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Mind-craft: Exploring the relation between "digital" visual experience and orientation in visual contour perception

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MIND-CRAFT:

EXPLORING THE RELATION BETWEEN "DIGITAL" VISUAL EXPERIENCE AND ORIENTATION IN VISUAL CONTOUR PERCEPTION

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BY

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ABSTRACT

Visual perception depends fundamentally on statistical regularities in the environment to make sense of the world. One such regularity is the orientation anisotropy typical of natural scenes; most natural scenes contain slightly more horizontal and vertical information than oblique information. This property is likely a primary cause of the "oblique effect" in visual perception, in which subjects experience greater perceptual fluently with horizontally and vertically oriented content than oblique. However, recent changes in the visual environment, including the "carpentered" content in urban scenes and the framed, caricatured content in digital screen media presentations, may have altered the level of orientation anisotropy typical in natural scenes. Over a series of three experiments, the current work aims to evaluate whether "digital" visual experience, or visual experience with framed digital content, has the potential to alter the magnitude of the oblique effect in visual perception. Experiment 1 established a novel eye tracking method developed to index the visual oblique effect quickly and reliably using no overt responding other than eye movements. Results indicated that canonical (horizontal and vertical) contours embedded in visual noise were detected more accurately and quickly than oblique contours. For Experiment 2, the orientation anisotropy of natural, urban, and digital scenes was analyzed, in order to compare the magnitude of this anisotropic pattern across each image type. Results indicate that urban scenes contain exaggerated orientation anisotropy relative to natural scenes, and digital scenes possess this pattern to an even greater extent. Building off these two results, Experiment 3 adopts the eye tracking method of Experiment 1 as a pre- post-test measure of the oblique effect. Participants were eye tracked in the contour detection task several times before and after either a "training" session, in which they played Minecraft (Mojang, 2011) for four hours uninterrupted in a darkened room, or a "control" session, in which they simply did not interact with screens for four hours. It was predicted, based on the results of Experiment 2, that several hours of exposure to the caricatured orientation statistics of the digital stimulus would suffice to alter the magnitude of participants' oblique effect, as indexed by the difference in the post-test relative to the pre-test. While no accuracy differences were observed in this primary manipulation, detection speed for canonical contours did alter significantly in the Minecraft subjects relative to controls. These results indicate that the oblique effect is quite robust at the level of visual contours and is measurable using eye tracking, that digital scenes contain caricatured orientation anisotropy relative to other types of scenes, and that exposure to naturalistic but caricatured scene statistics for only a few hours can alter certain aspects of visual perception.

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General Introduction

Underlying psychophysics is the notion that some systematic mapping exists between physical changes in the world and changes in corresponding perceptual experiences. Modern vision research suggests that the human visual system makes nearly optimal use of proximity and collinearity statistics of natural scenes during contour interpolation (Geisler, Perry, Super, & Gallogly, 2001). Another, even clearer relation between nature and perception can be found in the greater amount of human visual cortical tissue dedicated to processing horizontally and vertically oriented stimuli, relative to oblique stimuli (Furmanski & Engel, 2000). This “orientation anisotropy” is also present in nature. Natural scenes contain modest orientation anisotropy (H>V>>O). In perception, the interaction of these two properties – one neural and one external - begets the “oblique effect” (Appelle, 1972), or the finding that humans are generally better at processing horizontal and vertical information than oblique information. This is true across a variety of tasks and putative processes, including basic visual acuity for simple objects and Gabor patches (Campbell, Kulikowski, & Levinson, 1966; Heeley & Timney, 1988; Higgins & Stultz, 1965).

Yet the nature encoded by the sensory systems of many extant humans is swiftly changing. Human cultural evolution far out-paces biological evolution in its rate of change, and the visual and social world perceived by modern humans is far different from the one our perceptual and motor systems “expect”. Modern technological advancement manifests this with increasing acceleration; we are changing our environment much faster than our biological predispositions. A simple example of this mismatch manifested in early psychology research when Bonte (1962) replicated and extended earlier (but less rigorously established) findings indicating that hunter-gatherer groups in Africa were not as susceptible as to the “Müller-Lyer” illusion (see Figure 1). In its most common version, this illusion presents the viewer with two lines, one a stylized arrow with two pointers and the other possessing two “V’s” attached to its endpoints (see Figure 1). Western subjects typically see the latter, V-flanked line as longer than the stylized arrow.

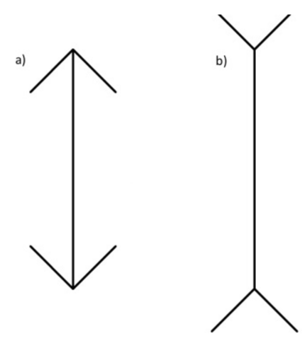


Figure 1. The Müller Lyer Illusion. Most Westerners, but not African tribesmen, see the vertical line in a) as shorter than the vertical line in b), despite the two lines being the same length.

