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A new visual illusion of aspect-ratio context

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ABSTRACT

Perception of local properties of the visual field is influenced by aftereffects of adaptation. The tilt aftereffect describes repulsion of the perceived orientation of a line from the orientation of an adapting line. Analogous effects of spatial context are often called illusions. Repulsion of the perceived orientation of a grating from the orientation of a surrounding grating is referred to as the tilt illusion. In the same manner, the size aftereffect and Ebbinghaus illusion form a complementary pair of temporal and spatial context effects of size. Here we report psychophysical evidence for a previously unknown aspect-ratio illusion which causes the perceived aspect-ratio of a rectangle to be repelled from the aspect-ratio of rectangles surrounding it. This illusion provides a spatial analogue to the aspect-ratio aftereffect.

1. Introduction

The appearance of elements of the visual field is influenced by their spatial and temporal context. For a changing visual field, those perceived properties represent a complex and dynamic interpretation of the instantaneous physical properties of the scene. A general mechanism underlying these effects can be revealed in a simplified representation of these conditions in psychophysical experiments.

Changes in perception induced by patterns presented in close temporal proximity, a temporal context, are often called aftereffects while the term illusion has been more-frequently applied to the effects of a steady-state spatial context (i.e. when patterns are simultaneously presented). The tilt aftereffect is a familiar example of a temporal context effect where the perceived orientation of a line is repelled from the orientation of a previously experienced line (Gibson & Radner, 1937; Kohler & Wallach, 1944; Kohn, 2007; Mitchell & Muir, 1976). The analogous spatial context effect in which perceived orientation of a grating is repelled from the orientation of a grating that surrounds it is known as the tilt illusion (Clifford, 2014; Gibson & Radner, 1937). A similar pair of effects is experienced for the perception of size. The size aftereffect causes the perceived size of an object to be repelled from the size of a previously experienced object (Blakemore & Sutton, 1969; Dickinson, Morgan, Tang, & Badcock, 2017; Sagara & Oyama, 1957) and in the Ebbinghaus (or size) illusion the perceived size of an object surrounded by other objects is repelled from the size of those objects (Ebbinghaus, 1902).

The aspect-ratio (AR) aftereffect has properties comparable to the aftereffects described above in that the AR of a rectangle or ellipse is repelled from the AR of a previously experienced rectangle (Dickinson et al., 2017; Regan & Hamstra, 1992) but to date it does not have a spatial context analogue. The current study provides evidence for such an analogue and proposes a mechanism for its induction that might be generalized across the pairs of temporal and spatial context effects mentioned above. The remaining question is then what value, if any, do these aftereffects and illusions have in the processing of visual information?

All of the aftereffects and illusions considered above have the effect of degrading the accuracy with which each particular stimulus property is encoded while exaggerating the difference in that property from that of the surrounding context in either space or time. This leads to the suggestion that adaptation might improve the capacity to discriminate between subsequently presented stimuli with similar magnitudes of a particular property. For orientation, however, the systematic misrepresentations of orientation in perception only result in a meagre improvement in orientation discrimination ability restricted to orientations close to the adapting orientation (Regan & Beverley, 1985). We have previously argued, however, that a scalar field of tilt aftereffects (where the tilt aftereffect is specified locally across the visual field) might provide a general mechanism for exaggerating the differences between successively experienced similar stimuli (Dickinson,

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Almeida, Bell, & Badcock, 2010). Rather than adaptation to orientation acting to enhance an observer's capacity to discern differences in the orientations of lines presented to an observer in the adapted state, the local repulsive aftereffects affect different parts of an object to varying extents and cause changes in an object's shape that exaggerate its difference to previously experienced shapes. The enhancement in sensitivity to difference is manifest at a higher level of the processing hierarchy than that where the state of adaptation is acquired (Dickinson & Badcock, 2013). Similar arguments could be made for fields of other local aftereffects, size and AR included.

Given the analogous nature of the aftereffects and illusions of size one might expect the AR aftereffect to be accompanied by an AR illusion of spatial context. This study examines whether such an illusion exists. We have previously demonstrated that judgements of AR and size can be dissociated (Dickinson et al., 2017) and that AR aftereffects are not simply due to adaptation to linear dimensions. This gives us confidence that any illusions seen are not due to context effects of size.

