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# Reexamining Visual Orientation Anisotropies: A Bias Towards Simple Horizontal Stimuli on Temporal Order Judgments

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## Abstract

Although not currently a widely accepted notion, evidence suggests an anisotropy between horizontal and vertical orientations in visual processing. While there is evidence of an early neurological bias due to a greater number of cortical neurons tuned to the horizontal orientation, recent behavioral evidence suggests a “horizontal effect”, where performance for broadband horizontal stimuli is *worse* compared to vertical and oblique. Importantly however, this effect has only been observed for complex stimuli and is speculated to counterbalance for the greater occurrence of horizontal stimuli in the environment. In this experiment, we used a staircase temporal order judgment task in three spatial configurations (horizontal, vertical, and both) to test for 1) a bias towards either horizontal or vertical simple stimuli, and 2) whether performance would vary across different planes of stimuli presentation. A bias towards horizontal stimuli was observed, but only when presented in the horizontal plane. Theoretical implications are discussed.

**Keywords:** Horizontal bias; visual processing; anisotropy, stimulus orientation; temporal order judgment

## Introduction

Research has shown that in humans as well as many other species, visual (and tactile) stimuli are processed differently depending on their orientation. One of the more commonly observed biases in visual perception is a phenomenon termed the “oblique effect”, where stimuli presented in an oblique orientation are usually processed worse (i.e., in speeded detection, identification, resolution acuity and contrast sensitivity tests) than stimuli presented in the horizontal or vertical position (Appelle, 1972; Essock, 1980; for tactile, see Essock, Krebs, & Prather, 1997). Crucially, this phenomenon operates on at least two different levels. First, it has been linked causally to lower level vision, where it is attributed to differences in the number of cortical neurons in V1 tuned to stimulus orientation (Anzai, Bearnse, Freeman, & Cai, 1995). Secondly, the effect also appears to be manifested in higher level cognitive processes such as memory, learning, and perception (for review, see Essock, 1980). The distinction between these two levels has in fact led to their classification as Class 1 and Class 2 oblique effects, respectively (Essock, 1980).

Apart from the well known oblique effect, studies that have attempted to compare anisotropies of horizontal and vertical orientations themselves against each other may not

have done so carefully (Hansen & Essock, 2004). It is worth noting that the current prevailing viewpoint is that horizontal and vertical stimuli are treated equally at the physiological level. Notwithstanding this dogma, there is considerable evidence suggesting that there is more neural circuitry in the visual cortex devoted to processing horizontal contours than vertical contours (Chapman & Bonhoeffer, 1998 (Figs. 1 and 2); Chapman, Stryker, & Bonhoeffer, 1996 (Figs. 1 and 2); Coppola, White, Fitzpatrick, & Purves, 1998; Mansfield, 1974; Mansfield & Ronner, 1978; Tiao & Blakemore, 1976). For instance, a study examining a large database of neurons in the cat’s striate cortex found that the largest population of cells are activated by orientations close to the horizontal position (Li, Peterson, & Freeman, 2003). Accordingly, it is curious that such a horizontal over vertical preference has not correspondingly been observed in behavioral tasks.

In fact, and despite the seeming neurological advantage for processing stimuli in the horizontal orientation, a study by Essock, DeFord, Hansen, and Sinai (2003) recently found diminished behavioral performance for horizontally presented stimuli (termed the “horizontal effect”). Furthermore, with complex “realistic” stimuli, they found that perceived orientation for broadband spatial content using horizontal, vertical, and oblique gratings was actually lowest for horizontal gratings, while oblique was instead seen best—a result seemingly contrary to the oblique effect, but solely at face value since the horizontal effect only appears to operate on complex stimuli. Interestingly, they explain these robust effects as being possibly due to a “whitening” mechanism that decreases the saliency of horizontal stimuli (which is argued to be most prevalent in natural scenes), thereby increasing the saliency of other broad-spectrum objects (such as predators, for instance).

Further research by Hansen and Essock (2004) replicated these findings in an experiment that used both simple and more complex “realistic” gratings. The classic “oblique effect” was seen with the simple gratings, whereas a “horizontal effect” (similar to Essock et al., 2003) was observed with the complex gratings. Additionally, the authors conducted an aggregate analysis of various natural scenes and found the prevalence of stimuli orientation in these scenes to be most prevalent in the horizontal orientation, then vertical, with the least prevalent being

oblique. They speculated that the horizontal effect may be a compensatory filter that at some level balances out for the greater abundance of such stimuli in the environment.

