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Paradoxical perception of object identity in visual motion

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ABSTRACT

In the course of perceptual organization, incomplete optical stimulation can evoke the experience of complete objects with distinct perceptual identities. According to a well-known principle of perceptual organization, stimulus parts separated by shorter spatial distances are more likely to appear as parts of the same perceptual identity. Whereas this principle of proximity has been confirmed in many studies of perceptual grouping in static displays, we show that it does not generalize to perception of object identity in dynamic displays, where the parts are separated by spatial and temporal distances. We use ambiguous displays which contain multiple moving parts and which can be perceived two ways: as two large objects that gradually change their size or as multiple smaller objects that rotate independent of one another. Grouping over long and short distances corresponds to the perception of the respectively large and small objects. We find that grouping over long distances is often preferred to grouping over short distances, against predictions of the proximity principle. Even though these effects are observed at high luminance contrast, we show that they are consistent with results obtained at the threshold of luminance contrast, in agreement with predictions of a theory of efficient motion measurement. This is evidence that the perception of object identity can be explained by a computational principle of neural economy rather than by the empirical principle of proximity.

1. Introduction

In dynamic scenes, parts of optical stimuli presented at different locations and different instants can "group" across space and time, i.e., appear to belong to the same object. This perceptual grouping gives rise to the experience of moving objects. How do visual systems derive stable object identities while the corresponding parts of stimulations are separated in space and time? This question was enunciated by Gestalt psychologists as the problem of "phenomenal identity" (Ternus, 1926; Wertheimer, 1923) and it instigated numerous studies (Bower, 1967; Chun, 1997; Dawson, 1991; Gepshtein & Kubovy, 2000; Hochberg, 1987; Jones & Bruner, 1954; Kahneman, Treisman, & Gibbs, 1992; Kellman & Spelke, 1983; Moore, Stephens, & Hein, 2010).

Several authors proposed that the experience of object identity was mediated by perceptual grouping according to the principle of proximity (He & Ooi, 1999; Kramer & Yantis, 1997; Ternus, 1926). According to this notion, stimulus parts separated by a shorter distance are more likely to group together. The principle was found to hold in many static visual displays (Hochberg, 1974; Kubovy & Wagemans, 1995; Oyama, 1961; Pomerantz & Portillo, 2011). It was expected to hold also in dynamic displays, where stimulus parts are separated by spatial and temporal distances. For example, the "Ternus display" (Fig. 1A) consists of two pairs of dots: marked "1" and "2" in the first frame t_1 and "3" and "4" in the second frame t_2. This display can be perceived in two ways. Spatial grouping of the concurrent dots {1, 2} and {3, 4} with consequent matching of the groups {1, 2} and {3, 4} leads to the perception of a single moving object: a group of dots ("group motion"). Alternatively, spatiotemporal grouping of dots {1, 4} and {2, 3} leads to the perception of two distinct moving objects ("element motion"). Decreasing spatial distances between the dots within frames makes group motion more likely, and decreasing temporal distance between the dots (i.e., decreasing temporal intervals between the frames) makes element motion more likely (Kramer & Yantis, 1997; Petersik & Pantle, 1979; Ternus, 1926).

Yet the results obtained with such simple dynamic displays do not generalize to more complex dynamic stimuli. For example, consider the stimulus called "motion lattice" (Gepshtein & Kubovy, 2000). Fig. 1B is a schematic representation of two frames