Similar cultural/developmental differences have been found regarding the oblique effect. Annis and Frost (1973) compared the pattern of results obtained from a sample of Cree Indians and a sample of Canadians living in modern conditions on a task indexing visual acuity for orientation differences of simple line gratings. The Euro-Canadian subjects manifested the typical oblique effect, with greater acuity for horizontal and vertical gratings than oblique, while the Cree subjects did not. The authors attributed this to the drastically different visual environments the two groups experienced during ontogeny. In a different study, a smaller but still significant difference was found in a comparison of Chinese and Caucasian infants and adults exposed to different architectural and writing systems during development (Fang, Bauer, Held, & Gwiazda, 1997). No difference was found between groups of infants, suggesting baseline equivalence early in ontogeny, but the adults did show a difference in the magnitude of the effect. This difference was driven by an increased sensitivity to oblique stimuli in the Chinese subjects, which was speculatively attributed to their greater exposure to oblique lines in their environment.

While a number of factors likely contribute to these differences, the prevailing theory as to why these effects exist is that Western, educated, industrialized, rich and democratic - "W.E.I.R.D." people (Henrich, Heine, & Norenzayan, 2010) - live in a "carpentered" world (Segall, Campbell, & Herskovits, 1966). In sharp contrast to the savannah, grasslands, and temperate forests of our hunter-gatherer ancestors, our modern visual landscape contains many more Y and arrow junctions entailing relative depth relations at visual corners and edges, leading to the group-level differences in the illusion presented above. Similarly, the oblique effect is thought to be reduced in Cree Indians because their visual world contains more oblique information and less canonical (horizontal and vertical) information than the visual world of W.E.I.R.D. people. In other words, the environments in which subjects lived and grew up corresponded with tell-tale differences in perception.

It is worth noting that these results and others illustrate how most psychology experiments, with their limited samples and culturally-bound hypotheses, are less than fully representative of human nature. But for the W.E.I.R.D. humans experiencing this rapid environmental and cultural shift, it is also important to characterize the extent to which our perceptual systems adapt to these changes. Now our world is not just carpentered, it is *digital.* The ubiquity of television and traditional computing interfaces in contemporary culture, as well as the recent advent of tablet computers and smart phones, poses an interesting set of problems for the human cognitive system.

One way screen media affects perception is by acting as a sort of "sensory cheesecake". To the extent we evolved an attentional system designed to adaptively allocate resources towards salient cues in the environment, smart phones and HDTVs hijack this system and capture our attention like no other stimulus, like cheesecake to the palate designed only for detecting moderate sweetness as a source of nutrition. Part of the reason television and other screen media became so popular may be because of the mismatch between these media types and our evolved perceptual systems.

This is especially true during development, when evolved predispositions and the neural plasticity of youth facilitate the adaptive acquisition of knowledge. Despite a recurring American Academy of Pediatrics (1999, 2011) warning that children under 2 years old should not be exposed to screen media at all, many parents maintain that television - especially "educational" programs - can be beneficial for intellectual development (DeLoache et al., 2010; Rideout & Hamel, 2006). The appeal of screen media technology is evident in the statistics of early television viewing. In a 2005 study, Anderson and Pempek found that children aged 1½ years watched an average 2.2 hours a day, whereas children aged 3½ years watched 3.6 hours a day. This monotonic increase in viewing time apparently persists throughout childhood, during which time children are exposed to 4-5 hours of television and videogames per day, not counting cell phone use (Swing, Gentile, Anderson, & Walsh, 2010). More recent industry statistics suggest that approximately 20% of children between 2 and 5 years old can operate a smart phone application – a greater proportion than can tie their own shoes (AVG internal research). Of course, adults too live in a highly digital visual world. While peer-reviewed data about adult screen media exposure is hard to come by, an observational study by the Council for Research Excellence (2009) suggests that adults spend a significant portion of their days – between 5 and 8 hours on average- in front of the television, computer, and smart phone. Given the rapid pace of change in these technology domains, these statistics are almost certainly underestimating current usage patterns, especially with respect to smartphones and tablets.

Studies examining the accrued impact of usage on clinical outcomes are important for understanding broad population level patterns, but there is also the question of whether exposure to screen media causally effects perception and cognition. Most studies asking a version of this question focus either on action videogames (Dye, Green, & Bavelier, 2009; Boot, Blakely, & Simons, 2011) or children's television shows (Anderson, Bryant, Wilder, Santomero, Williams, & Crawley, 2000) and their impact on affect or cognition. Still, few utilize the games themselves as "training" modules and instead attempt to correlate overall exposure and perceptual/cognitive differences, though there are exceptions (e.g., Kristjánsson, 2013). Even the more rigorous investigations of this matter only speculate as to what physical or social features of the screens are causing the effects the researchers observe. Thus, the actual causal impact of screen media exposure on cognition and perception has been difficult to disentangle from the role of pre-existing differences predisposing individuals to differentially expose themselves to these media.

