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Visual similarity modulates visual size contrast

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A B S T R A C T

Perception is relational: object properties are perceived in comparison to the spatiotemporal context rather than absolutely. This principle predicts well known contrast effects: For instance, the same sphere will feel smaller after feeling a larger sphere and larger after feeling a smaller sphere (the Uznadze effect). In a series of experiments, we used a visual version of the Uznadze effect to test whether such contrast effects can be modulated by organizational factors, such as the similarity between the contrasting inducer stimulus and the contrasted induced stimulus. We report that this is indeed the case: size contrast is attenuated for inducer-inducing pairs having different 3D shapes, orientations, and even – surprisingly – color and lightness, in comparison to equivalent conditions where these features are the same. These findings complement related work in revealing basic mechanisms for fine-tuning local interactions in space-time in accord to the global stimulus context.

1. Introduction

Relational determination is one of the key operating principles of perception. In most conditions, perceived object properties do not depend on local, absolute measurements of stimulus dimensions but on comparisons of such dimensions to other, contextual stimuli. Examples of this general idea abound. In the perception of surface color, for instance, the lightness of a patch (its achromatic color defined by the grey scale from black to white) is strongly affected by the ratio of the light intensity reflected by the patch to the light intensity reflected by the patch surround. Accordingly, in the well-known phenomenon of simultaneous lightness contrast (Fig. 1a), the same grey patch will tend to appear darker when surrounded by a white background and lighter when surrounded by a black background. In the perception of object size, reports of the apparent size of an object depend on the ratio of that object's subtended visual angle to the visual angle subtended by nearby objects. Accordingly, in widely known size-contrast phenomena such as the Ebbinghaus-Titchener and the Delbeuf illusions (Fig. 1c and d), figures subtending the same visual angle will appear larger or smaller when surrounded by contextual figures subtending smaller or larger angles.

However, the scope of relational determination in perception is not limited to such simple figure-surround contrast effects. If this were the case, perceived object properties would fluctuate wildly after any change of the context. Consider a grey object surrounded by other small black objects, all placed on some neutral background, and imagine that this object is now displaced to another location within the same background but now in the midst of large white objects. If the appearance of the target object were determined only by local figure-ground contrasts, such object should appear to change dramatically in its color and size. This does not typically happen in natural perception, suggesting that perceptual systems are somehow able to take into account contextual stimuli in a more global manner, implementing what seems to be a much more complex process of relational organization. In the case of surface color, for instance, intriguing effects of junctions (Todorovic, 1997), transparency (White, 1979), 3D spatial structure (Gilchrist, 1977), and organization within frameworks of illumination (Gilchrist et al., 1999) have all been shown to strongly affect lightness via relational determination within the global context. Similar effects have been described for the perception of object motion (for a review see Bruno & Bertamini, 2015). In fact, these cases of global relational determination are generally understood as key processes in promoting perceptual constancies (Corney & Lotto, 2007). Thus, when placed within the context of their global stimulus array, the very local relations that should cause object properties to change dramatically with changes in the surround become the effective basis for the perceptual stability of object properties.

Although these ideas/principles are widely accepted, the mechanisms that govern such global relational organization are much less clearly understood. One attractive idea is that local relationships may be weighted by perceptual systems according to simple rules of unit formation. If two perceptual elements tend to be grouped together, their local relationship should be weighted more, in comparison to other relationships, in the global process leading to a conscious percept.

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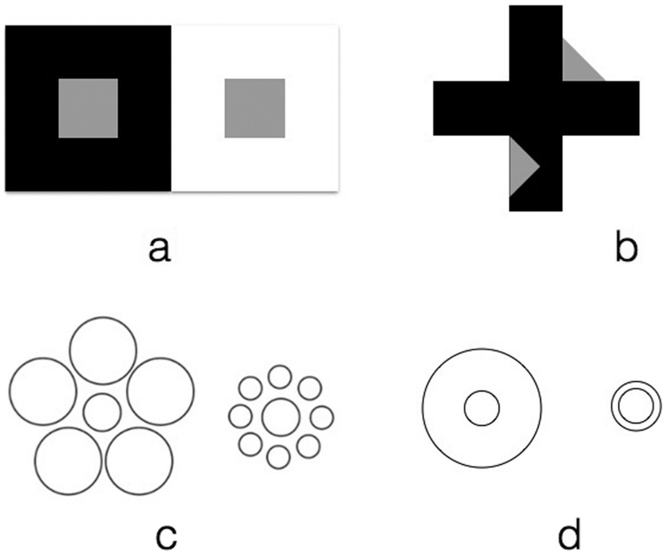

Fig. 1. Well-known visual illusions demonstrate that perception is relational. (a) In the lightness-contrast phenomenon, physically identical squares appear to have different surface colors due to different luminance relationships with their respective backgrounds. (b) In the Ebbinghaus-Titchener illusion, physically identical circles appear to have different sizes due to different size relationships with their surround disks. (c) In the Delbeuf illusion, a disk appears smaller when placed within a large annulus and larger when placed within a small annulus.

