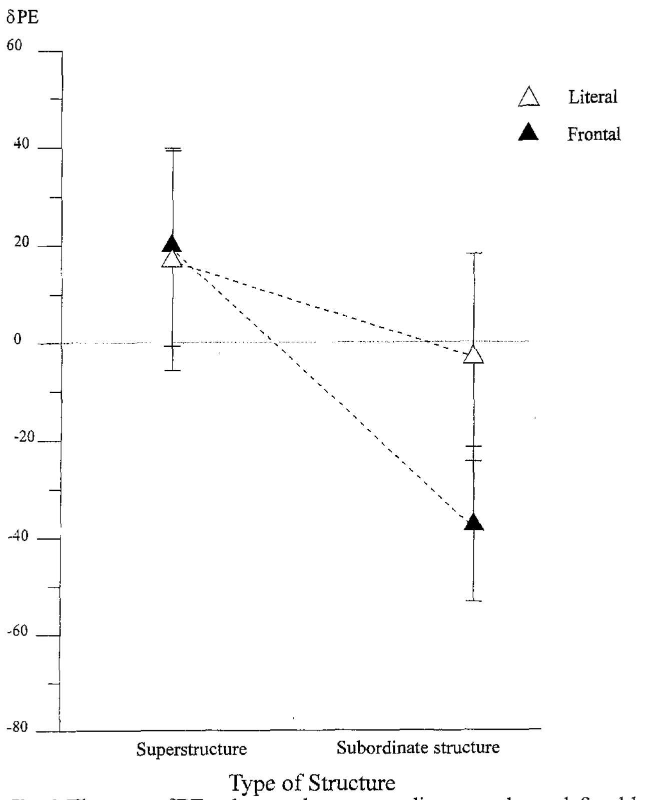


Fig. 9 The mean δPE values and corresponding error bars, defined by PE(Expl)− PE(Exp2)

Conclusion

The data favour the view that superstructures are perceptually more dominant than subordinate structures. This dominance reflects an internal aspect of an object representation and plays a role in the search for the simplest representation of an object. Once a representation is available, all the components within the organization of an object are equally accessible. The provided support for the superstructure dominance strengthens the notion of structural hierarchy in visual shape, as proposed within SIT.

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