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What does a compound letter tell the psychologist's mind?

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Abstract

The paradigm based on using compound stimuli for studying global and local processing is revisited. Noting that not all researchers employ compound stimuli for the same purpose, the issue of its purpose is discussed. It is argued that the paradigm is pertinent for examining at least three notions—formation preference, global addressability, and within-object global precedence. It is suggested that findings in the paradigm are accommodated well by a disjunction of those three perceptual dispositions. A number of further issues associated with the interpretation of findings obtained with it are examined as well. An experimental study is reported that is meant to examine one such issue—a possible artifact putatively introduced by the special attribute of element homogeneity characteristic of compound stimuli. Seven experiments were used to examine to what extent, if at all, global advantage observed in compound stimulus paradigms depends on element heterogeneity. Across those experiments, heterogeneity did not have any effect that could be interpreted as suggesting that the paradigm is biased in favor of the global structure due to element homogeneity.

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1. Introduction

A couple of decades of research with a paradigm might be expected to yield some common wisdom about the issue it has been devised to study. Sometimes, however,

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that desirable goal fails to fully materialize, because there is less than common wisdom about what the issue actually is or what the paradigm can actually test.

That seems to be the case with the paradigm of *compound stimuli* that I proposed (Navon, 1977) as a vehicle for exploring various effects of *global/local advantage* in order to test a hypothesis about the course of perceptual processing that I termed *global precedence*. In spite of ample research that has been done with the paradigm—mainly in cognitive psychology (see Kimchi, 1992, for a review) but also in cognitive neuroscience, abnormal psychology, comparative psychology, developmental psychology and the study of cognitive aging (e.g., Fagot & Masaki, 1999; Fink et al., 1996; Frick, Colombo, & Allen, 2000; Granholm, Cadenhead, Shafer, & Filoteo, 2002; Roux & Ceccaldi, 2001), a consensus is yet to be reached about what actually is the issue that it addresses. Thus, before discussing whether global advantage is a valid generalization about responses to compound stimuli, whether global precedence seems to be a disposition of the microgenesis of object perception, or whether the paradigm can serve to indicate something else, it might be useful to recast the exposition of the idea.

2. The paradigm revisited

2.1. Some basics

Let me first recapitulate some basic characteristics of both the hypothesis and the paradigm.

2.1.1. Holism

For a start, a disclaimer seems to be in order: The hypothesis concerns holism only in a limited sense.

Whether or not the whole exceeds the sum of its parts depends on what we consider to be the parts and what exactly we mean by "sum". Evidently, the nature of any whole is not fully captured by a list of parts, but there are other ways of representing wholes. A hierarchical network with nested relationships, for example, would certainly do better (e.g., Baylis & Driver, 1993; Palmer, 1975, 1977; Watt, 1988). A perceptual coding system (e.g., Leeuwenberg, 1967; Simon, 1972; Vitz & Todd, 1969) would do better as well. If the brain does represent wholes in some analytic way, the constituents of that representation (be they elements, features, attributes, or relationships) determine the perception of the whole by definition. Thus, rejecting naïve elementism does not necessarily lead to embracing radical holism.

We do often observe that the whole has some residual properties that our incomplete model of representation does not take into account. That epistemological embarrassment might tempt one to lean towards the ontological conjecture that the brain does not represent wholes in any analytic way. That, however, is not entailed. There are some good reasons for believing that the brain has a way to specify the whole by some constituents. It also makes sense to posit that that specification contains the constituents we obviously discern, and at the same time realize, minding the risk of experience error, that it contains some more that we cannot easily discern or define, mainly interactions between constituents. Elsewhere (Navon, 1983) I appropriated the oft-vague term "configuration" to denote those surplus properties. Ironically, those properties, often called holistic, may interfere with perceiving the "whole" about as much, and sometimes more, than they interfere with perceiving the "parts".

2.1.2. The hypothesis

Granting that, it remains to wonder whether or not some constituents have priority over others. Specifically, some constituents must be more global than others. Consider, for example, a simple pattern that may be crudely defined as a spatial relationship, R, between n elements each having a specific shape, e_i. The specific element shapes may interact in various ways. They may even interact with R, which would lead to the emergence of a more refined spatial relationship, R′. Regardless of the extent to which those interactions affect perception, one basic fact must be true: The spatial relationship, R or R′ whichever the case may be, is more global than the shapes of the elements.

For example, the stimulus in Fig. 1A may be roughly described as "four triangles arranged in a square pattern" and represented as a hierarchy having "a square pattern" at its top level, and four "triangles" at the immediately lower level. The global structure, namely the top level, is in this case roughly the spatial relationship between the centers of gravity of the elements that is by definition independent of the shapes of the elements (see Navon, 1981a). However, the global structure in Fig. 1B appears to be more complex, since it subsumes, or is affected by, the interaction of the adjacent triangle elements with the spatial relationship between the centers of gravity. [1]

Supposing that the global structure could be encoded independently of the processing of each e_i, would the perceptual system be preset or biased to evaluate it relatively early or faster, sometimes exclusively? This in essence is the issue of global precedence. A related, arguably distinguishable, issue is whether the global structure also benefits from *primacy*, namely given more weight in high-order processes, like similarity judgments.

2.1.3. Compound stimuli

The issue is thus testable only as long as the global relationship could be encoded well and apprehended independently of the elements. Hence, testing it requires stimuli having a good enough global structure (for example, Fig. 1C is probably better

[1] In the stimulus presented in Fig. 1B, each two collateral triangles form a shape of a V at their intersection, and the whole pattern has a serrate appearance. Such configurations may augment the hierarchical representation or even change it altogether. That evident fact might complicate the study of the issue, as the configurations may interfere with recovering the global structure or the local features. For example, the serrate appearance of the pattern in Fig. 1B presumably makes it hard to apprehend that the global structure is a sort of a square. That is evidently a hurdle on the way of comparing the perception of the global structure with the perception of the elements. However, local constituents might affect some global properties (e.g., the direction in which a triangle is perceived to point at) in a way that leaves intact the global structure (Palmer, 1980).

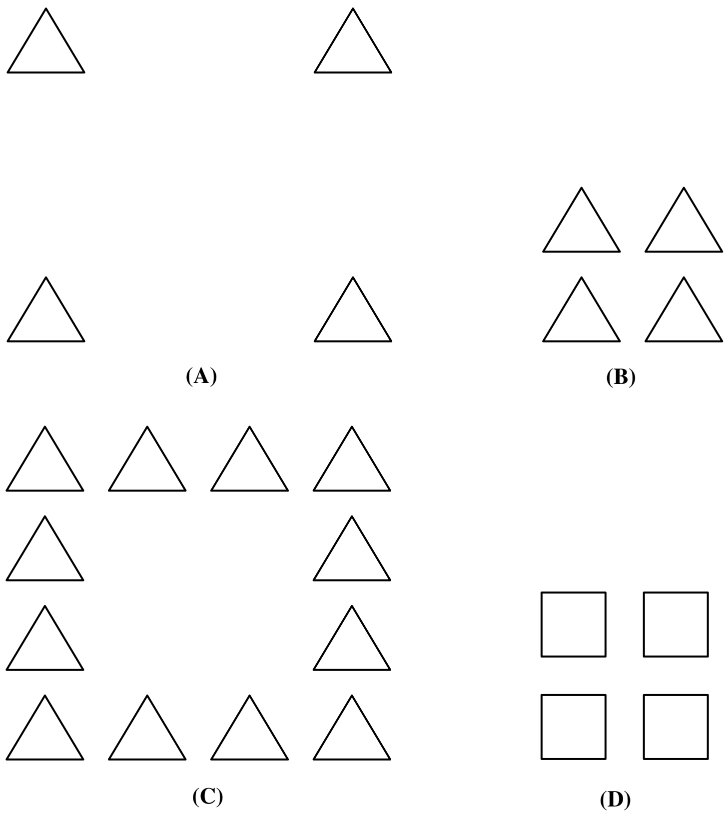

Fig. 1. Four examples of hierarchical patterns (see text).

than Fig. 1A and B) that evaluates to the same identity regardless of the shapes of the elements because element shapes minimally configure with it (note, for example, the difference between Fig. 1B and D).

Another desideratum for test stimuli is that their levels are stochastically independent. A correlation between the contents of the levels, as typically exists in real-world stimuli, might complicate any comparison between them, since the identities of some constituents could prime the identities of others. That can be avoided by using compound stimuli in which the identity of the global level is independent of the identities of the elements.

Finally, since the constituents of real-world stimuli vary on a number of factors, the levels are not equated in most of them. Hence, using them is not likely to tell us much about a general disposition. In contrast, the levels of compound test stimuli can be better equated across stimuli in terms of complexity, form goodness, familiarity, codability, identifiability, diagnosticity, and processing load. That clearly is a quite formidable task, but it is made more manageable by having all elements of a particular stimulus identical.

2.1.4. Prevalent tests

The issue, as originally put, refers to the course of identifying an object. [2] Being at the time a proponent of early selection, I also entered into the definition of the issue the presupposition that the object is attended to. However, even with a more skeptical, or liberal, view on the relevance of visual attention to identification, [3] it appears essential that any compound stimulus used to test the issue would meet two basic conditions—(a) be perceived as an object, (b) be related as such by the experiment requirements.

That can be attained quite straightforwardly by asking the subject to watch the stimulus or make some simple response to it as a secondary task, and measure the inadvertent effects of its different levels on the naming of an auditory stimulus (e.g., Martin, 1979; Navon, 1977, Exp. 2; Navon, 1991).

As a converging operation, it seems apt to put the hypothesis to a more challenging test—examining whether the global level cannot be ignored even when the subject is instructed to focus attention on the local level, as evidenced by an effect of cross-level compatibility (e.g, Navon, 1977, Exp. 3; Navon, 1981a; Navon & Norman, 1983, Exp. 2) or mere variability in the global level (Luna, Merino, & Marcos-Ruiz, 1990; Navon, 1981a). Even when a compatibility effect is not found, or not even tested for, a main effect of level on RT is often found (e.g., Navon & Norman, 1983, Exp. 1, selective attention condition). This test ought to be considered with some caution. First, focusing attention on a specific level, especially on the local one, seems to violate at least one of the two basic conditions listed above. Second, failures of focused attention typically require certain circumstances. Hence, the test does not actually probe global precedence but rather a possible corollary that can be readily accommodated by it yet is not entailed by it. Indeed, global-based interference was found not to covary systematically with the effect of level on RT (e.g., Amirkhiabani & Lovegrove, 1999; LaGasse, 1993; Lamb & Robertson, 1989; Navon & Norman, 1983). Despite that, this type of test has become, somewhat surprisingly in my view, the most popular.