The general purpose of this dissertation is to expand this burgeoning field by exploring the influence of screen media presentations on basic visual perception. To do this, I will present and integrate several methods able to index the relation between the emerging digital subset of nature and human visual perception and learning. The three experiments to follow are aimed at modernizing research methods on the oblique effect in visual perception and leveraging these new methods to understand the impact of screen media exposure on visual perception. First, Experiment 1 will establish a new eye tracking task able to rapidly and reliably index the visual oblique effect. Then Experiment 2 will use image analysis to establish that screen media presents the viewer with extremely caricatured orientation anisotropy relative to nature and cityscapes. This is an important second step, as it would indicate that the digital visual landscape so ubiquitous in modern society may be capable of supporting an even stronger oblique effect than the carpentered visual landscape that preceded it. Once this is adequately established, Experiment 3 will combine these two approaches to test the extent to which the oblique effect changes after naturalistic exposure to caricatured orientation-level scene statistics. Using the most popular and best-selling screen media stimulus of all time as an ecologically valid "training" stimulus, I will compare the oblique effect obtained from eye tracking individual subjects before and after hours of screen media exposure. If adult perception alters to a significant extent after this training, not only will this indicate that our relation to our visual environment is more dynamic than commonly believed, it will also be an important proof of concept for developmental research, given both the ubiquity of screen-based applications for youth and the malleability of the developing brain.

Taken together, this research will add to the burgeoning field of work attempting to address the complex interplay between visual perception and the emerging digital world the modern human faces. If a single period of exposure to Minecraft (Mojang, 2011) on a screen in a dark room is sufficient to change the dynamics of orientation perception in the short term, it stands to reason that our visual systems and cognitive systems in general may reflect modern ecological changes more than previously believed. The following work attempts to bring psychophysical rigor and new methods to bear on contemporary questions about the interaction between the human mind and the increasingly digital world around it.

Experiment 1: A Novel, Quick, and Robust Eye Tracking Demonstration of the Visual Oblique Effect

Introduction

Object perception fundamentally depends on accurate and invariant representations of visual contours (Biederman, 1987). These contours bound objects and their shadows and otherwise serve a number of useful functions in human vision. Contours in nature (Geisler, 2008; Geisler & Perry, 2009; Geisler, Perry, Super & Gallogy, 2001) and the laboratory (e.g. Field, Hayes, & Hess, 1993; Kovács & Julesz, 1993; Mathes & Fahle, 2007) are often discontinuous, and so a considerable amount of research has considered the question of how the visual system performs the spatial integration necessary to link disparate elements of the same contour into a coherent and singular percept. The prevailing wisdom from psychophysical studies as well as neurophysiological investigations (Bosking, Zhang, Schofield & Fitzpatrick, 1997; Cass & Spehar, 2005; Gilbert, Das, Ito, Kapadia & Westheimer, 1996; Gilbert & Wiesel, 1989; Stettler, Das, Bennett & Gilbert, 2002) is that a plexus of horizontal interconnections between orientation columns in early visual cortex underlie this process. These long-range, sparse excitatory connections manifest prior expectations about proximity and orientation information in visual scenes, leading to Gestalt-esque perceptual heuristics of proximity and collinearity (shared orientation between contour elements) that guide contour integration (Loffler, 2008; Stettler et al., 2002).

Orientation in particular is an extremely diagnostic source of information in visual scenes, and humans use it nearly optimally (Geisler et al., 2001). Yet not all orientations are equal in terms of perception. Since Mach (1861) discovered that humans can more accurately place a parallel line next to a horizontal or vertical comparator line than an oblique line, research into the so-called "oblique effect" (Appelle, 1972) has investigated meridional anisotropy of visual perception. This is apparently an emergent property of post-sensory perceptual processing. In an early test, Higgins and Stultz (1950) showed that visual acuity varied as a function of the orientation of the test object, such that perception for canonical orientations was greater than oblique orientations, and that this was not reducible to idiosyncrasies of basic eye movements during viewing. Heeley and colleagues (1997) also showed that this effect is likely not explicable purely in terms of differential sensory encoding, by demonstrating that the slightly greater noise during early sensory encoding of obliquely oriented gratings is insufficient to explain the magnitude of perceptual oblique effects.