Hence, there appears to be evidence for both a bias towards, and a bias against horizontal oriented stimuli. That is, evidence at the physiological level suggests that the greater number of neurons tuned to horizontal orientations may lead to a bias in favor of horizontal detection. On the other hand, evidence also implicates the existence of a filter that may operate correctively against a bias towards greater occurrences of horizontal stimuli in the environment.

In light of these somewhat varying (but not mutually exclusive) viewpoints, several questions become relevant to the discussion. One is whether this “horizontal effect” is robust across all levels of perceptual processing. Recall that thus far the horizontal effect has only been observed with complex stimuli, therefore it is important to explore whether the same mechanism operates with simple stimuli, or if instead this mechanism only selectively operates in more complex “natural” scenes—as has been demonstrated in at least two studies (Essock et al., 2003; Hansen & Essock, 2004). Another issue is that, if this horizontal effect is somehow related to the prevalence of horizontal stimuli in natural scenes, might behavior change when presented with experimental layouts which contain more or less horizontal elements, and which are also holistically setup in a horizontal or vertical manner? Lastly, given that there appears to be a neurological bias towards detection of horizontally oriented stimuli as compared to vertically oriented (which to our awareness has never been demonstrated on behavioral measures), the question remains whether such a bias could in fact be detected at a behavioral level using simple stimuli? To better answer these questions, we designed an experiment consisting of a behavioral temporal detection task to test whether this bias exists with simple stimuli, using different experimental spatial layouts that contain varying elements of horizontal and vertical orientations.

The temporal order judgment task (TOJ) is an established psychophysical tool designed to assess the temporal processing of successively presented items. The task requires participants to determine the correct order of successively presented stimuli, and allows for two measures of perceptual processing to be calculated: the just noticeable difference (JND), and the point of subjective simultaneity (PSS). The former is a measure of the resolution or threshold of temporal discrimination, while the latter is the time in which one stimulus can be presented before the other such that they are still perceived as occurring simultaneously. Therefore, if a bias towards horizontal stimuli were to be observed, for instance, the PSS scores would indicate that the vertical stimuli must precede the horizontal (by a specific amount of time) for them to be perceived as occurring simultaneously.

It is worth noting that since humans are generally proficient at temporal discrimination (Hirsh & Sherrick Jr, 1961), the TOJ task is well suited for detecting small biases

in orientation processing. That is, using such a task would leave room for less error from extraneous variables such as task difficulty and interference from other cognitive processes that may come into play with other more complex stimuli and tasks.

For these reasons, the TOJ task appears to be particularly well suited for assessing threshold detection differences between horizontally and/or vertically presented stimuli. Subsequently, and to the best of our knowledge, this is the first time an adaptive step-function TOJ task has been used to investigate the anisotropy of stimulus orientation while also employing an adaptive staircase approach and the use of different experimental spatial configurations. The staircase approach will ensure that the majority of trials will occur at or close to threshold level.

In light of 1) existing neurological evidence for a horizontal bias, and 2) the lack of evidence for a countering “horizontal effect” for simple stimuli (the effect has only been observed for complex stimuli), we hypothesize that participants should be biased towards detecting horizontal stimuli better than vertical, although it is unclear whether the magnitude of this bias will be detectable here.

## Methods

### Participants

Participants ( $n = 33$ ; mean age =  $23 \pm 4$ ; 24 females) were recruited from undergraduate courses at the University of Hawaii at Manoa, and were offered course credit for their participation. All participants were naïve as to the purpose of the experiment and had normal or corrected to normal vision. Ethical approval was obtained from the University’s Committee on Human Subjects.

### Stimuli

Visual stimuli were presented on a 20”, Intel Core2Duo iMac using Bootcamp and DMDX software (Forster & Forster, 2003). Observers sat approximately 60 cm from the display. The targets in all tasks were vertical and horizontal lines that occurred within placeholder squares ( $2^\circ$  wide). These placeholders flanked a fixation cross in one of three different layouts (see Figure 1). These layouts corresponded to the three different tasks in this experiment.