A task that seems slightly better in that respect calls for dividing attention between levels, e.g., by asking the subject to search for targets at either of them (e.g., Kinchla & Wolfe, 1979; Navon & Norman, 1983, Exp. 1, divided attention condition). Here too, however, the stimulus may not be related to as an object but rather as a composite pair of attention channels.

Another type of tasks requires the subject to relate to both levels, either by responding to stimuli defined as combinations of a specific global form and a specific

[2] Not to the course of processing the entire momentary retinal image or some large range of it, just in case anybody has construed the issue in that way.

[3] More cautiously, what is minimally required for identification in a field as cluttered as we often view in real-world vision, is that some initial parsing process circumscribes the to-be-identified stimulus as a supposed object (possibly along with other ones in the neighborhood). Further processing may or may not require commitment of resources, let alone of a unitary mechanism such as the beam of visual attention is prevalently believed to be, much less an intention to do so (see, e.g., Paquet & Merikle, 1988). Thus, whenever I mention "selection" henceforth, it is not necessarily the kind of selection studied in most experiments in selective attention.

local one (such as a U made of Us; e.g., Miller & Navon, 2002, Exp. 2; Navon, 1991, Exp. 5), or by making same–different judgments for which both levels are pertinent (e.g., Kimchi, 1988; Kimchi & Palmer, 1982; Navon, 1977, Exp. 4; Navon, 1983). The former seems to adequately satisfy both basic conditions listed above. The latter might be suspected, however, of being too much influenced by post-perceptual biases.

An interesting twist on the use of same–different judgments that may answer that bias (Kimchi, 1998) examines their sensitivity to the presence of a compound stimulus preceding the test stimuli (with variable SOA) that might prime either of the levels. The rationale is that the priming potency of a level varies with SOA in correspondence with how early that level is processed.

Whatever the effects are, they can indicate some *advantage*. [4] Inferring perceptual precedence requires further arguments, some empirical some theoretical.

2.2. Does the paradigm test what it was meant to?

Scientific paradigms often acquire functional autonomy once they are set in motion, in the sense that they are used also for other purposes on top of the one originally meant. Profitable as that may be, it might generate some confusion. A good deal of the controversy about the compound stimuli paradigm (see, e.g., Kimchi, 1992, for a review) may be due to differences in perspectives about what it can, or should, test.

2.2.1. Do all researchers address the same question?

The tasks that have been employed for testing the issue are not exceptionally complex. On the other hand, the logic underlying the use of compound stimuli is patently intricate. Since the hypothesis is about the course of perceptual processing of real-world objects—objects that generally have diverse local constituents whose identities matter (see Lasaga, 1989; Pomerantz, 1983; Pomerantz, Sager, & Stoever, 1977; see also Pomerantz et al., 2003) and that are often uniformly connected [5]—why test it with stimuli that lack all these properties? Whereas the rationale may seem basically sound, it still leaves some room for doubt about external validity.

The doubt is warranted, but it may grow to be a real quandary if the issue itself is interpreted to be a different one. Actually, there are two questions that one may ask about the effect of globality: (a) Is it the case that the perceptual system is inherently disposed to favor global constituents? (b) Is it the case that in the majority of real-world patterns global constituents have some advantage over local constituents?

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[4] I use this term to refer to *any* empirical effect, though it has evolved to selectively denote just the simple effect of globality level, typically on RT. Wherever I mention "effect" below, it is meant in that inclusive sense.

[5] However, many real-world objects are not fully connected. For example, characters of words, hour markers of analog clocks, most facial features—all appear disconnected or indirectly connected via some common ground. In some conditions, e.g., in night vision, even connected objects like buildings can be sensed as discrete patterns made of separate elements. Not very long ago, in the scale of biological evolution, light was scarce at night, so night vision had a heavier share of diurnal life.

Those are two separate questions that shall be labeled henceforth *disposition issue* and *prevalence issue*, respectively. The issue that started the study with compound stimuli is, of course, the one concerning disposition. It is understandable why whoever is interested more in the prevalence issue would be worried more about how well compound stimuli represent the variety of real-world stimuli.

His/her worry would be aggravated by the fact that the results of ample research done with compound stimuli indicate interactions with various factors. Most of those interactions, important as they may be, are not quite unexpected. One could well anticipate that global advantage would be moderated, offset, or even reversed by paucity or sparsity of elements (e.g., Kimchi, 1988; LaGasse, 1993; Martin, 1979; Navon, 1983, Exp. 1) and by factors that impede grouping or the recognizability of the global form (e.g., Enns & Kingstone, 1995; Han & Humphreys, 1999; Hoffman, 1980). One could foresee that the effect would dramatically interact with visual angle if stimuli had an element at fixation (Kinchla & Wolfe, 1979; Lamb & Robertson, 1990), but just be modulated if the levels were equated in term of eccentricity (e.g., Amirkhiabani & Lovegrove, 1996, 1999; Luna, 1993; Navon & Norman, 1983). One could also suspect that the effect might interact in some circumstances with exposure duration (Paquet & Merikle, 1984; but see Hibi, Takeda, & Yagi, 2002; Luna, 1993) and retinal position (Grice, Canham, & Boroughs, 1983; Lamb & Robertson, 1988; but see Luna et al., 1990; Miller, 1981a; Navon & Norman, 1983). One could even reason that the effect would not be easily manifested in the case that the discrimination called for is sensitive to connectedness (e.g., Han, Humphreys, & Chen, 1999; Kimchi, 1994). Actually, the interactions are not as embarrassing for the hypothesis as might seem. After all, the prediction that global constituents manifest an advantage is expected to apply *ceteris paribus*. Furthermore, the hypothesis itself focuses on what goes on when the whole stimulus is attended to, or at least perceived as an object. Some of the interactions diminish when control is tightened (see discussion in Navon, 1981a). Nonetheless, the very fact that tight control is needed seems to be a message of despair for whoever is primarily interested in the prevalence issue.

The problem, in my view, is less in the paradigm than in what has been sometimes expected about whatever it should deliver. The hope for a universal law, stating that the perception of global structures generally precedes the perception of local constituents, whichever is the whole and whichever are the constituents, has been unfounded to begin with. "One can't play twenty questions with Nature and win", wrote one of the founders of cognitive psychology (Newell, 1973).

A more realistic objective is to settle for examining the possible existence of a disposition in favor of global constituents. A disposition is not quite straightforward to examine, however, since it constitutes just one vector in a complex space in which vectors are not necessarily orthogonal. It might be counteracted by modulating factors in most real-world situations. Hence, the test of any disposition (e.g., in favor of the left side of the visual field) would require proper control and possibly special conditions.

The test is especially complex in the case of global/local precedence. First, the global–local distinction is not as operationally crisp as is, for example, the left–right distinction. Second, the levels of the hierarchy are less independent than sides of the visual field are. Finally, the hypothesis is neither about phenomenal experience nor about direction of attention but rather about a processing bias. As if to complicate matters, that bias is claimed to apply while the whole is being attended to (or at least, regarded as a whole), and it is a problem in itself to ascertain that that condition is met.

If a disposition in favor of one of the levels existed but was not strong enough to outweigh effects, main or interactive, of various other factors, the effect would not be robust to variation of those factors. Worse yet, on account of covariations of that sort, the answer to the prevalence question could be negative whereas the answer to the disposition issue was positive. The way to examine the latter is to apply proper control. A count of successes in obtaining the effect despite some relaxation in control would be instructive yet far from being critical.

The way to attain control, for studying the disposition issue, is not quite simple either. Consider, for example, the stimuli in Fig. 1. The elements are good triangles (or squares). The global structure, on the other hand, is not really a square: it has no angles, no connected sides and no closure in any strict sense. Worse yet, its recognizability as a quasi-square depends much on the configuration with the specific elements (as must be evident when Fig. 1B is compared with Fig. 1D). True, global structures are often like that, but that compromises the chance to attain the degree of control required for studying the disposition issue. Arranging that the elements have the same mediocre form that the global structure has (see Navon, 1983) still does not help to eliminate the configuration-proneness problem. What is thus required is employing a considerable number of elements (more elements the more complex the form is), making the elements themselves out of the same number of sub-elements, and using forms and densities that minimize configurations (see, e.g., Navon & Norman, 1983).

Yet, deciding to study the disposition issue requires giving some thought to another possible nuance in the interpretation of the issue: What actually is the disposition in question?

2.2.2. Objects versus object clusters

The issue has been traditionally regarded as a certain comparison between constituents of objects. Part of the discomfort with compound stimuli must have been due to two facts. First, actually they are not objects but rather formations—a term I would use (in order to avoid confusion with close terms that have other connotations) to denote well-grouped object clusters having some good overall form that is typically recognizable as well. Second, their elements are not features of the overall cluster form but rather distinct objects that collectively make up those features.

The need to use artificial formations as a model of objects has been justified by the grave shortcomings of using objects, let alone real-world objects, for that purpose.

A compound stimulus is ambiguous in that its interpretation depends on which level of globality is dominant. Consider, for example, a small herd of sheep arranged in a circular pattern. It is a potentially ambiguous stimulus. Given strict global precedence, it would be interpreted as a plain circle (provided that the sheep's shapes minimally configure with the global relationship; see Footnote 1). Given strict local precedence, it would be interpreted just as a herd of sheep.

Compound stimuli constitute a more controlled version of such ambiguous stimuli. Thus, elements of such stimuli function as "place-holders" (to use the term coined by Pomerantz, 1983), but for a purpose. Had they not—as is the case with objects defined by specific elements—certain elements might prime the global structure and vice versa, possibly not in a symmetrical fashion. The independence of levels renders each of the levels irrelevant to processing the other one: In much the same way that elements may function as "place-holders" when attention is directed to the global level, the global structure may function as a "receptacle" when attention is directed to the local level.