A likely physiological candidate for the origin of the perceptual oblique effect is cortical orientation anisotropy (Li, Peterson, & Freeman, 2003; Mannion, Mcdonald, & Clifford, 2010). Since Hubel and Wiesel (1968) it has been known that the striate and extra-striate cortex of highly visual mammals is organized into columns containing cells maximally sensitive to stimuli of particular orientations. More recent investigations using fMRI with humans (Mannion et al., 2010) and meta-analysis of cat neurophysiological data (Li et al., 2003) suggests at least two cortical mechanisms at play in the oblique effect. Mannion and colleagues (2010) show that more visual cortex is dedicated to processing canonical orientations than oblique. Li and colleagues (2003) also suggest an intracolumnar mechanism helping to drive this phenomenon. Modeling their enormous database of single-cell recording data suggested that the simplified linear response filter used to model simple cells fit oblique cell data better than canonical, such that canonical cells had a much greater (i.e. non-linear) response to their preferred orientation than oblique cells. This non-linear responsivity was paired with a tighter tuning curve as well, suggesting that horizontal cells tolerate less divergence from their preferred orientation than oblique cells. Westheimer (2003) adds further complexity to this admittedly simplified picture by showing that the oblique effect is general with respect to visual task, suggesting that the oblique effect may arise from a more distributed property of cortical processing (although he fails to address why these up-stream effects could not emerge from lower-level processing differences). Yet even in this more complicated characterization, Westheimer still interprets his findings as derived from early visual cortex, just not V1.

While the number of studies showing similar oblique effects is large and diverse, they are not without issues. Most tasks to date require either require overt responses or make experimental participation difficult by entrenching subjects in uncomfortable viewing conditions. The requirement for overt responses is especially troublesome for a number of reasons. First, if the oblique effect is a purely visual phenomenon, then its strength may be masked or artificially enhanced depending on how the visual system interacts with the other systems involved in task responding. For example, idiosyncrasies in how the hand holds a pencil during drawing may impact the degree to which an oblique effect is seen in a task in which subjects must draw lines of a similar orientation to a comparison line. Even more modern responding apparatus, like touchscreens or button boxes, suffer the lag of motor planning, which at least in certain populations may be an important caveat. This leads to a second concern about the necessity of overt responding in most tasks, that these tasks may have limited scalability across ages. Since different systems mature at different rates, it is clear that a mismatch between systems may skew results one way or the other.

This makes research into the origins of the oblique effect difficult, since little is known about the origins of the oblique effect beyond speculation about the role of natural scene statistics. We therefore set out to design a task capable of indexing the perceptual oblique effect quickly and robustly, and in a manner that requires no overt response. As a method, eye tracking fits these requirements well. The task I have developed is a contour detection task similar to those found in the primary literature (Field, Hayes, & Hess, 1993; Hipp, Dickerson, Moser, & Gerhardstein, 2014), with the main difference being that unlike all tasks in the literature to date, ours only requires fixation on the contour in order for successful detection. By embedding horizontal, vertical, and oblique (45 ° and 135 °) contours comprised of Gabor patches within noise also composed of equally densely distributed patches, I can test the degree to which each orientation automatically drives attentional allocation in a purely visual task.

Methods

Participants

Adults participants (*N*=15, *M*=6) were college students recruited via university channels and incentivized with class credit. Proper consent was obtained from all subjects. Following consent, participants' vision was assessed using a Snellen eye test, and all subjects exhibited normal or corrected-to-normal vision (20/20). If their vision was corrected to normal with contact lenses or glasses, they wore this correction during experiment participation.

Apparatus

A 120Hz SMI iView X remote eye-tracking system was used to collect gaze data. A 42" High Definition color LCD television (Samsung, 1920 x 1080 resolution) served as the viewing monitor for the experiment.

Stimuli

Practice and experimental "contour + noise" stimuli were created within MATLAB, using the Grouping Elements Rendering Toolbox (Demeyer & Machilsen, 2012), which itself relies upon the Psychophysics-3 Toolbox (Brainard, 1997). Standard deviation (σ) of the Gaussian component of the Gabor elements was set at 4 pixels. Spacing between Gabor elements is typically expressed in such stimuli as a multiple of λ, or the wavelength of an individual Gabor element (e.g. Kovács & Julesz, 1993; Hipp et al., 2014). In the present experiment, Gabor patch frequency was set to 0.08 cycles/pixel, the underlying sinusoid obscured by the Gaussian spanned 10 pixels, λ was set to 8 pixels, and spacing between contour elements was set to 50 pixels, .57° or 6.25λ. Patches were modulated from a neutral (50%) grey background.

Contours were comprised of six perfectly collinear Gabor patches, each of which fell on a linear path 270 pixels (4°) in diameter. Noise patches were randomly oriented about their central axis.

An equal number (*n* =20) of horizontal, vertical, 45°, and 135° contours were presented during each session.

Care was taken to include only images with contours not impinging on the image boundaries, and contours were equally likely to appear in each of the four quadrants of the screen around a 350 pixels by 350 pixels invisible exclusionary zone surrounding the center of the screen. Experimental stimuli were both presented for a maximum of 1000ms, and trials were concluded after 100ms of fixation accrued consecutively (these values were doubled for practice trials so subjects could acclimate to the task demands). Viewing distance was set to 200cm from the television display (25.6°), and lights were turned off except for the television. Only the television illuminated the subject area, as the experimenter computer was hidden from view by a barrier.