### Procedure

Throughout each trial, the fixation cross and the two (in the horizontal and vertical layouts) or four (in the combined layouts) placeholders would remain on the display (see Figure 2). A target (either horizontal or vertical line, equiprobably) would appear in one of the place holders (also equiprobably) for a specified stimulus onset asynchrony (SOA) interval, followed by the other stimulus in the opposite place holder. The stimuli remained on the screen until participants then made an unspeeded forced choice response on the keyboard to indicate either “horizontal” or “vertical” first responses. An adaptation of Stelmach and Herdman’s (1991) step-function procedure was used to

determine the SOAs for each trial. Each trial began with an SOA of 167 ms. Depending on whether a correct or incorrect response was made, the SOA would respectively increase or decrease (by 16.7 ms) on the next trial. The experiment terminated after a total of 12 correct/incorrect reversals occurred.

In all three tasks, participants were first presented with onscreen instructions followed by a short sequence of practice trials, with accuracy feedback directly appearing after each trial. The experimenter monitored completion of the practice trials and ensured that participants understood the task requirements (repeating the practice session if necessary). Target presentation location (i.e., left, right, up or down) and stimuli order (e.g., horizontal or vertical line first) were randomized, as was the order of experimental tasks (i.e., horizontal, vertical, and combined) for each participant.

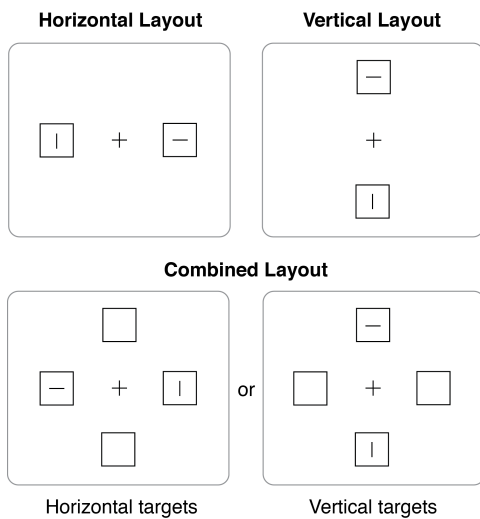


Figure 1. The three TOJ configurations. Each participant was tested on all three configurations. Note that on each trial in the combined layout, the task could occur on either the horizontal or vertical plane.

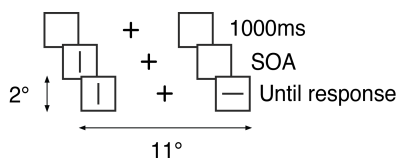


Figure 2. Example stimuli and time course for the TOJ task (horizontal layout displayed here; similar sequence occurred for the other layouts).

## Results

The results from the TOJ task can be analyzed to determine the point of subjective simultaneity (PSS). The PSS is the point in time in which one stimulus can be presented before the other such that they are still perceived as being

simultaneous. Note that this measure is usually expected to fall at 0 ms (or close to it, unless there is a bias in response). Additionally, the minimum amount of time that must separate two events such that they are still accurately perceived as occurring successively (and not simultaneously) can be measured. This is referred to as the just noticeable difference (JND) and is essentially a measure of the resolution or threshold of temporal discrimination. For this study we are more interested in the PSS than the JND, as the PSS can provide a measure of bias towards horizontal or vertical stimuli.

The calculation of both the PSS and JND was based on approaches used by previous research (for examples of other studies using similar methodologies and analyses, see Spence, Baddeley, Zampini, James, & Shore, 2003; Stelmach & Herdman, 1991). To begin with, the data from each of the three tasks were pooled together according to layout. The average ratio of responses "horizontal line first" was then plotted as a function of the time in which the horizontal line preceded the vertical line. For TOJ tasks, response rates typically follow a sigmoidal curve, from which data can be fit using the following logistic function:

$$f(x, a, b) = \frac{1}{1 + \exp(-(x - a)/b)}$$

where the response rate is mapped as a function of the SOA ( $x$ ), with two estimated parameters of central tendency ( $a$ ) and slope ( $b$ ; see C. Spence, et al., 2003).

Data was fit to this equation by minimizing the weighted sum of squares to obtain parameter estimates for  $a$  and  $b$ . The PSS, or SOA at which the participants considered the two stimuli to be simultaneous, corresponds to parameter  $a$ . The JND, or smallest interval between two stimuli giving a correct judgment probability 75% of the time, is directly related to parameter  $b$  (analogous to the slope of the central portion of logistic function). Here the relationship is that a steep slope will result in a smaller JND, and a shallow slope in a larger JND.