Whoever feels that this justification is too weak would probably have to give up the hope of using compound stimuli for obtaining an answer to the issue of a disposition of global precedence in objects. However, s/he could admit compound stimuli as vehicles for studying another, related issue that may be termed *formation preference*.

Processes of organization operating before attention is paid to the stimuli [6] are believed to produce a more or less parsed representation of the visual field (e.g., Kahneman & Henik, 1981; Kramer & Jacobson, 1991; Moore & Egeth, 1997; Neisser, 1967; Palmer & Rock, 1994; Pomerantz & Kubovy, 1986; Wertheimer, 1955/1923). They do not, however, relieve the viewer's mind of a certain tacit "decision" that has to be taken once a well-segregated cluster of objects is detected and selected for further processing—whether to grant processing priority to the properties of the cluster or to those of one element or more. That decision does not seem very crucial, but it turns to be a real dilemma when early organizational processes leave some ambiguity about object boundaries. An old-time hominid would be liable to pay dearly, had s/he failed to recognize a pair of glowing dots in the bush at dark as the eyes of a predator, mistaking it for two fireflies. The cost of glossing over the presence of a unitary object is high enough to recommend a general strategy that amounts to a clear preference to interpret a cluster as an object in its own right, hence selectively process its overall properties. Actually, this is an extension to disconnected patterns of the problem of unum-and-duo with regard to connected figures (see Koffka, 1963/1935, p. 153).

But even more generally, since a pattern generated accidentally by a number of unrelated causes operating coincidentally on its elements must be unlikely to have a very good Gestalt (whichever that means—simple, regular, stable, satisfying the minimum principle, etc.; see, e.g., Attneave, 1954; Garner, 1970; Hochberg & McAllister, 1953; Kanizsa, 1979; Leeuwenberg, 1967, 1969, 1971; van der Helm &

[6] Actually, those processes might operate just before attention is *focused* (e.g., Rock & Mack, 1994), in which case they are pre-focal (see Navon & Pearl, 1985) rather than pre-attentive. In any event, they are probably determined not only by spontaneous interactions of elementary units extracted from proximal input, as Gestalt thinkers believed, but also by partial output of early interpretation processes, including the first pass of identification (e.g., Palmer, Brooks, & Nelson, 2003; Palmer & Rock, 1994; Peterson & Gibson, 1994).

Leeuwenberg, 1996; Wagemans, 1995), let alone a considerable degree of familiarity, a pattern having either of those may be reasonably taken to have it for some reason. That reason might happen to be significant for the viewer from an adaptive point of view: A good form is likely to constitute the global structure of an object, or else may serve as a clue that there is some cause or purpose to it that might be a waste to miss. It thus seems a priori plausible that there exists in the perceptual system a built-in formation preference, namely a preference to select cluster properties rather than element properties provided that the cluster makes up a good form or a familiar pattern. That also entails a tendency to apply amodal completion for extrapolating a cluster or an outline beyond those constituents contained in the proximal data (e.g., Gerbino & Zabai, 2003; Sekuler & Palmer, 1992; van Lier, 1999), which fits nicely with the SIT notion (e.g., Leeuwenberg, 1967, 1969, 1971; van der Helm & Leeuwenberg, 1996) that the interpretation of a visual pattern tends to correspond to the simplest code generated by applying regularity-based globally oriented coding rules to pattern constituents.

Note that this hypothesis can be directly tested with compound stimuli. It is fairly straightforward to induce from a result obtained with experimental stimuli such as a circle made of small Xs to object clusters such as a circle made of sheep.

Here too, however, some people might be interested in a prevalence description more than in the existence of a disposition. Obviously, most of the patterns in which we may see objects within our ecology are accidental, hence predominantly bad. It thus seems a priori unlikely that patterns are generally perceived earlier or more frequently than their elements are. The significant question is, however, a different one: How frequent are cases in which formations, namely clusters having good or recognizable forms, are preferred to their elements?

This question, aside of being very difficult to answer as is the prevalence question in the domain of objects, is also quite vague, mainly because it requires an agreed criterion for what a good, recognizable form is, a rather elusive enterprise.

In contrast, whoever favors the disposition issue would find it much easier to state a testable hypothesis: Do we seem to prefer a formation, provided that it has a form as good and recognizable as the form of its elements?

The answer indicated by carefully controlled experiments with compound stimuli seems to be positive, at least within a range of parameters that in my view is most relevant. [7]

[7] To illustrate, global RT advantage is reversed with stimuli larger than 10° (Kinchla & Wolfe, 1979) when visual angle is randomized and the levels are not equated in eccentricities (but not when eccentricities are equated, Amirkhiabani & Lovegrove, 1996, 1999; Navon & Norman, 1983). The question is how frequently we view stimuli as large as that in natural settings and still attend to them as objects or even as formations. Clearly, "...If the perceiver is close enough to the forest, he will probably see a tree rather than a forest" (Navon, 1977, p. 380), due to sensory limits or cognitive biases. The issue of the reasonable range of parameters is discussed at some length in Navon (1981a).

2.2.3. The principle of global addressability

If we do prefer formations, it falls out that when whatever appears like a formation turns out to be an object, its global form is already processed to some extent. Furthermore, if we preferred formations, it would turn out unlikely that we focus early on some local constituent of any object.

That advantage for global constituents of objects must be somehow related with how we interpret the array of visual input. Whichever the way that is actually done (see, e.g., Biederman, 1987; Leeuwenberg, 1967, 1969; Leeuwenberg, van der Helm, & van Lier, 1994; Marr, 1982; Scharroo & Leeuwenberg, 2000), part of it must be mapping the array to visual schemata, namely long term memory representations of familiar objects or scenes (regardless of how those are implemented—neural networks, semantic nets, etc.). That may not be often an easy job in real-world perception, since even a restricted segment of the visual field often contains a scene with several levels of globality (see Fig. 2 for a schematic illustration of the problem). It is not quite clear which of them corresponds to a global constituent of some object schema. How does the mapping process proceed? Supposing that due to formation preference, Blob-1 (rather than Blob-2 or Blob-3) is matched against candidate schemata, are the schemata addressed by their local constituents (e.g., Y invokes S_1 via its match with P, etc.) or by their global ones (e.g., X invokes S_1 via its match with R_1, etc.)?

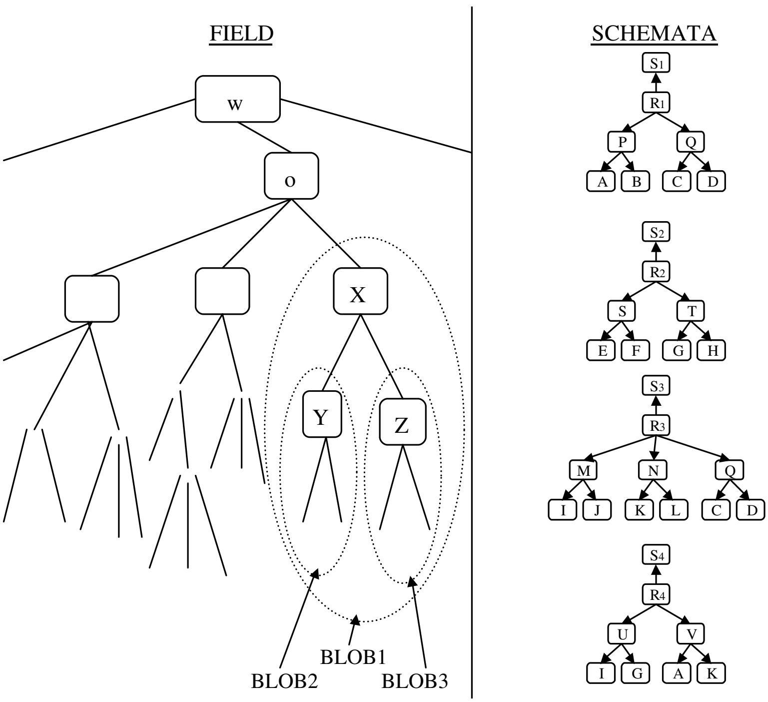


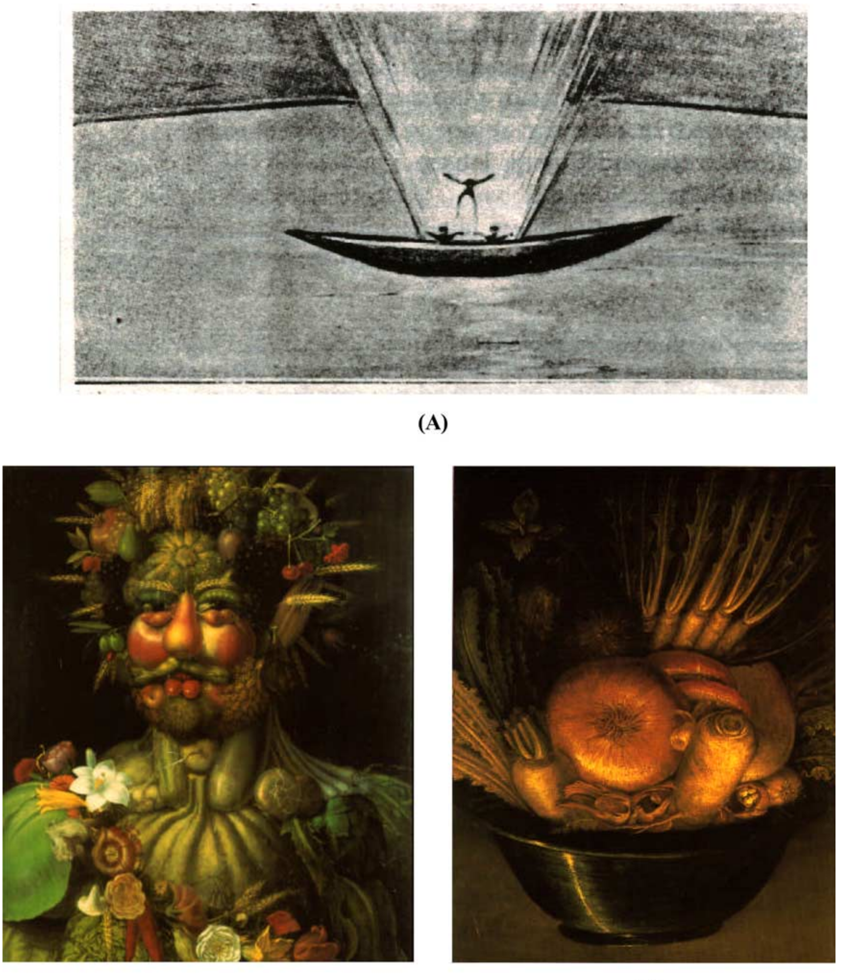
Fig. 2. A schematic illustration for the problem of mapping input in the visual field onto perceptual schemata (see text).