If instead they are kept separated and perceived as belonging to distinct perceptual units, then their relationship should be given less weight. Support for this idea has come from studies of surface lightness. In the classic Benary cross illusion (Fig. 1c; Benary, 1924), for instance, two triangles having the same luminance share borders of identical length with both the white and the black regions. The two triangles therefore are not only identical in terms of absolute amounts of reflected light, but also in terms of local relationships with their respective bicolored backgrounds. Nonetheless, they do not appear identical. This is generally explained by invoking a contextual effect: the geometry of the scene supports grouping one of the triangles with the black cross, and the other triangle with the white background. If such grouping process tends to weigh more the corresponding relationships, one would indeed predict that the former becomes lighter, i.e., contrasts more with the black surround, and the latter darker. In an elegant study, Agostini and Proffitt (1993) described an even stronger effect that can be interpreted in the same way. They presented stripes of grey, black, and white disks that translated on a blue computer screen in different directions. In some trials, the grey disks translated in the same direction as the black disks. In other trials, they translated in the same direction as the white disks. Unsurprisingly, these differences in motion direction created strong grouping effects due to the Gestalt principle of common fate, such that in some trials the grey disks formed perceptual units with the black ones, whereas in others they formed units with the white ones. Much less predictably, this motion manipulation affected the color of the disks, in the direction of emphasizing contrast within perceptual units. Thus, when the grey disks moved with the white ones, they appeared darker in comparison to the situation when they moved with the black ones.

While these phenomena are generally consistent with the idea that the processing of luminance relations is affected by visual grouping (Economou, Zdravkovic, & Gilchrist, 2015), it is less clear whether this principle applies to other visual dimensions. In this paper, we seek to extend it to the perception of size by asking whether modulations of size contrast can be demonstrated by manipulations of unit formation between two objects of different sizes. The main motivations for our study are twofold. First, there have been earlier suggestions that similarity modulates size contrast in the Ebbinghaus-Titchener illusion (Coren & Miller, 1974; de Fockert, Davidoff, Fagot, Parron, & Goldstein, 2007; Deni & Brigner, 1997; Jaeger & Guenzel, 2001; Vuk & Podlesek, 2005). These reports however have been criticized for not providing a clear definition of similarity and for confounding shape, size, and contour manipulations (Rose & Bressan, 2002). In addition, it has been suggested that the contextual effect observed in the Ebbinghaus-Titchener illusion may not be a form of size contrast, but may stem from interactions at the level of contours (Jaeger, 1978; Jaeger & Klahs, 2015; Jaeger & Pollack, 1977). Second, there has been an intriguing report of modulations of haptic size contrast by similarity (Kappers & Bergmann Tiest, 2014). The latter study exploited a powerful haptic size-contrast effect originally described by Uznadze (1966). Suppose I ask you to don a blindfold and then place two balls in your hands, a small ball in the left hand and a large ball in the right hand. You squeeze them, re-open your hands, and repeat this a few times. At this point I substitute these initial (adapting) balls with two medium, identical balls. As might be expected, you will experience a strong size contrast effect: one of these test balls will feel definitely smaller and the other larger. Kappers and Bergmann Tiest (2014) asked what would happen if the adapting and test objects were not the same 3D shape, as were our imaginary balls. In one condition, for instance, they adapted participants to spheres and later tested them again with spheres. In another condition, they adapted participants to spheres but later tested them with tetrahedra. They found that even with these different 3D shapes there was a size contrast effect, but this was less pronounced in comparison to conditions where the shapes were the same.

Kappers and Bergmann Tiest (2014) interpreted their result as due to a cognitive contribution to haptic size perception. We note however that their finding is nicely consistent with the idea that the strength of contrast is modulated by unit formation. Objects with different 3D shape are grouped less strongly, and this may reduce the weight assigned to their size relationship. At same time, however, it could be argued that spheres and tetrahedra differ on several simple stimulus dimensions besides 3D shape, such as, for instance, the presence of rounded vs flat surfaces. To fully rule out that some of these affected size contrast (for reasons that have little to do with shape similarity) is not straightforward. A potential strategy to address this issue is to study analogous effects in vision, where similarity can be modulated in several ways while keeping size constant. In the present paper, therefore, we first of all sought to develop a visual analogue of the Uznadze size contrast effect, and then used this to test whether the strength of contrast is modulated by unit formation based on the Gestalt principle of similarity. Based on five experiments, we report that visual similarity does indeed modulate visual size contrast. This happens along the dimension of visual 3D shape (a visual analogue of the report of Kappers). Interestingly, however, this also happens for other dimensions of perceived similarity that – crucially – leave local geometrical features of the contrasting objects unchanged. Specifically, we show that visual size contrast is modulated by figure orientation with respect to the vertical and horizontal frames of reference – a manipulation whereby physically congruent shapes take on different perceived shapes, such as a square and a diamond (Mach, 1897/1959) or triangles pointing in different directions (Attneave, 1968). Even less predictably, we also show that visual size contrast is affected by similarity in surface color, a dimension that is sometimes assumed to be independent from object size and form (Cant, Large, McCall, & Goodale, 2008; Cavina-Pratesi, Kentridge, Heywood, & Milner, 2010; but see also Cohen, 1997). We interpret these results as evidence that visual similarity indeed modulates the gain of a contrast signal within the visual system.

2. General methods

2.1. Apparatus

All studies were run using an Intel Core i7 computer running E-