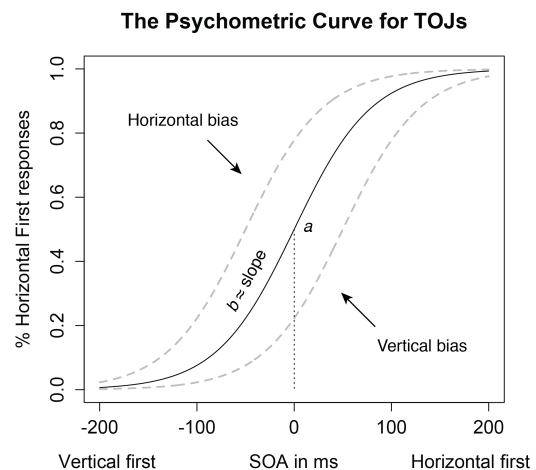


Figure 3. A typical TOJ response curve. Any bias in performance would be observed as a lateral shift of the curve, and correspondingly, the PSS score.

Confidence intervals (95%) for each group statistic were calculated using a parametric bootstrap method with 999 replications (for a similar bootstrap method employed in a TOJ study, see Azañón & Soto-Faraco, 2007; for an overview of the bootstrap, see Efron & Tibshirani, 1993). Given the unique nature of our dataset, we used a parametric bootstrap resampling approach for the statistical analyses due to particular benefits over more traditional means. That is, due to the varied number of trial observations and different response patterns resulting from the adaptive staircase paradigm, each individual's data points could vary significantly, and fitting the logistic function individually did not always converge or yield meaningful estimates. Thus, pooling data from all participants in each layout allowed for a better distribution of scores across all SOAs for the logistic fit from which we were able to extrapolate the overall PSS and JND values for each task using the above functions, and to subsequently estimate population parameters using bootstrapped confidence intervals<sup>1</sup>.

Furthermore, and in order to determine whether a PSS score, or bias towards a particular orientation was significant, we compared the results from each layout to a logistic function with identical parameters and characteristics, with the exception that the PSS was centered on 0 ms. This effectively allowed us evaluate the null hypothesis of whether the bias was significantly different from zero<sup>2</sup>.

### PSS scores

**Horizontal layout.** In the horizontal only configuration, there was a significant bias towards responding horizontal first ( $p < .05$ ). The magnitude of the PSS bias was 7ms, meaning that for horizontal and vertical lines to be perceived as occurring simultaneously, vertical lines had to precede horizontal lines by 7ms on average (CI = 1 to 12ms).

**Vertical layout.** In the vertical only configuration, the PSS was not significantly different than zero ( $p = 0.3$ ), with a 2ms bias towards horizontal first responses (CI = -3 to 8ms).

**Combined layout.** In the combined layout, when pooling the data across layouts, there was a significant PSS bias towards responding horizontal line first ( $p < .05$ ). The magnitude of this bias was 6ms (CI = 1 to 10 ms).

As the combined layout consisted of trials where the horizontal and vertical targets only occurred in either the horizontal or vertical plane (see Figure 1), we conducted a further analysis between these two sub-types to determine any differences in performance within the layout.

The PSS for the horizontal trials was significantly biased towards the horizontal stimulus ( $p < .05$ ). The magnitude of