I have elsewhere (Navon, 1983) proposed that visual schemata may be accessed mainly by their global constituents, a principle that I termed *global addressability*. The implication from that principle is that in default of any information to the contrary, an input segment (e.g., a circle) is presumed to be the global constituent of some object schema rather than the local constituent of another object schema. In other words, that input segment invokes a schema within which it constitutes the global constituent. That seems to be a reasonably efficient rule. First, global constituents are by and large fewer than local ones. Second, due to earlier activation of low spatial frequency channels (e.g., Breitmeyer, 1975; Henning, Hertz, & Broadbent, 1975; Hughes, 1986) sensory data that are registered early are more likely to be global constituents than local ones. Hence, it makes sense that global constituents serve as entry points to their corresponding schemata, namely that they are matched with any selected input segment.

Consider, for example, the drawing in Fig. 3A reprinted from a book by Newell (1964). You presumably see in it a multi-object scene that you would probably describe as two people sitting in a boat and a third one hovering over it on the background of something shaped like an inverted trapezoid. However, if you turn now the page upside-down, you will find out a familiar object. In that orientation, the pattern viewed at the middle is sufficiently familiar to suggest the global structure of a human face. Given that in the antipodal orientation the same pattern fails to successfully address any familiar schema, does the system attempt at all mapping the local aspects of the input to local constituents of any schema (e.g., a mouth)? The principle of global addressability suggests that it rather interprets them as global constituents of several schemata (e.g., boat, person).

Consider now stimuli such as a fruit-face (see Palmer, 1975; or the painting by the Renaissance artist Arcimboldo in Fig. 3B (www.skoklostersslott.se), reprinted from a book by Kriegeskorte, 1992). Could it be that the face schema is accessed via the facial features? It does not seem likely, given that in themselves those features better match fruits or vegetables. More plausibly, the global constituents of the face schema are invoked by the overall pattern. When such a match is hard to attain (as when Fig. 3B is inverted; see also Fig. 3C (http://www.rccr.cremona.it/doc_comu/mus/engl_mus_ala_ponzone.html)), local shapes invoke the *global* constituents of various fruit or vegetable schemata.

Findings in the compound stimuli paradigm may be regarded as compatible with the hypothesis of global addressability. If matching the input stimulus with visual schemata is done via their global constituents (e.g., R_1, R_2, etc. in Fig. 2), then the global structure of the stimulus (e.g., X in Fig. 2) is predicted to have priority over elements and local features (e.g., Y in Fig. 2). That priority is dictated by the way in which schemata must be accessed, though sensory factors like visual angle or retinal position may help or hinder it. In the case that the global match fails, the turn of elements comes, but they too are matched with global constituents of schemata. Indeed, American subjects were found to respond faster to an English local letter when it was embedded in an unfamiliar Armenian letter, and still faster when it was embedded in a shapeless array (Regan, 1981).



(A)

(B) (C)

Fig. 3. Three drawings to illustrate the effect of the principle of global addressability (see text). For colour versions of Fig. 3B and C, the reader is referred to the web version of this article. Fig. 3A is reprinted by kind permission of Dover Publications. Fig. 3B is reproduced by kind permission of Skoklosters slott, Skokloster, Sweden. Fig. 3C is reproduced by kind permission of Museo Civico Ala Ponzoner – Pinacoteca, Cremona, Italy.

One might wonder whether global addressability results from formation preference or vice versa. It is not at all clear that there is a good answer to that. Dispositions characterizing mechanisms that subserve the functioning of organisms are probably selected by the evolutionary process to optimize adaptation. Dispositions that can cooperate have a better chance to cosurvive than dispositions that interfere with each other.

2.2.4. And back to object recognition

It thus seems that the paradigm offers a fairly direct way to test the issue of formation preference. Extending the inference to the issue of a disposition for global precedence in objects is certainly less direct, but can be buttressed by the following composite argument.

If formation preference existed for object clusters, it would be sensible, and at least parsimonious, to presume that an analogous preference existed for equivalent patterns that are familiar enough to be known as objects despite not being seen to be fully connected (see Footnote 5). Since it is unclear whether discriminating between objects and object clusters is made early enough, incompatible dispositions could lead to conflicts.

The case might in principle be different for unitary, uniformly connected objects (whose unity is given at the entry level, see Palmer & Rock, 1994). But why should it?

First, whereas object clusters were claimed to be preferred over the objects being clustered only when they make up good forms (unless they happen to resemble some familiar object), the global structure of a familiar object must be identifiable as such by definition, regardless of how good its form is. For example, although the overall pattern in Fig. 4A is evidently a poor rectangle, it can be quite easily identified as the global level of the face of at least one familiar playing card. Likewise, although the form of the outline in Fig. 4B looks quite irregular, it is presumably recognized readily as the global structure of the well-known Sydney opera house (by anybody familiar enough with the building).

Second, there is some reason to suspect that the identifiability of global constituents is at least not smaller than that of local constituents. The principle of global addressability entails that the system must have acquired high practice in identifying global constituents, in using them to prime identities of local constituents, and in diagnosing by them the identity of the whole object. And indeed, it is quite good

(A) (B)

Fig. 4. Two illustrations for the identifiability of a global structure that is not apprehended as a familiar unitary pattern in itself (see text). For a colour version of Fig. 4B, the reader is referred to the web version of this article.

at retrieving object identity by the global outline alone (see Boucart, Humphreys, & Lorenceau, 1995).

Third, even had all constituents been equally identifiable, it is hard to imagine that they are equally diagnostic about the identity of the whole. It seems reasonable to surmise that for most objects, the global structure would at least not be less diagnostic than any local constituent picked at random out of the many that exist (cf. Palmer, 1975).

In view of that, the extrapolation from evidence indicating formation preference to a similar disposition in object recognition, however convoluted, does not seem too far-reaching.

It could still be argued that the extrapolation is misleading, because the elements of a compound stimulus are not really local constituents. The premise of this argument is true in a sense: The elements are not the features of the global form. They are constituents on their own, like an eye is within a face. Thus, the advantage demonstrated is, to put it differently, of features of the global form over features of the local constituents. Yet, how can that advantage tells us anything about global precedence in a stimulus (like the letter H) that unlike a face has no separate local constituents, just features (e.g., the horizontal bar) that make up the whole?

On the other hand, do we really have a better choice? Can we at all operationally pit the perception of an H against the perception of any of its putative features without determining ex-cathedra what the features are? And suppose we managed to do that for the stimulus H or for any other particular stimulus, would that advance any reasonably general scientific claim? The way to tell whether or not any disposition exists is to attempt to somehow equate the load on processing of global and local constituents, and that cannot be done with most real-world stimuli.

The product is not a familiar object, but it can be made to have a hallmark of most such objects, by having both levels matter for the task. Global advantage has been found also when subjects were asked to respond just to targets defined as combinations of a specific global form and a specific local one (e.g., Miller & Navon, 2002, Exp. 2; Navon, 1991, Exp. 5). In such a task, the identity of elements does matter for determining a conjunctive response, which approximates better what happens in the perception of many real-world objects.

The ultimate test is, of course, empirical—whether performance with compound letters somehow corresponds to processing disposition in real-world objects. A sign that it does has been recently provided by Macrae and Lewis (2002): Face recognition in an experimental lineup was disrupted when it followed a session during which the subject responded to the elements of compound letters, but was enhanced by a preceding global-directed task. Assuming that the effects are due to long-lasting activation of processing modes, it seems that elements of a compound stimulus are after all not qualitatively different from the elements of a fairly prevalent real-world stimulus such as a human face.

2.2.5. Accommodation of elements

Suggesting an object schema may be just the first phase of a process in the course of which a number of schemata are tested in parallel until the best interpretation eventually wins (e.g., McClelland & Rumelhart, 1981; Norman & Bobrow, 1976; Palmer, 1975). Testing may involve, in theory, a number of top-down queries about the fit of various input features to schema constituent, a process that I have elsewhere (Navon, 1975; see also Broadbent, 1977) termed *inquiry*.

Actually, however, the inquiry might often be cursory. It perhaps must be cursory to meet the high perceptual load in most real-world situations. But even when it is not, the expectancy to detect schema constituents induces a low criterion for fit, so that an input element that just barely fits the expected constituent would be accommodated by the schema even when in itself it better fits another schema, perhaps as its global constituent. The fact that people might not at first notice vegetables in Arcimboldo's paintings (see Fig. 3B and C) when seen at the face-biased orientation illustrates that effect. It is not necessarily that the local level is suppressed or overlooked, but rather that because it is compatible with the overall schema, the distinctive properties of each individual input element by itself become irrelevant.

A similar effect must be sometimes taking place with compound stimuli, such as an S made of small Hs. A local H is often not noticed as such, and its momentary representation may be argued to be devoid of any figural properties (see Kimchi, 1992). The account might be fairly simple: Functioning as a form-free element, a sort of a blob, is exactly what is expected by the S schema suggested for fitting the overall stimulus, so the local letters accommodate. Some support for that is that the effect has been found to be smaller, the worse or less familiar the global form was (e.g., Regan, 1981). Apparently, small input elements get a better chance to make a suggestion when the global suggestion is hard to verify, let alone fails.

I would even go as far as making the speculation that inquiries are not particularly frequent. There is arguably any need to completely identify all objects encountered by the eye in a casual inspection of the visual world. Suggestions may do. Later on, when the interest in a particular object is aroused, confirmation of identity may be required (cf. Rock, 2001). But even then, the process could be short of a thorough inquiry. The prior activation of the schema may allow for quick identification by any constituent that happens to be focused at by focal attention. When visual attention wanders around rapidly and land on some detail, like a human chin or a tree branch, that may be sufficient for valid identification thanks to the suggestion made at an earlier phase, presumably via global constituents (cf. Hochberg, 2003). Often that suggestion suffices for interpreting the sensory data in a globally coherent manner despite absence of much detail due to factors such as occlusion (van Lier, 1999; van Lier & Wagemans, 1999).