Four of the eight practice stimuli were made easier, such that relative noise density (D) was set to 2.0, entailing that the contour elements were twice as dense as the noise elements. This served to make the task trivially easy so that participants could be introduced to the general method of the experiment. Following four trials with $D = 2.0$, four more practice trials with $D = 1.0$ were presented. Everything else about the practice stimuli was identical to the experimental stimulus conditions described above. For the 80 experimental trials, $D = 1.0$, ensuring that trials were as easy as possible while still requiring subjects to use visuospatial integration to find the contour, which would not be the case at greater values (Kovács & Julesz, 1993). See Figure 2 for an example stimulus image.

Procedure

Immediately prior to participation, and after reporting they had acclimated to the darkness of the room, subjects were calibrated using iView calibration software. Calibration was repeated until a minimum criterion accuracy of 1.5° in both the X and Y dimensions was met or exceeded.

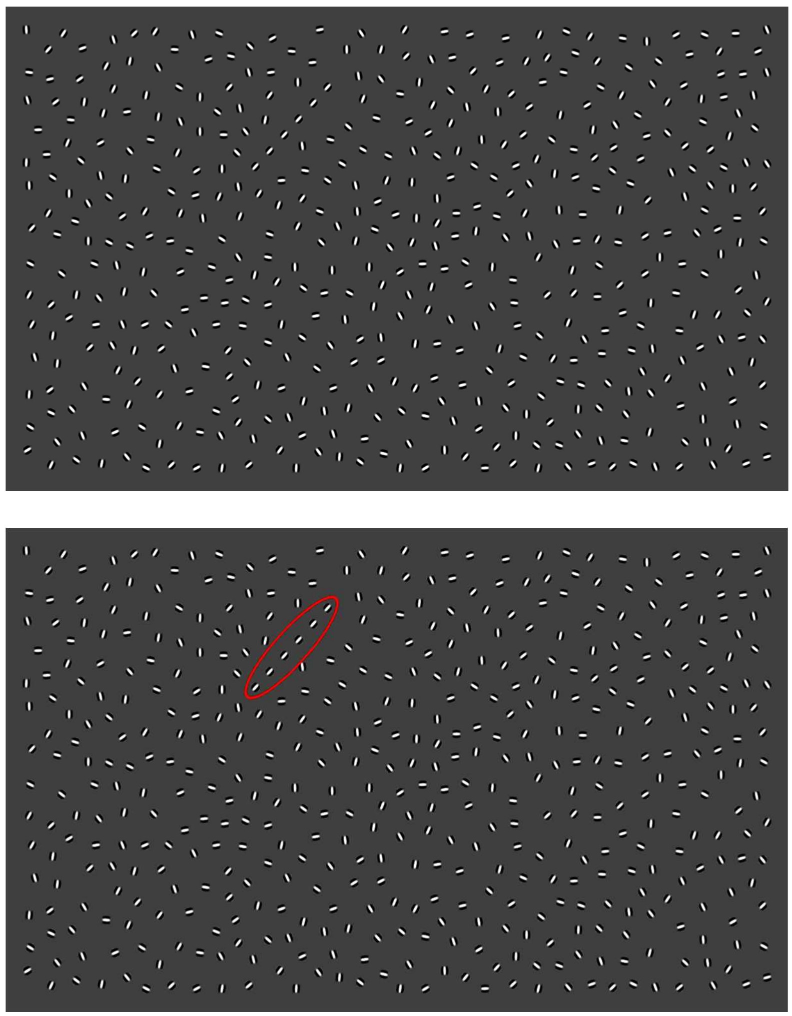


Figure 2. An example contour detection stimulus. An oblique contour is embedded in visual noise. The bottom image shows the same stimulus with the contour highlighted in the manner participants saw following successful fixation on the contour.

A black fixation cross on a grey background preceded stimulus presentation on every trial. An invisible, square area of interest surrounded the fixation cross, and subjects had to fixate for 200ms (350ms during practice) on the cross in order to bring about the next stimulus presentation. In this regard, the experiment was self-paced, although participants tended to proceed quite rapidly through the trials. Experimental participation took approximately 8-10 minutes to conclude once calibration was achieved.

Once the fixation cross was successfully fixated upon for 200ms, the stimulus image appeared for up to 1000ms, or until the subject fixated within a 350px by 350px area of interest surrounding the contour for 100ms. If successful fixation occurred within the 1000ms, a red oval appeared around the contour for 500ms, which served as confirmation for the subject that they had successfully located and fixated upon the contour. After the red oval, an animated .gif image appeared in the center of the screen, depicting a set popular cartoon characters (the "minions" from the film "Despicable Me"). The animated .gif was paired with the sound of the laughing "minions", serving as a reward. See Figure 3 for a schematic of each trial's procession.