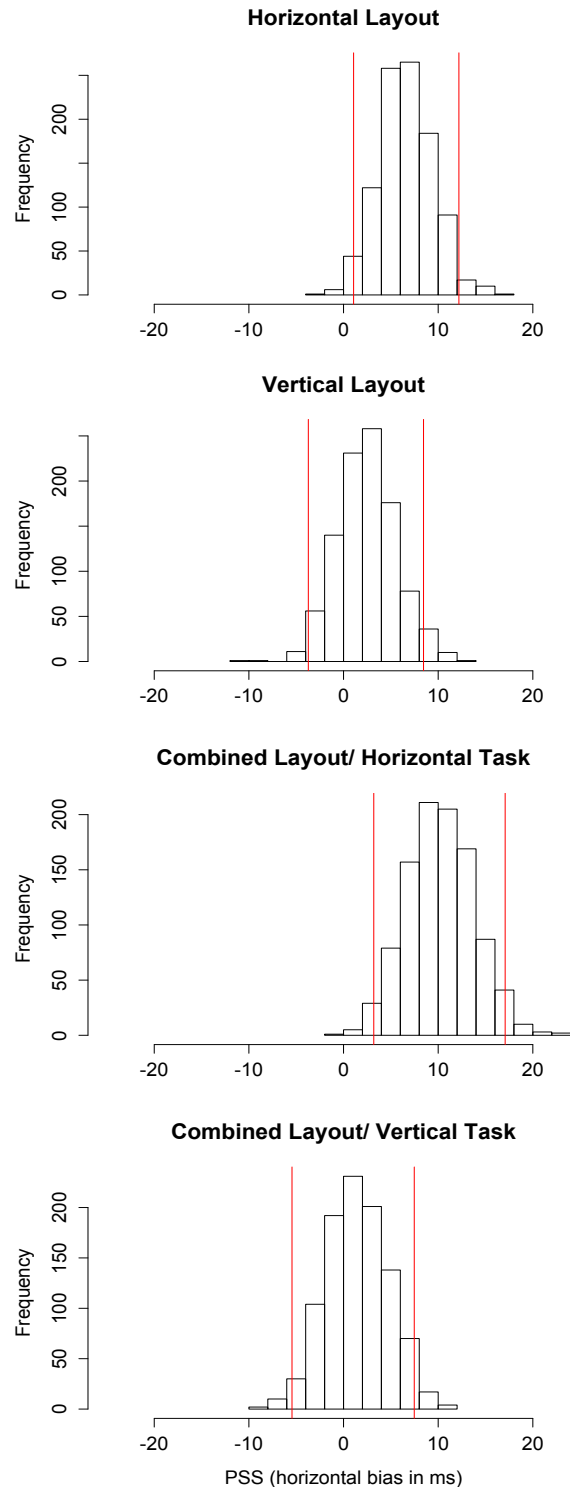


Figure 4. Parametric bootstrap resamples for each configuration (red lines denote 95% confidence intervals).

Positive PSS scores reflect a bias towards horizontal stimuli, whereas negative scores reflect a bias towards vertical. A zero PSS score would indicate lack of bias for either type of stimuli.

<sup>1</sup> Note that there is a growing consensus that certain exploratory techniques such as confidence intervals may be as useful as confirmatory ones (for a review, see Loftus & Masson, 1994). For details on bootstrap CIs, see Efron & Gong (1983).

<sup>2</sup> Given the existence of prior evidence for a bias towards horizontal orientations over vertical (see Introduction), a bootstrap comparison analogous to a one tailed  $t$ -test was used throughout.

this bias was 10ms (CI = 4 to 17 ms). In contrast, the PSS for the vertical trials not significantly different than zero ( $p = 0.4$ ) with a 1ms bias towards horizontal stimulus (CI = -4 to 7ms).

Given that both trials occurred within the same task configuration, we also ran a direct parametric bootstrap comparison test between the horizontal and vertical trials, and found that horizontal biases between the two trial types, as reflected by the magnitude of the PSS shifts (10ms vs 1ms) was significantly different ( $p < .05$ ).

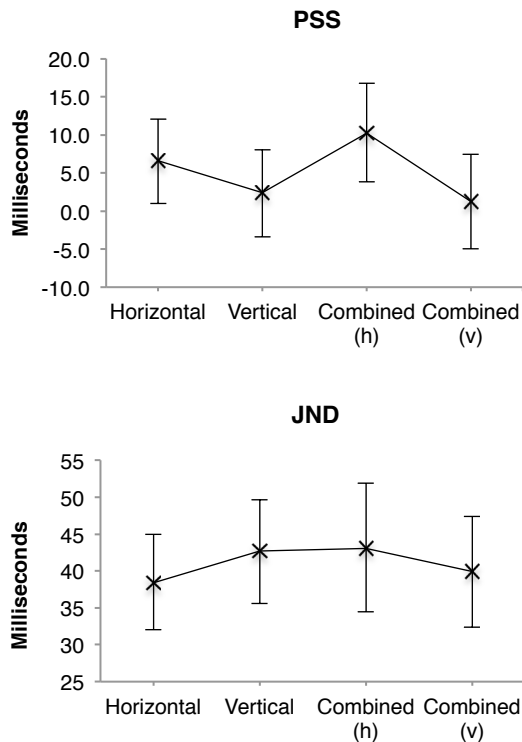


Figure 5. PSS (positive values indicate bias towards horizontal stimulus; negative towards vertical) and JND scores across the three tasks, with 95% confidence intervals.