2.2.6. A brief overview

The paradigm was originally meant to test some simple hypothesis about disposition, not a comprehensive theory of perception. Much research done with it has been even less theory-oriented, concentrating on tracing the boundaries of the disposition or its sensitivity to various stimulus properties, situation parameters and individual differences, or localizing it in the brain. In retrospect, however, it seems that the results of that research have gained enough mass to suggest at least a disjunction of three interrelated dispositions—formation preference, global addressability and within-object global precedence.

To be cautious, I should stop here, not before noting that perhaps one or two of these three concepts might turn out to be gratuitous. It might prove helpful, nonetheless, to go a bit beyond what can be safely concluded and venture suggesting a story that hopefully weaves all three concepts into an overall view.

The story is not restricted either to percepts that we are most aware of or to processes that we spend most effort on. What we are most aware of is often what is deemed significant to pay attention to, but while doing that we sense at the background a host of stimuli. Despite some evidence suggesting that we can report almost nothing on a totally unattended background (e.g., Mack & Rock, 1998; Most et al., 2001; Rock & Mack, 1994; but see Moore & Egeth, 1997), pre-focal attention (see Footnote 6) might suffice for making the background not only organized, but also interpreted to a considerable degree, though possibly not in an exhaustive manner and certainly not in a way highly accessible to retrieval. Focal attention elaborates on some sector of a provisionally processed field that is taken for granted. What is to be accounted for is both the elaboration of the selected sector and whatever makes the remainder taken for granted.

Processes that overlay some provisional interpretation on top of the output of organizational processes must first determine what to interpret. The disposition of formation preference leads the system to select cluster properties provided that the cluster is well-segregated and makes up a good form or a familiar pattern. The principle of global addressibility, in turn, determines that the system is disposed to interpret a formation or any other potentially ambiguous piece of visual input as the global feature of some object. That is conceivably done in parallel across a considerable portion of the visual field, which results in linking sets of suggested schemata to sectors of the already-parsed input. With that done during pre-focal processing, the job of further processing any selected object must be easier. For cursory verification, a few evaluated constituents might do, given that the relevant schema is already activated. For more thorough processing, as is required, for example, for some experiments in cognitive psychology, an ordered (presumably global-first) inquiry might be initiated. In any event, global precedence is instated by the very fact that global constituents have been already activated.

If any of that is true, does it argue in favor of holism? Not of radical holism, to be sure. On the other hand, it does help to counter the simplistic view that the whole is perceived just by assembling local features. It does suggest that properties like the circular arrangement of hour markers in a clock face participate in its identification no less, and plausibly even more, than properties like the specific identities of hour markers. It is mute with respect to the role of surplus interactions (e.g., a strong configuration produced by spoke-like markers, as opposed to digit markers), though it is consonant with the thesis that those are potent enough to considerably affect the percept.

2.3. *Yet, could the effect not be accounted for differently?*

It might be argued that an observed global advantage is interesting only as long as it reflects a perceptual disposition that specifically relates to levels in a hierarchical representation (as would be the case, e.g., with a processing rule prescribing that in the course of identification the hierarchy is traversed from the top down). Some doubts have been raised concerning that.

2.3.1. Does the effect simply reflect relative size?

A prominent example is the claim that global advantage is just a special case of some sensory effect having to do with physical size, probably mediated by the differential rate of low and high spatial frequency channels.

Size clearly has a role in the effect (Kinchla & Wolfe, 1979), though not independent of expectancies (Lamb & Robertson, 1990). Interestingly, that role is not quite the one that could be inferred based on the results reported by Kinchla and Wolfe: When the levels are equated on eccentricity, visual angle does not modulate the main effect of level. Also, a large enough visual angle eliminates, but does not reverse, the asymmetry between levels in cross-level interference (e.g., Amirkhiabani & Lovegrove, 1996, 1999; Navon & Norman, 1983).

Thus, a global structure seems to have an advantage over any element simply due to its larger retinal size: The combination of size and eccentricity is presumably sufficient to account for effects of global advantage in that case, if it is assumed that the eccentricity effect and the size effect approximately cancel each other.

Does the mere fact that the effect can often be accounted for by simple stimulus factors suggest that it does not tell us anything about the way by which the mind interprets stimuli?

Suppose it was really the case that there is a functional sense in giving global features some advantage over the elements, which must have caused such a disposition to be selected in the course of evolution (which seems moderately plausible in view of phylogenetic trends found in responding to compound stimuli, see Deruelle & Fagot, 1998; Fagot & Masaki, 1999). If Nature concurred, it would have to find some way of doing that. A special mechanism that detects globality early and determines processing priority by it would probably evolve, had there not been any other way. However, Nature sometimes opts for developing parasitic systems when possible. A special mechanism might be a waste, provided that globality was inherently confounded with some other, readily available perceptual dimension. Relying on the latter would constitute a shortcut to diagnosing globality with reasonable certainty.

Fortunately for Nature, there exists such a perceptual dimension. Relative size is not some nuisance variable that happens to correlate with globality. It is rather an inherent concomitant of part–whole relationship. It is quite a challenge to conceive of a whole that is not larger than its parts, or for that matter of a global structure that is not larger than the elements. Hence, relative size is a reasonable candidate for being parasitized.

The conjecture that such a mechanism was indeed selected for its adaptive value in the course of evolution seems consistent with the finding that size and eccentricity interact in a manner that yields between-level RT differences that are strikingly similar throughout most conditions (Amirkhiabani & Lovegrove, 1996).

If it is disappointing that the global structure is not given precedence by virtue of being more global per se but rather by virtue of being larger, that might follow from some unholy mixture of an hypothesis about computation and a model of algorithm or implementation (see Marr, 1982). At the times that cognitive psychologists construed the mind as a serial, digital device, it was quite natural to look for rules of processing that prescribe order or allocation of processing resources. I myself suggested such a rule (Navon, 1977, pp. 354–355) as a possibility. With present views of how computation is implemented in the brain, it may be easier to accept that a disposition might be mediated in various other ways. A fairly economical one is capitalizing on a sensory mechanism such as the differential rate of low and high spatial frequency channels (e.g., Badcock, Whitworth, Badcock, & Lovegrove, 1990; Broadbent, 1977; Hughes, Fendrich, & Reuter-Lorenz, 1990; LaGasse, 1993; Lamb & Yund, 1993, 1996; Robertson, 1996; Shulman, Sullivan, Gish, & Sakoda, 1986; but see Hibi et al., 2002; Hubner, 1997; Lamb, Yund, & Pond, 1999). A claim that a certain disposition exists is not made less parsimonious by having some good idea of the mechanism that mediates it (or that produces it as a side effect), basic as it may be. This is especially true when the disposition seems to have a clearer function than the mechanism has.

Thus, the reason that a global letter has an advantage over the local ones may be basically the same reason that a large letter has an advantage over a small letter presented concurrently—a sensory edge to begin with, often amplified by effects of competition or conflict between unequal rivals. What seems so trivially true for two laterally presented rivals appears not to be so a priori obvious for rivals that are two levels of the same object. True, the latter are supposed to collaborate in the identification of an object. However, since the issue tested by the paradigm is which rival is considered earlier or has a greater contribution, the answer must depend to a great extent on whatever might affect the outcome of rivalry.

That being said, it is doubtful that size, eccentricity, as well as other sensory factors account for all of the variance. For one, they cannot handle the effect of the familiarity of the global pattern (e.g., Regan, 1981). They can neither handle some effects attributable to attention discussed below.

2.3.2. Does the effect really have an early locus?

It is tempting to attribute the effect to allocation of visual attention. One, the effect surely reflects some bias, and bias is often associated with attentional selection. Two, direct or indirect manipulations of attention typically modulate the effect (e.g., Kinchla, Solis-Macias, & Hoffman, 1983; Lamb, Pond, & Zahir, 2000; Navon, 1991; Paquet & Merikle, 1988; Robertson, 1996; Robertson, Egly, Lamb, & Kerth, 1993; Shulman & Wilson, 1987; Stoffer, 1993; Ward, 1982). On the other hand, since attention may accentuate biases that are generated prior to the focusing of attention, the bias in favor of the global level could start as early as pre-attentive processing. Global effects are exerted also by non-attended objects (e.g., Paquet, 1992; Paquet & Merikle, 1988) and they resist attempts to eliminate them by manipulations that tap attention (Paquet, 1992, 1994; Paquet & Wu, 1994).

An attentional account suggests a post-perceptual locus to believers in late selection (see Miller, 1981b; Navon, 1981b). However, a post-perceptual locus is a possibility regardless of the magnitude of the role of attention in the effect. Although a number of researchers concluded that the source of the advantage is perceptual (e.g., Han & Humphreys, 1999; Hughes, Layton, Baird, & Lester, 1984; Navon & Norman, 1983; Shulman & Wilson, 1987), though not necessarily very early (Boer & Keuss, 1982; Ward, 1982), it is quite possible that the effect is due to bias in the use of the levels, once perceived, by decision processes further downstream (Miller, 1981a), or that a small perceptual advantage is magnified during response selection (Heinze & Munte, 1993; Lamb & Robertson, 1989). It seems, however, that the advantage is considerable even before response selection is done. Some evidence for that is provided by the results of Miller and Navon (2002): Lateralized readiness potentials measured in left/right/no-go tasks using compound stimuli showed global hand activation totally irrespective of the relevance of the global shape to the response.

Does the disposition reflect just an acquired habit that is possibly reversible? That does not seem to be the case. The disposition has been found to be stubborn enough to resist extensive practice with local-directed attention. Paquet (1992) found that such practice acts to produce more local-to-global interference but does not reduce the reverse, global-to-local one. Dulany and Marx (2002) found that, though more than 10,000 trials of practice with local-directed attention were sufficient to induce suppression of trained global shapes, that suppression did not transfer to non-trained global shapes. It seems that although people can learn to ignore specific global shapes, the general disposition remains intact.

2.4. But are compound stimuli not too unrepresentative?

As claimed above, compound stimuli are not meant to be representative, but rather to provide a test field in which the levels are made independent and equated as much as possible. It might be felt, though, that perhaps the baby is being thrown out with the bathwater.