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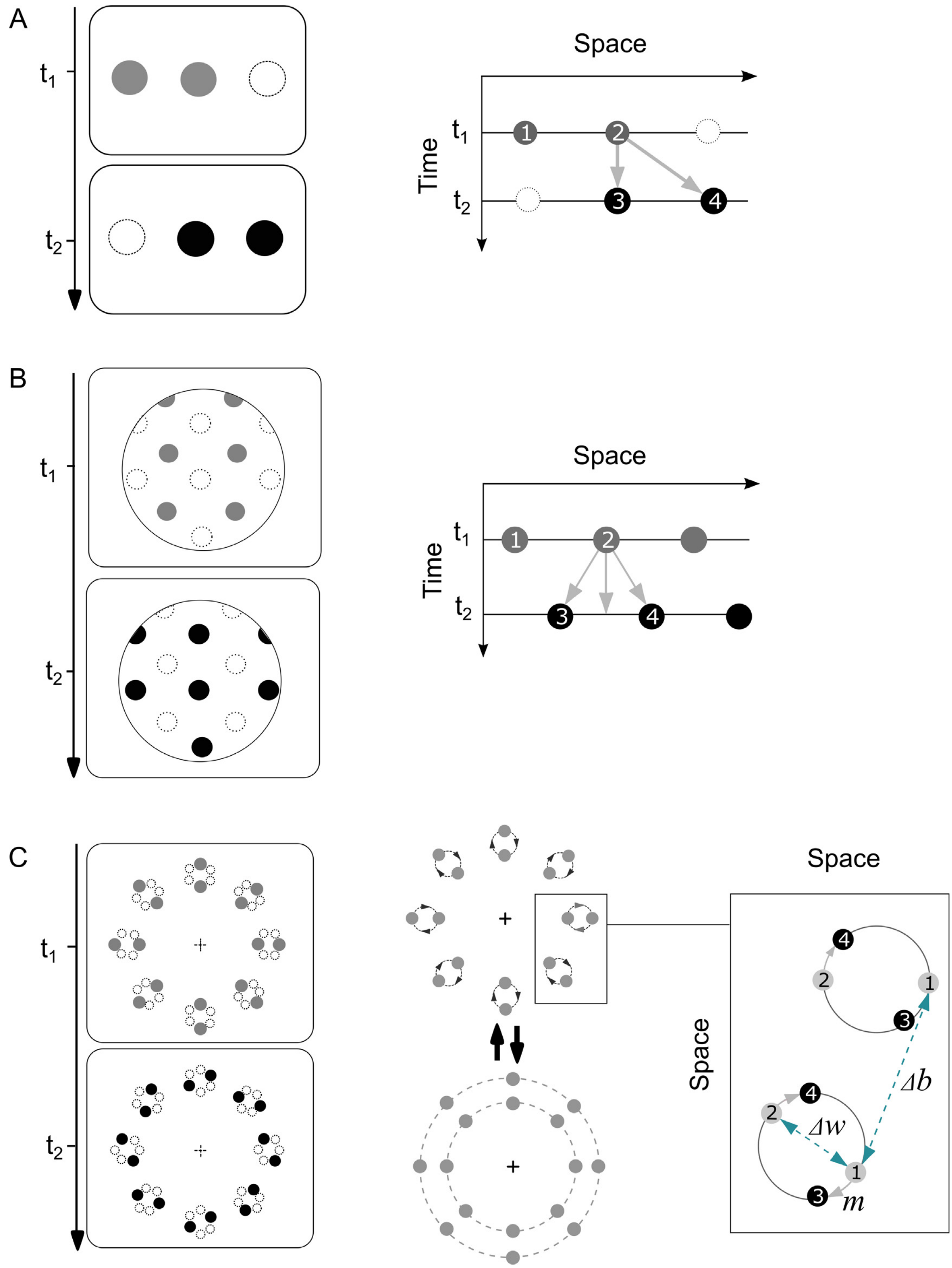

Fig. 1. Motion displays. Dots 1 and 2 appear in the first frame (grey); dots 3 and 4 appear in the second frame (black). Grey arrows indicate possible groupings across frames. (A) The Ternus display. Left: two subsequent frames of the display. Right: event diagram. Grouping {2,3} represents "element motion" and grouping {2,4} represents "object motion" where dots 1 and 2 move together, as a single entity. (B) Motion lattice. Left: two subsequent frames of motion lattice. Right: event diagram. Groupings {2,4} and {2,3} corresponds to element motion. Grouping of rows of dots (represented by the vertical arrow) corresponds to downward group motion. (C) Display used in the present study. Dashed arrows indicate possible dot groupings within frames. Left: two subsequent frames of the display. Middle: two alternative percepts of the display: multiple rotating dipoles vs. two pulsating circles (illustrated in Movies 1 and 2). Right: diagram of two dipoles. Distance Δw separates dots within the dipole, distance Δb separates dots in adjacent dipoles, distance m separates dots between successive frames. Grouping over distance Δw corresponds to perception of dipoles and grouping over distance Δb corresponds to perception of circles.

of a motion lattice seen through a circular aperture. In the first frame, dots appear in the even rows of the lattice; in the second frame they appear in the odd rows. Alternation of frames gives rise to the perception of upward or downward motion. For example, downward-right motion is seen when the dots are grouped between frames along the arrow drawn between dots 2 to 4, and