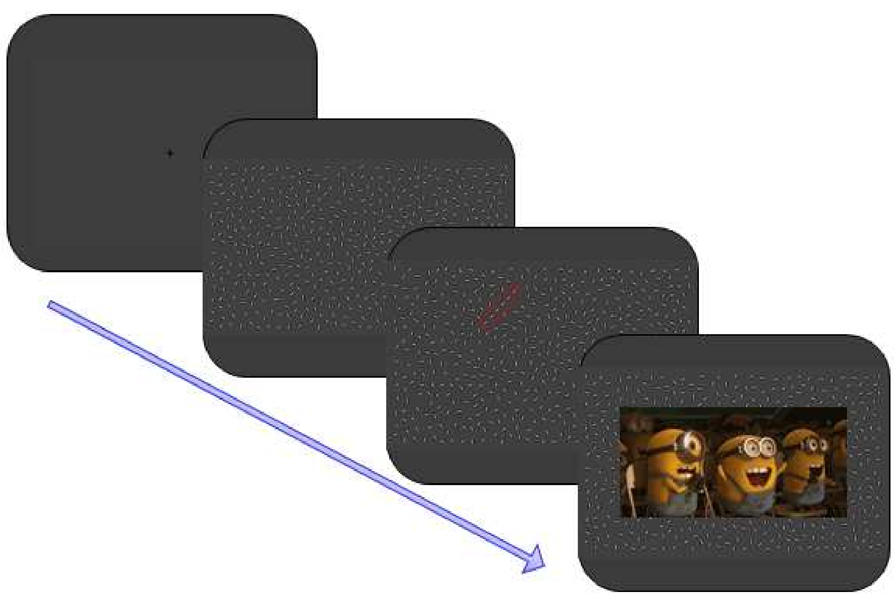


Figure 3. A schematic depicting the procession of a single trial. Following successful fixation (200ms) on the fixation cross, the contour+noise stimulus was presented until the contour was successfully fixated upon (or until 1000ms had elapsed). Once successful fixation occurred, a red oval surrounded the contour for 500ms, followed by an animated .gif image for 1800ms, depicted here as a still image in the fourth box.

Analysis

Trials with impossibly low reaction times were removed from analysis (less than 100ms after fixation cross offset, only 1% of trials). Binomial and linear mixed models were employed in order to test the role of contour orientation in detection accuracy and reaction time for correct responses, respectively. "Detection speed for correct responses" was operationalized as the latency of the first saccade into the area of interest around the contour, though other similar metrics were tested (e.g. latency to first fixation) and revealed highly convergent patterns of results.

Analyzing accuracy data using a logistic model instead of a linear model is preferable since accuracy data are by nature binary (Dixon, 2008). Modeling the log odds (or logit) of accuracy as a linear function of the factors in the design avoids issues such as averaging artifacts, which may occur when aggregating accuracy data as proportions, as is typically done in ANOVA methods (see Dixon, 2008 for a comprehensive discussion of this problem). To perform our mixed model analyses, the lmer package was used (lme4 package; Bates & Sarkar, 2006) and the ANOVA package was used for model comparison (car package; Fox & Weisberg, 2009) in the R system for statistical computing (R Development Core Team, 2006).

Results

Accuracy

Participants successfully fixated on the contour on 78.6% of trials, suggesting that the spatial and temporal dynamics of the stimuli and trials were appropriately calibrated in terms of difficulty. Horizontal contours were successfully detected on 86.0% of trials, vertical contours on 82.6% of trials, and oblique contours on 73.0% of trials.

Binomial mixed effect models were constructed and contrasted using backwards selection for fixed effects, forward selection for random effects, and ANOVAs for comparing AIC. The model included two fixed factors: orientation (horizontal, vertical, and oblique) and eccentricity. Eccentricity was trichotomously operationalized as close (200 pixels - 499 pixels), medium (500 pixels - 699 pixels), and far (700 pixels - 900 pixels) distance from the centrally located fixation cross. The "close range" was defined 100 pixels larger than the others for balancing reasons and to avoid placing contours that contacted the exclusionary region around the fixation cross. Vertical orientation was included as the reference orientation for comparison with the other two, both for theoretical (Horizontal fluency is typically slightly greater than vertical and vertical is typically much greater than oblique) and empirical reasons (accuracy for vertical contours was intermediate with respect to the other two orientations). Random effects specified included subject and trial, though trial was shown to not significantly contribute to the model, suggesting that participants' performance did not systematically improve or degrade as trials progressed.

Accuracy for horizontal contours was only marginally greater than for vertical contours, (a 4% advantage for horizontal contours, $z = .901$, $p > 0.05$). However, accuracy for vertical contours was significantly greater than for oblique contours ($z = -2.722$, $p < 0.01$). No overall accuracy differences between eccentricities were observed, nor were any significant interactions observed between eccentricity and contour orientation. Figure 4 depicts these results graphically.