Consider the issue of element homogeneity. The local level of most natural objects typically does not consist of features or elements all identical with each other. That is true, to a lesser extent, also of object clusters: A herd may comprise of sheep, lambs, goats, etc. Naturalness is thus sacrificed to attain more control. Fortunately, that does not generate a bias in favor of the research hypothesis, because compound stimuli characterized by element homogeneity seem to be biased in favor of the local level.

To perceive the local level, one of the elements should suffice. If all the elements were processed in parallel, the particular one that happened to win the horse race could determine the response in a local-directed condition and the interference in a global-directed one. The more identical elements there are, the shorter the expected latency of the "winner" (see demonstration in the study described below).

That should yield an overestimation of the speed of local processing in natural forms in which the local level is made up of variegated constituents. It seems implausible that local processing is over once the processing of the "fastest" local constituent is. Nose shape is probably not enough for identifying a face. Thus, comparing the global constituent with the "fastest" local one does not answer the really important question. It would be adequate for testing a particularly strong version of the global precedence hypothesis, namely that global processing strictly precedes any local processing. However, it is doubtful that such a simplistic claim has ever been made, let alone that it is now seriously held by anybody in the field.

The purpose of using identical letters in the local level seems to justify the cost of bias in its favor. However, that cost has been apparently too high with the original type of stimulus, in which one of the elements was strictly foveal, hence had a particularly high chance to win the race. The use of stimuli in which all features were about equally eccentric was called for. A tighter control of eccentricity was later attained with a different type of stimulus, the elements of which are about equally eccentric, [8] such as the letter C (Amirkhiabani & Lovegrove, 1996; Luna, 1993; Navon & Norman, 1983). With eccentricity controlled for, the results are highly supportive of the global precedence hypothesis.

Thus, homogeneity does not seem to generate a bias in favor of the global level. That, however, depends on some implicit assumption—that within the representation generated by organizational processes, the elements constitute distinct units. One might argue, though, that elements of a compound stimulus do not meet that condition, in that organizational processes do not grant them any separate existence beyond that of taking part in forming higher-order units, much like the role played by cereal flakes in a cereal dish. Homogeneity probably has something to do with that. Element similarity is known to be a potent determinant of organization (e.g., Koffka, 1963/1935; Kubovy, Cohen, & Hollier, 1999). Coupled with considerable numerosity and density, it might make the local level appear like a surface having unitary texture (see, e.g., Goldmeier, 1972/1936; Julesz, 1981) rather than having distinct elements. Consider the page you are now reading. It certainly does not even resemble the phenomenal quality of a cereal dish. Yet, it would have probably approached that appearance, had it contained only repetitions of a single letter, especially if there had been no spaces between strings.

Common sense suggests, however, that stimuli like an H having 17 identical elements are quite different in that respect. For one, they are not characterized by regularity over a large, continuous area. Yet, common sense might be wrong.

How can this ‘‘cereal dish appearance’’ hypothesis be tested? It might be useful to introduce element heterogeneity. If homogeneity made the local level of compound letters less perceptible as letters, a sufficient degree of heterogeneity should modify that, hence act to counteract global advantage. If, on the other hand, no manipulation of heterogeneity was found to have any effect on global advantage, it would be quite safe to stick with common sense.

[8] Which makes one wonder why many experimenters keep using the other type that does not control for eccentricity (e.g., S and H). A possible intent may be to leave more room for studying individual differences or specific stimulus properties, but the preference for S–H type of stimuli seems to be too prevalent to be accounted for by that.

3. A study of the effect of heterogeneity

For this matter, I have conducted a study in which Israeli subjects were presented with compound Hebrew letters. The elements were either all homogeneous or heterogeneous to various degrees. Heterogeneity was attained in three different ways between experiments. In four experiments, subjects responded to an auditorily presented letter name while viewing a compound letter and making a go/no-go response to its variable location (see also Sections 2 and 2.1.4). Since by hypothesis heterogeneity must act to increase the perceptibility of local letters as such, it is expected to make auditory RT more sensitive to compatibility with the local level but perhaps less sensitive to compatibility with the global one. In another set of three experiments, subjects responded either to the global level of a compound letter or to its local level in separate blocks. Heterogeneity is expected here to increase the effect of cross-level compatibility in the global-directed task but to decrease it in the local-directed task.

3.1. Method

3.1.1. Apparatus and setting

Presentation and data acquisition were controlled by a SiliconGraphic O_2 computer. Visual stimuli were presented on the computer display. Viewing distance was about 115 cm. The room was fully illuminated. The subject sat in front of the display with the middle and index fingers of her dominant hand placed on two keys of a computer keyboard. In Experiments 1–3 and 7, the subject was also wearing headphones through which the auditory stimuli were played, and the index finger of her non-dominant hand was placed on another key.

3.1.2. Stimuli

The auditory stimuli (in Experiments 1–3 and 7), were the names of two Hebrew letters, "heth" (ח) and "teth" (ט), uttered by a male Hebrew speaker, digitized and stored in two sound files, which were played back according to need through the headphones worn by the subject.

The visual stimuli are presented in Fig. 5. Each was a large pattern made up of smaller ones. A local character measured 6 mm (0.3° of visual angle) vertically, and a global character measured 60 mm (3.29° of visual angle) vertically.

The entire set of stimuli for homogeneous trials is presented in Fig. 5A. All were used in Experiments 1–3 and 7. As can be seen, the global level was either a rectangle or one of the Hebrew letters heth and teth. The local level comprised of elements of either of the above types. In Experiments 4–6, subsets of those, each in a different condition, were presented (see below).

In heterogeneous trials, the local level comprised of a mixture of elements. In Experiments 1 and 4, the two response-relevant letters (heth and teth) were mixed with some proportion (1/3, 1/2, or 2/3) of letters of a response-neutral type, the Hebrew letter kaf (כ). The latter elements were placed at random locations within the global pattern, with the constraint that at least one would be placed at each of its

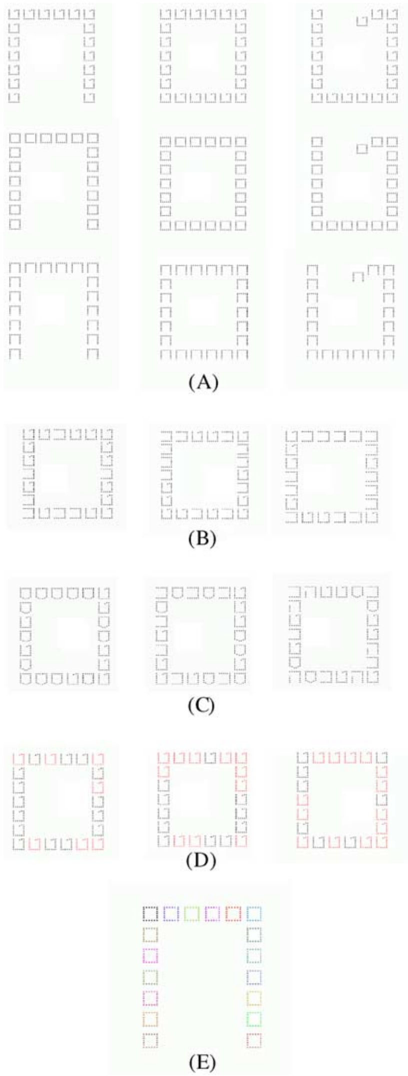


Fig. 5. The visual stimuli used in this study. The nine possible homogeneous ones are presented in panel A. Panels B–D illustrate the different ways heterogeneity was manipulated in Experiments 1 and 4 (panel B), in Experiments 2 and 5 (panel C), in Experiments 3 and 6 (panel D), and in Experiment 7 (panel E), as applied to a global rectangle. For a colour version of Fig. 5, the reader is referred to the web version of this article. *Note*: The colors may not look exactly as they did on the SiliconGraphic screen.

sides (see examples in Fig. 5B). In Experiments 2 and 5, the two response-relevant letters were mixed with letters of one to three response-neutral letter types, the Hebrew letters kaf, hey (ה), and samekh (ס), at random positions within the global pattern (see examples in Fig. 5C). In Experiments 3 and 6, the local level was homogeneous with respect to element identity but comprised of a mixture of two colors in one of three proportions (1/3, 1/2, or 2/3) at random positions within the global pattern (see examples in Fig. 5D). In Experiment 7, color heterogeneity was increased even further: Each element was presented in a different color. Colors were assigned to elements on a random basis (see illustration in Fig. 5E).

3.1.3. Design and procedure

In Experiments 1–3 and 7, each trial began by a 10 ms warning beep and a presentation of a 0.5 mm cross-shape fixation mark at the center of the screen; 500 ms after the onset of the fixation mark, a visual stimulus was presented for 80 ms. Stimulus location was varied. The stimulus was presented with its center either 12 mm to the right or 12 mm to the left of the fixation mark; 200 ms after the onset of the visual stimulus, an auditory stimulus was presented. The subject was to respond to the auditory stimulus by pressing on either of two keys. Assignment of keys to responses was varied between subjects, such that half of them responded by the right key to the heth, and the other half—to the teth. Reaction time was measured from the time the computer initiated stimulus presentation; 2000 ms were allowed for making the response; 1200 ms after the subject made the response or after 2000 ms have elapsed, the subsequent trial started. In addition, the subject was to respond to the location of the visual stimulus (right or left of fixation) by pressing with the index finger of the non-dominant hand on a pre-assigned key when the location was left of fixation (and hold off otherwise). Subjects were instructed, however, that the auditory task is the primary one to be responded to first.

Subjects were run individually in a single session. All the factors, except for response-key assignment, were manipulated within subjects and randomized within blocks. To generate a factorial design of the factors heterogeneity, global compatibility, and local compatibility, the nine stimuli types (see Fig. 5A) were crossed with levels of heterogeneity (four in Experiments 1–3, two in Experiment 7), the two locations (left, right) and the two auditory stimuli (heth, teth). There were 576 experimental trials in total. Those were presented in four equal blocks with a brief break separating between each two consecutive blocks. A block with 64 practice trials preceded the experimental blocks.