2. Methods

2.1. Apparatus

Visual stimuli were created in MATLAB (Mathworks, Natick, MA, USA) and presented from the frame buffer of a Cambridge Research Systems (CRS) 2/3 graphics card (Cambridge Research Systems, Rochester, Kent, UK) to a Sony G420 monitor (Sony Corporation, Tokyo, Japan) refreshed at 100 Hz. Luminance was specified for 1,024 by 768 individual pixels over a linear eight-bit range with a maximum of 90 cd/m^2 and minimum near zero. Monitor calibration was performed using a CRS Optical (Cambridge Research Systems) and its associated software. Observers viewed the monitor in a darkened room from a position, stabilized by a chinrest, 115 cm along the normal to the center of the screen. At this distance each pixel subtended 1′ of visual angle. Responses were recorded using two buttons on a CRS CB3 button box.

2.2. Observers

One of the authors (ED) and three naïve observers participated in the study after giving their informed consent. All observers had normal or corrected to normal visual acuity. The study was approved by the University of Western Australia ethics committee and was, therefore, conducted in accordance with the Declaration of Helsinki.

2.3. Stimuli

Stimuli were comprised of a single test pattern surrounded by four rectangles, providing a spatial context (see Fig. 1). Stimuli were composed of rectangles to remove the possibility of effects of orientation context as edges within the stimuli are always either parallel or perpendicular. When square, the test pattern had a side length of 64 pixels (64′ of visual angle) but was selected on a trial by trial basis from nine ARs (height/width) ranging from 0.882 (60′/68′) which is slightly wider than square to 1.133 (68′/60′) which is slightly taller than square. The ARs of the context rectangles were chosen on a trial by trial basis from the set, 1/16, 1/8, 1/4, 1/2, 1, 2, 4, 8, 16. The surrounding rectangles, when square, had a side length of 64′ and all rectangles had the same area. The side lengths of all test and context rectangles were integer numbers of pixels and so the rectangles had step changes in luminance marking the edges. The surrounding rectangles provided context (context rectangles) and were centred at (96′, 192′), (−192′, 96′), (−96′, −192′) and (192′, −96′), on average, with respect to the test pattern but all of the rectangles were jittered within a range of a quarter of a degree horizontally and vertically on a trial by trial basis to prevent the build-up of after images. Background luminance was 45 cd/m^2 with all rectangles presented at a Weber contrast of 0.25. Stimuli were presented for 200 ms, a sufficiently short duration to prevent the initiation and completion of eye movements (Carpenter & Williams, 1995), removing the possibility of systematic adaptation effects within trials. Two example stimuli are shown side by side in Fig. 1 for illustrative purposes.

Due to the free viewing of the examples above some of the context effect experienced might be due to aftereffects accumulated over eye movements. In the study, however, the stimuli were only presented for 200 ms, too short a period to initiate and complete eye movements within a trial, and the conditions of context were interleaved to prevent accumulation of aftereffects across trials.

2.4. Procedure

After each single-interval trial of duration 200 ms, the observer was required to report whether the test pattern appeared wide or tall. Twenty trials for each pairing of context and test AR were presented over four blocks of trials and within each block the order of trials was pseudo-randomized to ameliorate any potential aftereffects accumulated over trials. The responses to the trials were collated into separate psychometric functions for each observer representing the proportion of tall responses across the test ARs for each of the nine context ARs. A cumulative Gaussian distribution was fitted to each psychometric function with the mean yielding the AR of the test pattern for which the observer would be expected to respond wide and tall with equal probability, the point at which the test pattern was subjectively square, for each context condition. The point at which the observer is equally likely to report wide or tall might be considered the point of subjective

Fig. 1. Two examples of stimuli used in the study. In both stimuli the central test pattern is square. In the example on the left the context rectangles have an AR of 4 and the test pattern appears slightly wider than square. In the example on the right the context rectangles have an AR of 0.5 and the test pattern appears slightly taller than square.

