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Temporal properties of the chromatic and achromatic Craik–O'Brien–Cornsweet effect

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Abstract

The Craik–O'Brien–Cornsweet effect (COCE) is a visual illusion in which a difference in brightness is observed between two regions of equal luminance separated by a contrast edge with opposite luminance gradients on each side. The COCE also occurs with chromatic contrasts. It has been hypothesized that the COCE is mediated by a cortical filling-in process. According to the filling-in hypothesis, the filling-in or spreading of neural activity proceeds at finite speed, and therefore exhibits some temporal tuning as a function of the width of the area to be filled in. In the present study, observers varied the temporal frequency of a COC grating to determine the maximum temporal frequency at which a temporal modulation of brightness or color was perceived. In the achromatic COCE, contours were modulated along the luminance axis of the DKL color space; in the chromatic COCE, contours were modulated either along the L − M or the S − (L + M) axis. For the achromatic condition, the critical temporal frequency at which the COCE was still perceived had the shape of an inverted U, inconsistent with the filling-in hypothesis: the critical temporal frequency increased with increasing spatial frequency only up to 0.2 cycles/deg, but then decreased for higher spatial frequencies. For the chromatic COCE, the critical temporal frequency decreased with increasing spatial frequency, which is also inconsistent with filling-in. Thus, the results of the present study are inconsistent with the idea that the temporal dynamics of the COCE, both achromatic and chromatic, are due to filling-in. Instead, our results are consistent with the spatial filtering properties of the luminance and chromatic systems.

Keywords: Filling-in; Craik–O'Brien–Cornsweet effect; Temporal frequency; Spatial frequency

1. Introduction

The Craik–O'Brien–Cornsweet effect (COCE) is a visual illusion in which two surfaces with the same luminance appear to differ in brightness because of an intervening luminance gradient at the borders (Cornsweet, 1970; Craik, 1966; O'Brien, 1958). The surface adjacent to the decrement part of the contour appears darker, while the surface adjacent to the increment part of the luminance gradient is seen as lighter. Thus, the visual impression of a COC grating is similar to a square-wave grating (Fig. 1). It has been shown that the COCE also occurs with chromatic borders (van den Brink and Keemink, 1976). However, the COCE is more pronounced for achromatic than for chromatic stimuli (Cole, Hine, & Scott, 1993; Wachtler & Wehrhahn, 1997; Ware & Cowan, 1983). Similarly, a weaker effect at isoluminance has been also shown for the missing-fundamental illusion in which a square wave with its fundamental Fourier component removed still appears like a square wave (Kingdom & Simmons, 1998).

It has been hypothesized that the COCE is mediated by a cortical filling-in processes (Grossberg and Todorović 1988; Neumann, Pessoa, and Hansen, 2001; Ratliff and Sirovitch, 1978; Todorović, 1987). Filling-in is a process where neural activity at the boundaries of a region spread into the interior region. Filling-in assumes that brightness information is represented in a cortical map and is thus an isomorphic theory. In the COCE, contrast information from the luminance

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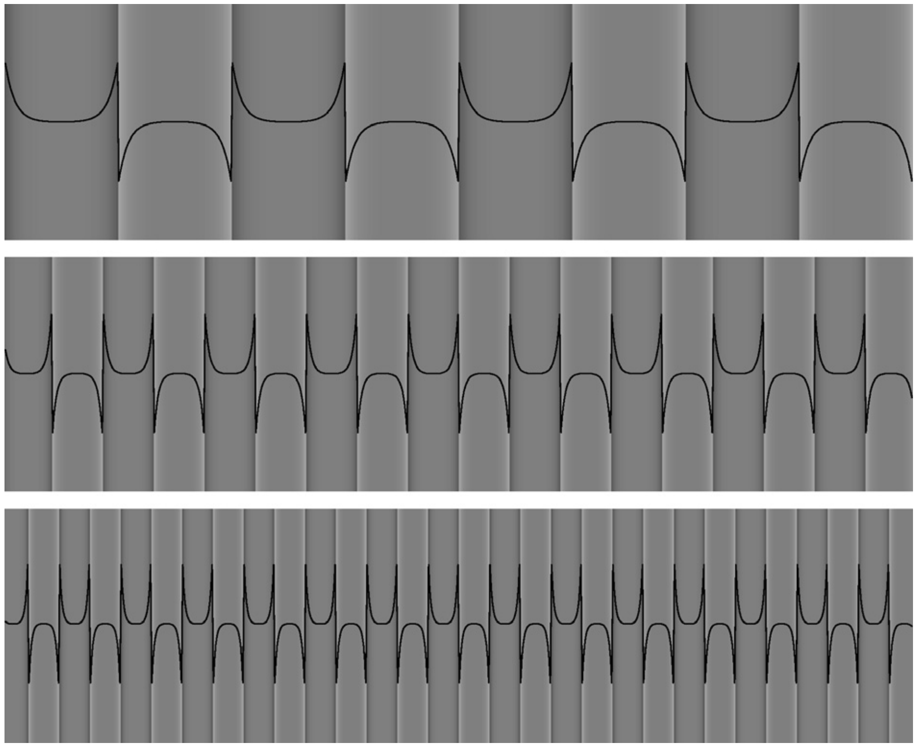