In Experiments 4–6, no auditory stimuli were presented, and the subject was to make a binary response to either of the levels of the visual stimulus, in different attention conditions (global-directed or local-directed) administered in different blocks. Reaction time was measured from the time the computer initiated the presentation of the visual stimulus; 2000 ms were allowed for making the response; 700 ms after the subject made the response or after 2000 ms have elapsed, the subsequent trial started. Attention condition was manipulated between blocks. Half of the subjects responded to the global level in the first two blocks and to the local level—in the last two blocks. The other half were assigned to the reversed order of attention conditions. All other factors (except for key-response assignment) were manipulated within subjects and randomized within blocks.

The number of possible stimuli was smaller in Experiments 4–6—six in each condition. Within the global-directed condition, rectangular global patterns were not used. Within the local-directed condition, rectangular elements were not used. To generate a factorial design of the factors heterogeneity and compatibility within attention conditions, with 32 replications per cell, the six stimuli types used in each condition were crossed with the four levels of heterogeneity and the two locations (left, right). There were 768 experimental trials in total. Those were presented in four equal blocks with a brief break separating between each two consecutive blocks. A block with 48 practice trials was administered at the beginning of each attention condition, namely before the first and third blocks of experimental trials.

3.1.4. Subjects

In each of the experiments, 16 undergraduates at the University of Haifa participated as part of their course requirement. All had normal or corrected-to-normal vision. None of the subjects participated in more than one of the experiments reported here.

3.2. Results

Analyses were performed on arcsine square root transforms of percentages of incorrect responses and on mean latencies of correct responses. Trials with latencies shorter than 200 ms or longer than 2000 ms were excluded from analysis. Data were cast into within-subject three-way repeated measures ANOVAs.

3.2.1. Experiment 1

The results are presented in Fig. 6A. In the analysis of mean latencies, a significant main effect was found only for the global compatibility factor, $F(2, 30) = 10.43$, $p < 0.0005$. In post-hoc Duncan analyses on the global compatibility factor, significant differences (at the 0.05 level) were found between incompatible trials and neutral ones as well as between neutral trials and compatible ones. In the analysis of error transforms, no significant effect was found, neither was there any indication for a possible speed-accuracy tradeoff.

The finding of major importance for our concern is that the heterogeneity factor did not manifest any effect, neither main nor interactive. Thus, the response to the auditory stimulus was not affected at all by the local level, even when it was absolutely homogeneous, but was affected by the global level regardless of element heterogeneity.

3.2.2. Experiment 2

The results are presented in Fig. 6B. In the analysis of mean latencies, a significant main effect was found only for the global compatibility factor, $F(2, 30) = 23.10$, $p < 0.0001$. The pattern in the analyses of both performance measures is identical with the pattern observed in Experiment 1. Most important, the heterogeneity factor did not manifest any significant effect, neither main nor interactive. There was, however, some sign, $F(6, 90) = 2.02$, $p = 0.07$, for a possible interaction between heterogeneity and global compatibility on the error measure, in that in the most

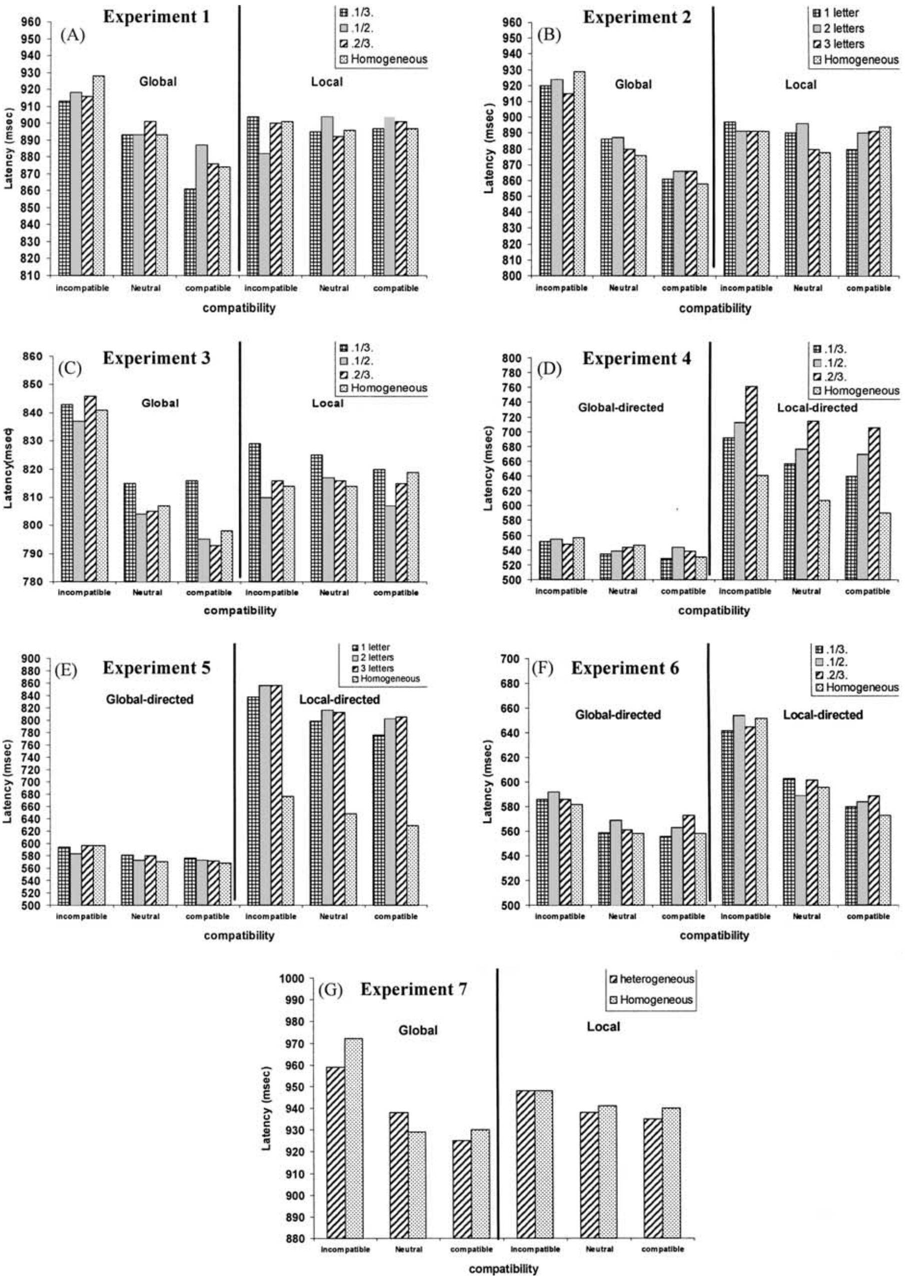


Fig. 6. Mean latency as a function of the factors manipulated in the experiments (global compatibility, local compatibility, and heterogeneity in Experiments 1–3 and 7; compatibility, attention condition and heterogeneity in Experiments 4–7).

heterogeneous condition there appeared to be some cost not only to incompatible trials but to compatible ones as well. This might have resulted from the similarity of one of the response-neutral letter types with either of the response-relevant ones. Notwithstanding, the picture here is on the whole quite alike the one obtained in Experiment 1: The auditory stimulus was not affected at all by the local level, even when it was absolutely homogeneous, but was affected by the global level regardless of element heterogeneity.

3.2.3. Experiment 3

The results are presented in Fig. 6C. In the analysis of mean latencies, a significant main effect was found only for the global compatibility factor, $F(2,30) = 10.09$, $p < 0.0005$. There was also a sign, $F(3,45) = 2.42$, $p = 0.08$, for a possible main effect of heterogeneity. No other main or interactive effect even approached significance. In post-hoc Duncan analyses on the global compatibility factor, a significant difference (at the 0.05 level) was found between incompatible trials and neutral ones but not between neutral trials and compatible ones. In the analysis of error transforms, no significant effect was found, but there was a sign, $F(2,30) = 3.26$, $p = 0.052$, for a slight main effect of local consistency (a difference of about 0.5% between incompatible trials and neutral ones). There was also no indication for a possible speed-accuracy tradeoff.

Thus, like in Experiments 1 and 2, the heterogeneity factor did not manifest any significant effect, neither main nor interactive.

3.2.4. Experiment 4

The results are presented in Fig. 6D. In the analysis of mean latencies, all main effects were found to be significant: $F(1,15) = 78.76$, $p < 0.0001$, $F(2,30) = 51.26$, $p < 0.0001$, and $F(3,45) = 31.33$, $p < 0.0001$, for attention condition, compatibility and heterogeneity respectively. Attention condition was also found to interact with compatibility, $F(2,30) = 9.82$, $p < 0.0005$, as well as with heterogeneity, $F(3,45) = 32.73$, $p < 0.0001$. On the other hand, heterogeneity did not interact with compatibility, $F < 1$, neither was the triple interaction found significant, $F < 1$. In post-hoc Duncan analyses on all three main factors, significant differences (at the 0.05 level) were found between all their values. In further tests meant to explore simple effects, compatibility was found to have a significant effects within both attention conditions, $F(2,30) = 6.76$, $p < 0.005$ for the global-directed condition and $F(2,30) = 43.54$, $p < 0.0001$ for the local-directed condition, but heterogeneity had a significant effect only within the local-directed condition, $F(3,45) = 42.28$, $p < 0.0001$.

In the analysis of error transforms, significant effects were found for the main effect of compatibility, $F(2,30) = 12.35$, $p < 0.0001$, and for the interaction between heterogeneity with attention condition, $F(3,45) = 13.86$, $p < 0.0001$, but no indication was found for a possible speed-accuracy tradeoff.

In sum, a considerable global advantage was observed, and the heterogeneity factor did not interact with it. Not surprisingly, heterogeneity had a monotonic effect on latency within the local-directed attention condition, since it must have acted to increase the mean time to detect a response-relevant element. However, heterogeneity did not moderate the effect of compatibility of the local level with the irrelevant global letter. Furthermore, the response to the global level in the global-directed condition was not affected at all by the heterogeneity of the local level.