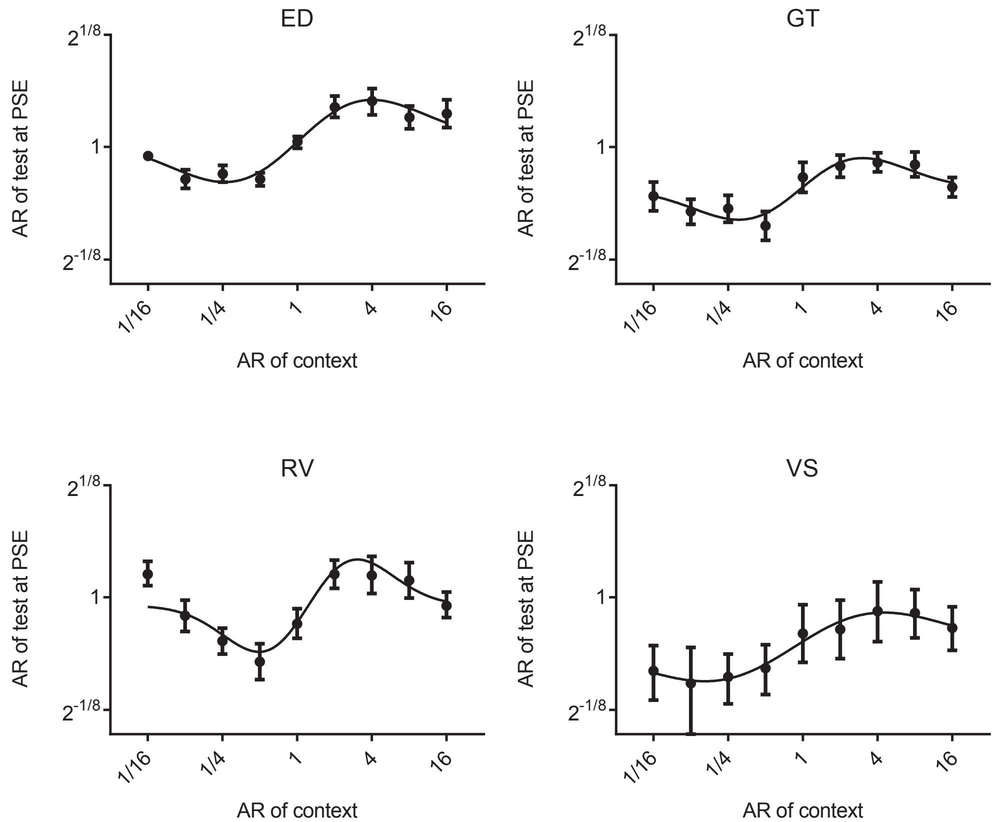

Fig. 2. Aspect-ratio (AR) of the test pattern at the point of subjective equality (PSE) of the height and width of the test rectangle plotted against the AR of the context rectangles. Error bars represent 95% confidence intervals. Both axes of the plots are logarithmic.

equality (PSE) between the perceived side lengths of the test pattern in the horizontal and vertical dimensions.

3. Results

The ARs that the observers perceive as square are plotted against the AR of the context rectangles in Fig. 2.

The fits to the data shown in Fig. 2 are of the following function:

$$ln(Y) = -ln(A)\left(\frac{1}{\sigma^2}\right)ln\left(\frac{X}{X_0}\right)e^{-\left(\frac{\left(ln\left(\frac{X}{X_0}\right)\right)^2}{2\sigma^2}\right)} + ln(Y_0) \quad (1)$$

The function is the first derivative of a Gaussian (D1) function with the dependent and independent variables being the log of the AR of the test rectangle when it is perceived to be square ($ln(Y)$) and the log of the AR of the context rectangle ($ln(X)$) respectively. The free parameters in the fit are A, σ, X_0, and Y_0. Parameter A determines the amplitude of the D1 function and σ the width. Parameters X_0 and Y_0 specify the position of the point of inflection of the D1 function; X_0 returns the AR of the context when its effect is zero and Y_0 the AR of a rectangle that an observer would perceive to be square when the context has no effect. The size of the effect of the context at a particular point on the function is given by the ratio between Y and the value of Y_0.

The geometric means of X_0 (and 95% CIs) and Y_0, across the four observers, were 1.008 (0.790, 1.285) and 0.982 (0.951, 1.015) respectively, consistent with a context AR of 1, a square context, having no effect on the perceived AR of the test stimulus. The parameter σ determines where the peaks of the function occur, with the second derivative of Eq. (1) equal to zero, indicating peaks, when $ln\left(\frac{X}{X_0}\right) = \pm\sigma$. If we assume that X_0 is 1, as estimated above, then the geometric mean of the values of σ, which is equal to 1.244 (0.829, 1.867) across the observers, places the strongest illusion where the context rectangles have ARs of 3.469 (2.291, 6.469) and 0.288 (0.436, 0.155). These mean maxima compare with maxima for AR aftereffects at ratios of 6.8 and 0.15 (Dickinson et al., 2017). However there is substantial variation across individuals and for the only individual common to this study and that investigating AR aftereffects (ED) the widths of the functions are similar. For observer ED the peak amplitudes of the function describing the AR illusion are at factors of 3.928 (2.948, 6.253) and 0.255 (0.156, 0.339) and those of the function describing the AR aftereffect are at factors of 5.197 (4.446, 6.080) and 0.192 (0.164, 0.225).

