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Global orientation aftereffect in multi-attribute displays: implications for the binding problem

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Abstract

We investigated the binding problem (e.g. the combination of edge information across attributes), using an orientation aftereffect paradigm (OAE). Horizontal layers of vertical edges were phase-shifted to create a global near-vertical orientation. Multi-attribute displays were created by alternating the attribute defining edges (e.g. luminance, colour, texture or motion) across layers. OAE magnitude was dependent only on the attributes used in the adaptation phase, and the similarity of attributes from adaptation to testing phase had no significant effect. Moreover, compared to single-attribute conditions, the cooperation between attributes is moderate. These results favour segregation models of the binding mechanism.

Keywords: Global orientation; Orientation aftereffect; Contour binding; Feature integration; Segregation mechanism

1. Introduction

Object perception is based on multiple sources of information. Visual contours that define shape are often encoded in different attribute modules (Barlow, 1986; Fodor, 1985). Physiologically, these modules may be related to different brain areas (Goodale & Milner, 1992; Lennie, 1998; Livingstone & Hubel, 1988; Ungerleider & Mishkin, 1982). Information about contours can interact across attributes defining them (Albert, 2001; Hernández-Lloreda & Jáñez, 2001; Kubovy, Cohen, & Hollier, 1999; Poom, 2001a, 2001b; Smith & Over, 1977). This interaction allows many tasks to be performed based on the combined information across attributes, including visual search (Krummenacher, Müller, & Heller, 2001; Treisman & Sato, 1990; Wolfe & Cave, 1999), apparent motion (Cavanagh, Arguin, & von Grünau, 1989), and other tasks (for more examples, see Kubovy et al., 1999). However, the combination of information across attributes is usually associated with some sort of binding cost, which can be measured as decreased acuity, increased error rates, and/or slower reaction time (Cavanagh et al., 1989; McIlhagga & Mullen, 1996; Poirier & Frost, submitted; Treisman & Gormican, 1988; Treisman & Schmidt, 1982).

1.1. Adaptation paradigm

The present experiment investigates binding using an orientation aftereffect paradigm (OAE, also called: "the tilt aftereffect"; Gibson & Radner, 1937). In this paradigm, an OAE occurs when adaptation to a slanted grating (adaptation phase) causes a subsequently viewed vertical grating (testing phase) to appear slanted in the opposite direction. An OAE produced on one attribute may or may not transfer to other attributes (Berkley,

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DeBruyn, & Orban, 1994; Paradiso, Shimojo, & Nakayama, 1989), which indicates whether or not cues interact across those attributes. If the OAE transfers, then the two attributes must be connected and allowed to influence each other. In the present experiment, OAEs and OAE transfers were measured for orientations defined by the combination of visual contours both within and across attributes, to better understand the mechanisms underlying binding.

1.2. Global vs. local orientation

Before investigating cue interactions and binding using the adaptation paradigm, it is important to reduce the contributions to the OAE from other sources of orientation information. We manipulated this by separating the orientation information into "local" orientation (i.e. spatially restricted) and "global" orientation (i.e. extending over the whole pattern; see Lauwereyns & d'Ydewalle, 1997; Navon, 1977). In the present experiment, even though single edges were vertical (local orientation), the misalignment between subsequent edges integrates into an oblique orientation (global orientation), which may be right- or left-slanted from vertical.

1.3. Integration across attributes

To investigate integration across attributes, we modified the single attribute conditions such that the attribute defining vertical edges alternates from one edge to the next. Thus, to recover global orientation, integration across attributes is required.

The effect of interleaving two attributes on the OAE is currently unknown. At one extreme, alternating attributes could significantly block integration across edges, thus impairing the percept of a global orientation and blocking the OAE. At the other extreme, the OAE may well be insensitive to attribute change across edges, in which case the OAE size would be similar to OAE sizes measured in single attribute displays containing equivalent orientation information.

1.4. Segregating vs. integrating

Also, the direction of binding (integration vs. segregation) has been a major issue separating psychophysics and Gestalt theoretical approaches (for a review, see Chen, 2001). On one hand, binding could recursively *integrate* features and parts into objects (e.g. Marr, 1982), with inhibitory connections serving the simple function of preventing all visual features from coalescing into a single percept (Palm, 1990; von der Malsburg, 1985). Alternatively, binding could proceed in reverse order: *segregating* the visual scene into objects and features when necessary.

The binding direction can be inferred by how well the OAE spreads to other attributes that were not in the adaptation display. Here, we assume that the OAE transfers to attributes that are bound with the adapted attribute(s), during the adaptation phase. *Segregation models* assume that attributes are initially pre-bound together, thus OAE transfers should be large. In contrast, *integrative models* assume that attributes are initially independent, thus OAE transfers should be negligible.

1.5. Equality of attributes

Finally, there is also the question of whether certain attributes are more important for binding, as has been suggested in the context of capture: color edges are readily captured by high contrast luminance edges or by motion (Cavanagh, Tyler, & Favreau, 1984; Ramachandran, 1996; Ramachandran & Gregory, 1978; see also Walker & Shank, 1988). In the context of the OAE, unequal attribute status would mean that certain attributes would be more resistant to adaptation than others. Alternatively, given that many attributes are apparently processed the same way (Cavanagh, Arguin, & Treisman, 1990; Cavanagh et al., 1989; Clifford, Spehar, Solomon, Martin, & Zaidi, 2002; Gray & Regan, 1997; Regan, 2000; Rivest & Cavanagh, 1996), different attributes may adapt to similar extents.

The question of special attribute status is also relevant to certain attribute pairs. For example, motion and depth are more relevant to the "where" pathway, and color, texture, and 3D surface shape are more relevant to the "what" pathway (Ungerleider & Mishkin, 1982; for related ideas, see Goodale & Milner, 1992; Livingstone & Hubel, 1988; Lennie, 1998). Thus, attributes may be more readily integrated within defined groups, and transfer can be expected to be strongest within these groups.

1.6. Summary of expectations

A *baseline condition* was used to assess whether local vertical edges could integrate into a global orientation capable of supporting an OAE.

Single attribute conditions were used to verify that (1) the OAE supported by integrated global orientation occurs for all attributes, and (2) reducing the number of edges reduces the OAE.

In *dual attribute conditions*, we expect that (3) integrated stimuli will support an OAE, (4) *segregation models* predict that the OAE will transfer to different attribute pairs, whereas *integration models* predict that the OAE will only occur if there is overlap of attributes from adaptation to testing phases, (5) OAE size will be dependent on the attribute pair used during the *adaptation phase* : certain attribute pairs will consistently generate larger OAEs than others, and (6) unless certain