3.2.5. Experiment 5

The results are presented in Fig. 6E. In the analysis of mean latencies, all main effects were found to be significant: $F(1,15) = 123.24$, $p < 0.0001$, $F(2,30) = 60.50$, $p < 0.0001$, and $F(3,45) = 120.15$, $p < 0.0001$, for attention condition, compatibility and heterogeneity respectively. Attention condition was also found to interact with compatibility, $F(2,30) = 10.05$, $p < 0.0005$, as well as with heterogeneity, $F(3,45) = 113.76$, $p < 0.0001$. On the other hand, heterogeneity did not interact with compatibility, $F < 1$, neither was the triple interaction found significant, $F < 1$. In post-hoc Duncan analyses on all three main factors, significant differences (at the 0.05 level) were found between all their values of, except for the three different numbers of response-neutral letters used for manipulating the extent of heterogeneity. In further tests meant to explore simple effects, compatibility was found to have a significant effects within both attention conditions, $F(2,30) = 15.88$, $p < 0.0001$ for the global-directed condition and $F(2,30) = 39.80$, $p < 0.0001$ for the local-directed condition, but heterogeneity had a significant effect only within the local-directed condition, $F(3,45) = 134.01$, $p < 0.0001$.

In the analysis of error transforms, significant effects were found for the main effects of attention condition, $F(1,15) = 15.44$, $p < 0.005$, compatibility, $F(2,30) = 5.63$, $p < 0.01$, and heterogeneity, $F(3,45) = 6.99$, $p < 0.001$, as well as for the interaction between heterogeneity with attention condition, $F(3,45) = 9.22$, $p < 0.0001$, and the interaction between heterogeneity with compatibility, $F(6,90) = 3.22$, $p < 0.01$, but no indication was found for a possible speed-accuracy tradeoff. The only result that is somewhat informative here is the latter interaction, arising from a slight discrepancy between the simple effects of the number of response-neutral letters within compatible trials and within the other two types of trial. There does not seem to be any easy explanation for this, but anyhow it does not seem to be very relevant to the hypothesis in question.

In sum, the results of this experiment replicate fairly well the pattern observed in Experiment 4: Basically, a considerable global advantage was observed here, and the heterogeneity factor did not interact with it. Specifically, the response to the global level was not affected by the heterogeneity of the local one, neither did heterogeneity moderate the effect of the compatibility of the response to the local level with the global letter.

3.2.6. Experiment 6

The results are presented in Fig. 6F. In the analysis of mean latencies, two main effects were found to be significant: $F(1,15) = 10.75$, $p < 0.01$, and $F(2,30) = 63.40$, $p < 0.0001$, for attention condition and compatibility respectively. Attention condition was also found to interact with compatibility, $F(2,30) = 13.77$, $p < 0.0001$. On the other hand, heterogeneity did not interact with compatibility, $F < 1$, neither was the triple interaction found significant, $F < 1$. In post-hoc Duncan analyses on the compatibility factor, significant differences (at the 0.05 level) were found between incompatible trials and each of the other two types of trial. In further tests meant to explore simple effects, compatibility was found to have a significant effects within both attention conditions, $F(2,30) = 13.60$, $p < 0.0001$ for the global-directed condition and $F(2,30) = 57.81$, $p < 0.0001$ for the local-directed condition, though its extent was larger in the latter condition.

In the analysis of error transforms, a significant effect was found only for the main effect of compatibility, $F(2,30) = 21.79, p < 0.0001$, and no indication was found for a possible speed-accuracy tradeoff.

The results of this experiment, unlike Experiments 4 and 5, do not indicate any effect of heterogeneity, neither main nor interactive. This is probably due to the fact that in this experiment, unlike in the preceding two, the manipulation of heterogeneity was not confounded with the demands of processing the response in the local attention condition. Thus, this is perhaps the strongest evidence for the irrelevance of heterogeneity for global/local advantage. In any event, the results of this experiment reinforce the basic pattern observed in Experiments 4 and 5: A considerable global advantage was observed, and the heterogeneity factor did not interact with it.

3.2.7. Experiment 7

The results are presented in Fig. 6G. In the analysis of mean latencies, a significant main effect was found only for the global compatibility factor, $F(2,30) = 10.26$, $p < 0.0005$. No other main or interactive effect even approached significance. In post-hoc Duncan analyses on the global compatibility factor, a significant difference (at the 0.05 level) was found between incompatible trials and neutral ones but not between neutral trials and compatible ones. In the analysis of error transforms, no significant effect was found. There was also no indication for a possible speed-accuracy tradeoff.

Thus, despite the extreme degree of heterogeneity used in this experiment, here too the heterogeneity factor did not manifest any significant effect, neither main nor interactive.

3.3. Discussion

The results presented above do not provide any evidence that element heterogeneity affects global/local advantage. Experiments 1–6 employed three different manipulations of heterogeneity in two paradigms used to observe global/local advantage. In none of the manipulations was there any sign that heterogeneity affected the global advantage obtained, though the heterogeneity itself was quite visible. [9] When neither level required a response (Experiments 1–3), heterogeneity did not have a

[9] In a pre-test, the level of accuracy in distinguishing between homogeneous and heterogeneous trials ranged from 93.1% under the conditions of Experiment 3 to 83.5% under the conditions of Experiment 1. These figures probably underestimate visibility, because most errors seem to result from anticipations of the more frequent response, viz. "heterogeneous".

main effect, neither did it interact with the compatibility of either level with the to-be-responded, auditory stimulus. When attention was rather directed to either of the levels (Experiments 4–6), heterogeneity did not have any effect on the response to the global level. It did delay, as might be expected, the response to the local level when it was manipulated by reducing the number of response-relevant elements (Experiments 4–5), but not at all—when it did not correlate with that number (Experiment 6). In any event, it never affected the interaction between level and compatibility. In Experiment 7 color heterogeneity was maximized. Still, it did not manifest either a main effect or an interactive one.

Of course, failing to find evidence does not prove that no evidence could ever be found. However, one might wonder what else could be done to search for such evidence in this case. Hundred-twelve subjects were used across all experiments, and there was not even a hint for an effect of heterogeneity.

Thus, no support was found for the hypothesis that global precedence is basically an organizational phenomenon manifested whenever the local level of compound stimuli is perceived as unitary texture rather than as a set of distinct elements. If the local level in the homogeneous condition was perceived as texture, considerable disruption of homogeneity would be expected to dispose the system to perceive the local letters as distinct units, presumably with explicit forms. By hypothesis, that disposition would probably have given rise to a discernible effect on RT, at least with some manipulation of the type of heterogeneity or its extent.

The present results converge with two other findings. One, Miller (1981a, Exp. 2) asked subjects to respond to global letters made of local letters. He compared a condition in which the local letters were all different to the standard condition in which all elements were the same, and found no difference whatsoever. Miller could not test whether heterogeneity interacted with attention condition and cross-level compatibility, since he did not include a local-directed condition in his design. However, the absence of any main effect suggests that no manipulation of heterogeneity is likely to interact with compatibility. Two, in a study of reflection judgment on compound letters modeled after Robertson and Palmer (1983; cf. Kunde & Hoffman, 2000), Yassky (1991) used stimuli in which the local letters were all different, in contrast with the identical local letters in the stimuli used by Robertson and Palmer. She replicated their results, particularly the strong global precedence effects, despite the total loss of homogeneity.

The union of these results with the result of Experiment 7 reported here suggests that global advantage does not require any degree of element homogeneity. Even if some effect of element heterogeneity nonetheless existed, it seems doubtful that it could play a significant role in generating the findings seen as indications for global precedence. In any event, there is no practical reason to suspect the working hypothesis that there is no harm in using compound letters having identical elements.

As mentioned above, local constituents are often accommodated to the schema suggested by the global structure. In compound stimuli, that results in neglecting identification, and presumably other aspects of figural analysis, of the elements (which seems compatible with the minimum principle; cf. Hochberg, 2003). That neglect does not, however, indicate that the local level of compound stimuli cannot have any figural status or identity. It certainly does when attention is directed to it. It probably does whenever local-to-global interference is manifested.

Furthermore, lack of figural analysis does not entail that the unanalyzed input is not a distinct perceptual unit. An element may constitute a low-level perceptual unit regardless of whether its form, let alone identity, has been analyzed (cf. Trick & Enns, 1997). It probably does, if organizational processes often finish before the process of interpretation does, as common wisdom has it. It probably should, because keeping the distinct status of an element serves to maintain the option for later processing its identity, or else skipping it if the process of interpretation can do without that.

4. Conclusion

The study reported above addresses an aspect in the paradigm that could be suspected to generate a problem in interpreting data collected with it. It suggests that what could be a problem is probably not so, surely not a grave one. That, of course, does not necessarily generalize to other doubts one might have about the paradigm. However, it might lead us to ponder about the source of those doubts.

Testing a disposition to prefer global structures, by using stimuli as artificial as compound stimuli clearly are, naturally arouses the worry that external validity has been overly sacrificed. Doubts of that sort have been addressed here both by arguments and by data. Some of the doubts, however, do not concern the defining properties of the paradigm but rather stem from a particular variation of it that gained special popularity. Using compound letters as stimuli is, of course, the cornerstone of the paradigm. Instructing the subject to direct attention to a particular level, let alone measuring interference emanating from a to-be-ignored level, is not.

Having the subject focus attention at a particular level detracts from the verisimilitude of the process guiding the subject's behavior to the kind of perceptual processing with which the global precedence hypothesis is concerned. The rationale of the paradigm (see Section 2.1.4) is that the compound stimulus be perceived as an object and be relevant as such at the moment of testing. However, when a subject is asked to selectively attend to the identity of elements, he might resort to task- and stimuli-specific strategies, such as trying to focus visual attention on a particular element, so as to process that element as an object in itself. The risk of that is high when the stimulus is presented with spatial certainty, let alone when some element appears exactly at fixation.

Other variations of the paradigm, like measuring the effects of the levels of a compound stimulus diffusely attended on naming an auditory stimulus, seem better in that respect.

Reservations notwithstanding, ample research has been done with compound stimuli in the years following the seminal study. So, a word of summary is in order. With proper control, of pattern goodness and eccentricity on top of stimulus set and all other variables known to be relevant, global advantage effects are sufficiently consistent to indicate the existence of a disposition. That disposition seems to be a perceptual one. It is yet to be ironed out what exactly is the nature of that disposition—within-object global precedence, global addressability, formation preference, or any combination of those. There does not seem to be much reason for dispute over the existence of a formation preference as defined above. Global addressability appears to follow suit logically. The relevance of effects found with compound stimuli to global precedence in unitary, connected objects has been justified by a reasoned extrapolation reinforced by a fortiori arguments. That does not seem too bad in my mind, considering the alternative—banishing the issue to the realm of undecidability.

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