### JND scores

Across all conditions, JND scores were 40ms on average, and as expected, scores did not significantly vary (all  $p > 0.1$ ). This confirms that the detection thresholds were similar in all configurations (see Figure 4), and that PSS differences across horizontal and vertical tasks were unlikely to be caused by extraneous variables such as the difficulty levels of the tasks.

## Discussion

Several novel findings were seen in this experiment. To our awareness, this is the first empirical investigation to examine performance among thousands of trials (the majority of them near threshold level SOAs) in a TOJ task to explore orientation bias between horizontal and vertical simple stimuli. We believe that this unique setup may have

allowed for the detection of orientation anisotropy between horizontal and vertical stimuli. Accordingly, an average bias of 9ms towards horizontal lines was observed during a horizontal task, suggesting that the vertical line must be presented on average 9ms before the horizontal line for simultaneity to be perceived. Thus, all things being equal, the horizontal orientation is preferred and appears to be processed more efficiently. Furthermore, this anisotropy was non-symmetrical in nature. That is, even in counterbalanced configurations with vertical placeholders, no similar bias towards vertical lines was observed (in fact, a very slight bias of 2ms on average towards horizontal lines was still observed in the vertical tasks, although this was not significant).

These findings are important for at least two reasons. First, in contrast to the prevailing view of equal treatment by the visual system for horizontal and vertical orientations, there is evidence that there may actually be an anisotropy between horizontal and vertical orientations. In fact, a bias towards the horizontal orientation has been observed at the neurological level in the visual cortex of several non-human animals (Chapman et al., 1996; Coppola et al., 1998; Li et al., 2003; Mansfield, 1974; Tiao & Blakemore, 1976) with visual systems expected to be ontogenetically analogous to humans. Thus our findings are the first to show a bias towards horizontally oriented simple stimulus, which speculatively may align with such findings of larger observed proportions of horizontally tuned cortical neurons. As stated by Essock et al. (2003), this result may not have been observed in the past due to the difficulty in obtaining large and unbiased samples. The use of the adaptive staircase design and parametric bootstrap analysis used here, however, offers a way of addressing this problem. Nevertheless, it is curious finding that we only observed this bias in the presence of a horizontal “plane”.

The fact that similar biases were only seen when performing the horizontal task (both in the horizontal and combined layouts) may suggest two possibilities: first, that the process of performing a horizontal task may facilitate the horizontal bias. The second possibility is that the process of performing a vertical task may inhibit the horizontal bias. Whether facilitation or inhibition (or both) is/are responsible for these results is beyond the scope of this paper. However, given the fact there we observed small (but non-significant) biases towards horizontal stimuli even for vertical tasks, we speculate that the inhibition argument may carry more weight.

Moreover, these results may dovetail with findings relating to the prevalence of horizons in natural scene layouts. Indeed, much of the world is sprawled out in a horizontal fashion due to the constraint of gravity, and it is thus conceivable for organisms to both have evolved visual systems that differentially process horizontal configurations for greater efficiency, and also to behaviorally adapt to such regularities in the natural world. Indeed, several examinations have been conducted on the statistical frequency of visual orientations in both naturalistic and

man-made environments, and have found greater occurrences of horizontally oriented stimuli (Baddeley & Hancock, 1991; Hansen & Essock, 2004; Keil & Cristóbal, 2000). To further add to this picture, learning may also play a vital role, as there is evidence of cross-cultural differences in visual anisotropies that can not be accounted for by mere exposure to a *carpentered* environment (Timney & Muir, 1976).

Interestingly, our findings can also be seen in a way to supplement the “horizontal effect”, which has been observed with complex broadband stimuli (Essock et al., 2003; Hansen & Essock, 2004). Specifically, in these studies the evidence for a “whitening” of (i.e., bias against) horizontally perceived orientations only occurred when complex broadband stimuli were used. From this study, we have confirmed that not only does the “horizontal effect” not apply to simple stimuli (lines), but also revealed the opposite: that in fact a bias towards simple horizontal stimuli can occur under conditions when a horizontal plane or task is present. Consequently, it is clear that comprehensive theoretical accounts of visual processing must ultimately reconcile and take into account these different phenomenological findings and the respective mechanisms responsible for such multi-level anisotropies.

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