Fig. 1. Example of a Craik–O'Brien–Cornsweet effect (COCE) used in the first experiment. In this phenomenon, the central regions differ in perceived brightness, although the intensity of each of these regions is similar. The intensity profile (solid scalloped lines) has been added for illustration only and was not visible during the experiment.

gradients is thought to fill-in the homogeneous interior regions, such that observers perceive something different from the physical background depending of the surrounding area. Most neurons in the early visual system are sensitive to luminance discontinuities and respond less to homogeneous achromatic surfaces. Only a subset of cortical neurons responds well to uniform fields (Rossi, Rittenhouse, & Paradiso, 1996). According to the filling-in theory, brightness information signaled by contrast-sensitive neurons spreads from the luminance contrast at the edges towards the homogeneous inner region of the bars in the COC grating. Filling-in assumes an active spreading of neural activity, which proceeds at a finite speed, and should consequently exhibit a temporal tuning as a function of the size of the region to be filled-in: the larger the region, the more time is needed for filling-in. Davey, Maddess, and Srinivasan (1998) have investigated this hypothesis by manipulating the temporal modulation frequency of an achromatic COCE for various spatial frequencies. For each spatial frequency, there is a temporal frequency at which the brightness changes will not occur because the filling-in process does not have enough time to complete. The critical temporal frequency should vary with the width of the induced area and with the temporal frequency of the flickering contours. The principle finding of Davey et al. (1998) was that induced modulations were stronger and persisted to higher temporal frequencies for higher spatial frequencies, consistent with the isomorphic filling-in hypothesis. Along similar lines, Rossi and Paradiso (1996) investigated brightness induction in temporally modulated square-wave gratings and found that the highest temporal frequency at which brightness induction occurs decreased as the area of the stripes in the square-wave grating increased. Their findings are also consistent with an induction process such as filling-in that takes longer for larger areas.

Davey et al. (1998) (see also Maddess, Srinivasan, & Davey, 1998) suggested that their results could also support an interpretative hypothesis (called also the symbolic theory; for a review, see von der Heydt, Friedman, & Zhou, 2003). The early visual system is relatively insensitive to *achromatic* low-spatial frequency stimulation and shows only small responses to homogenous *achromatic* regions (Campbell & Robson, 1968). Thus, the retinal response pattern elicited by an achromatic square-wave is quite similar to the retinal response for an achromatic COCE. These similar patterns could be interpreted at a later stage by a symbolic "default-to-square-wave" rule (Campbell, Howell, & Johnstone, 1978; Ratliff & Sirovitch, 1978). For Maddess et al. (1998), this hypothesis is consistent with their results because the time required for the recognition process might be influenced by spatial frequency. Information about lower spatial frequencies is processed over greater cortical distance, thus the limiting process might be the speed at which the brain recognizes the low- or high-spatial frequencies in the image. This line of thinking indicates that the experiments by Davey et al. (1998) did not necessarily demonstrate that an isomorphic filling-in occurs in the COCE, and that the interpretative theory cannot be rejected.