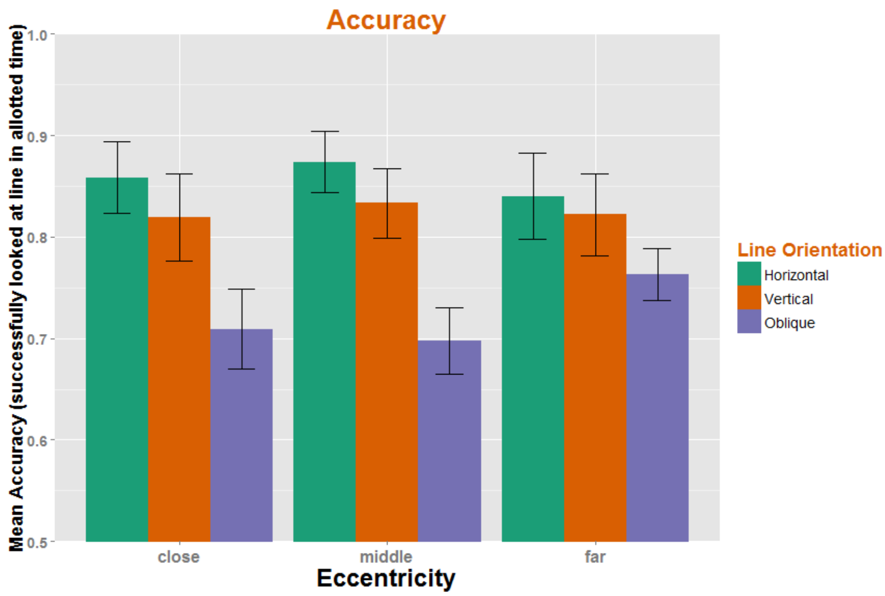


Figure 4. Contour detection accuracy as a function of orientation and eccentricity.

The variability in the locations of the contours and the reported differences in visual spatial integration between foveal and peripheral vision (Shani & Sagi, 2005; Lev & Polat, 2011) made it necessary to account for eccentricity, the absence of eccentricity effects on accuracy within our task should not be taken to indicate that eccentricity is unimportant for accurate contour detection. This is because subjects were free to direct their gaze anywhere on screen once each trial began, which displaces actual eccentricity with respect to participants' fixation. That is, when a participant made their first large-scale eye movement, the portion of the screen in their periphery moved with it, degrading the utility of eccentricity as operationalized in the current design.

Detection speed

A secondary index of perceptual fluency worth considering is reaction time for correct responses, here operationalized as trial duration on trial in which the contour was successfully detected. This measure may indeed be a more sensitive metric than accuracy under the current stimulus parameters. Mean reaction time for correct responses to horizontal contours was 633ms (SE = 10.1ms), to vertical contours was 679ms (SE = 10.8ms), and to oblique contours was 719 (SE = 7.9ms).

Response time data were negatively skewed, and so inferential statistics were conducted on log-transformed values. Additionally, eccentricity did impact reaction time during preliminary model testing, such that contours located close to the center were detected slightly faster than contours at the medium distance, $z = -2.09$, $p < 0.05$. A single interaction term was also significant - the RT difference between vertical and oblique contours was slightly greater at small eccentricities, $z = 2.70$, $p < 0.01$. However, the inherent problems with measuring eccentricity in a free-viewing task (described in the accuracy section above), concerns over statistical power (the reaction time analyses already deals with a reduced subset of the total data), and its only tangential relevance to the main research question at hand led us to exclude eccentricity from the final model. As in the accuracy analysis described above, the only random effect surviving model comparison was subject (intercept only).

In the final model, contour orientation was the only fixed effect included, and subject was the sole random factor. A significant difference was once again observed between horizontal and vertical contours (horizontal contours were detected slightly faster than vertical, $p = 0.002$), and between vertical and oblique contours (oblique contours were detected slowest, $p = 0.002$). Figure 5 depicts these relations graphically.

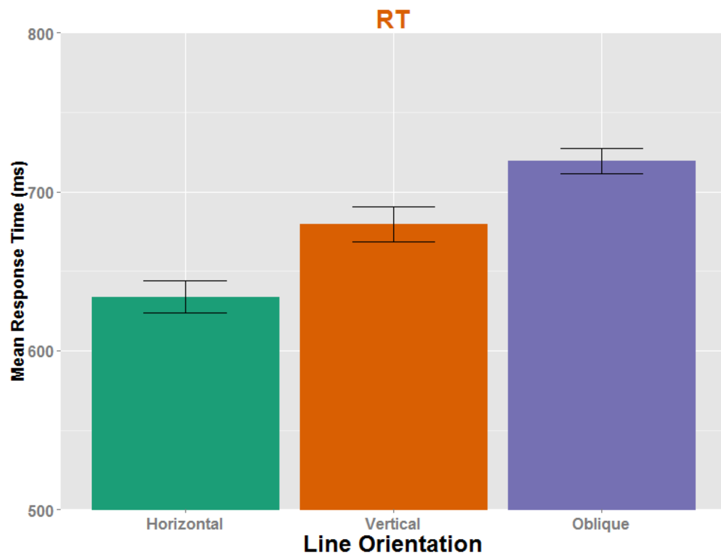


Figure 5. Mean response time as a function of contour orientation. Horizontal contours were detected faster than vertical contours, and vertical contours were detected faster than oblique.