4. Discussion

The results suggest the existence of a previously unreported spatial context effect of AR analogous to the AR aftereffect. The effect might be considered an illusion introduced by AR context. Moreover, the spatial context effect is repulsive and increases to a maximum and then decreases as the difference in AR is increased between the context and test rectangles, in a manner that is similar to that reported for the AR aftereffect (Dickinson et al., 2017). This pattern of results, when attributed to aftereffects, is taken to be indicative of a multi-channel based encoding of the stimulus property that is being adapted (Clifford, Wenderoth, & Spehar, 2000; Dickinson, Harman, Tan, Almeida, & Badcock, 2012; Tang, Dickinson, Visser, & Badcock, 2015). In such an encoding model, each channel is assumed to be sensitive to a limited range of that property, with a sensitivity that peaks at the channel's preferred value for the property. When a particular channel is activated, its sensitivity is reduced through adaptation, diminishing its response to subsequently experienced stimuli to which it is tuned. The response of a population of channels that are collectively sensitive to the whole range of the property in question is, therefore, biased by the previously experienced stimulus. The centroid of the response of the population of channels is displaced away from the adaptor, resulting in the repulsive aftereffect.

The model described above is similar in concept to models proposed to describe the tilt aftereffect. A simple multi-channel model of the tilt aftereffect was shown to predict the relative magnitude of the tilt aftereffect over the whole possible range of orientation differences between adaptor and test lines (Dickinson et al., 2012). Individual channels of the model had a Gaussian orientation sensitivity profile and were assumed to be reduced in sensitivity in proportion to the degree to which they were stimulated by the adaptor. The perceived orientation of the test line is then predicted by the collective response of the population of channels to the test line. In the model the response of each channel is represented by a vector. The length of a vector indicates the strength of response to the test line and the direction the preferred orientation in the channel the vector represents. The perceived orientation is predicted by the direction of the sum of the vectors representing the activities of the whole population of orientation selective channels. Such a model was first proposed to model directions (Georgopoulos, Kettner, & Schwartz, 1988; Georgopoulos, Schwartz, & Kettner, 1986) and because a line is self-similar after rotation by 180° the model required adjustment to accommodate it to the representation of orientation. The responses of the orientation-selective channels were represented in a double angle space where 180° of rotation was mapped onto a two-dimensional space. In such a space perpendicular lines are represented by vectors pointing in opposite directions (Clifford, 2002). This vector model of the tilt aftereffect essentially returns a centroid for the perceived orientation but accommodates its periodic nature with lines repeating their orientation after each 180° rotation.

The tilt aftereffect describes a D1 function of orientation difference between adaptor and test lines (Dickinson et al., 2010). The same D1 relationship is seen between the log of the AR aftereffect and the log of the ratio between ARs which prompted Dickinson et al. (2017) to propose a multi-channel model comprised of channels with log-Gaussian sensitivity profiles to AR, distributed at exponentially increasing intervals. The perceived AR is then given by the centroid of the population response of this bank of channels and is repelled away from the AR of an adaptor. Logically the same bank of channels must signal the AR of the test pattern surrounded by context rectangles and the same D1 relationship is seen for the AR illusion in this study, suggesting that the channel sensitivities are modified in a similar manner. Here we propose that inhibitory lateral connections in the visual cortex exist between neurons that represent AR sensitive channels with the same preferred AR, as they do for many other stimulus properties (Blakemore, Carpenter, & Georgeson, 1970; von Békésy, 1967). This immediately leads to analogous results for the temporal and spatial context effects which might be generalized across mechanisms responsible for the encoding of orientation, size and AR.

The aftereffects and illusions described above can be isolated in psychophysical experiments by judicious choices of simple stimuli. In natural scenes, however, they will interact in ways that conceal the effects of individual components. Perceived properties of the visual field will depend on the spatio-temporal context of local areas, and instantaneous perception of the world will be subject to a field of combined local effects. Local changes in perception will have the greatest effect on downstream visual processing when they represent components of a larger whole. The perceived shape of a continuous closed path, for example, can be radically changed by small systematic changes in perceived orientation propagated around the path (Dickinson et al., 2010; Dickinson et al., 2012; FRASER, 1908).

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