Discussion

By combining a contour detection task with eye tracking methodology, this work produced a novel demonstration of the perceptual oblique effect in a quick and efficient manner. The results from the accuracy and reaction time analyses presented above converge on the predicted results, namely that oblique contours embedded in visual noise are detected slower and less accurately than canonically oriented contours. This new task even reproduces the subtler fluency difference reported elsewhere between horizontal and vertical contours, at least in accuracy. This in itself is a novel result; while many studies demonstrate a perceptual oblique effect, none to date have done so in a way requiring no overt response, and most require extended experiment participation, while the current work manifested the effect using only 80 trials and a fully between subjects design.

In terms of visual function, this experiment suggests that the perceptual oblique effect survives the removal of overt responding from the task demands. This suggests, as others have claimed from neurophysiological and neuroanatomical perspectives (Li et al., 2003; Mannion et al., 2010), that the oblique effect is a visual cortical phenomenon. Whether this effect is primarily driven by initial encoding differences or by reduced top-down attentional allocation for oblique stimuli remains an open question. In fact, this may be the wrong question to ask, as new data suggests that significant reverberation between bottom-up and top-down signals in early visual cortex occurs (Awh, Belopolsky, & Theeuwes, 2012), which limits the degree to which researchers can successfully infer whether either or each of these types of processes are at work within a given task. The temporal characteristics of the current task certainly do not rule out either interpretation. However, the fact that eye movements are putatively controlled by the superior colliculus (Robinson, 1972; Sparks, 1988) in a manner reflecting cortical input about salient regions of the visual field (Gitelman, Parrish, Friston, & Mesulam, 2002) suggests that at least some attentional component is at work.

This task, while novel in its own right, was designed for two ulterior purposes. First, it will serve as a pre- and post-test for an experiment testing whether visual experience with caricatured but naturalistic visual stimuli (as measured in Experiment 2) can alter the magnitude of the oblique effect (Experiment 3 in this dissertation). Secondarily, and outside the scope of this dissertation, it will also become part of a test-battery for assessing visual function in young children, including children at risk for Autism.

Experiment 2: Characterizing the Caricature: Analyzing the Orientation Anisotropy of Natural, Urban, and Digital Scenes

Visual information in complex natural scenes is biased in a number of ways, and these biases in turn serve as important sources of information about the structure of the world for the visual system. One important example concerns the relative preponderance of orientation information in scenes. Natural scenes tend to display an orientation bias, such that horizontal orientations are slightly over-represented relative to vertical orientations, and canonical orientations (i.e. both horizontal and vertical) are greatly over-represented relative to oblique (Baddeley & Hancock, 1991; Coppola, Purves, McCoy, & Purves, 1998; Girschik, Landy, & Simoncelli, 2011; Hancock, Baddeley, & Smith, 1992; Hansen & Essock, 2004; Keil & Cristobal, 2000; Switkes, Mayer, & Sloan, 1978). Gross, large-scale image features such as horizon and tree lines can alter the magnitude of this orientation anisotropy (O.A.) for any given image, but analyses of a large corpus scenes reveals this pattern is more general, deriving from the nature of textures and the general structure of most natural objects. This pattern is largely invariant across spatial scales, although lower spatial frequencies tend to exhibit a stronger anisotropic pattern (Schweinhart & Essock, 2013).

The orientation bias in nature is partially compensated against by biased perceptual suppression of horizontal and vertical information (Hansen & Essock, 2004). The precise mechanism by which this suppression occurs is still not well understood, however the process itself has be effectively characterized at an algorithmic level (Marr,

1976) as salience re-weighting under ecologically valid (i.e. complex) conditions. This leads to paradoxically better performance with oblique orientations in complex natural scenes (see Hansen & Essock, 2004, who coined this inverse result the "horizontal effect) despite the numerous studies showing poorer performance for obliquely oriented isolated gratings during simple psychophysical tests, such as orientation estimation tasks using gratings or contour detection (e.g. Field, Hayes, & Hess, 1993; Experiment 1, this volume). Despite this important caveat, most researchers nevertheless consider orientation anisotropy in nature the underlying reason for the various idiosyncrasies (including the oblique effect) within orientation perception, either via experience with scene statistics during ontogeny (Hipp, Dickerson, Moser, & Gerhardstein, 2014) or phylogeny-mediated predispositions (Geisler, Perry, Super, & Gallogly, 2001).

As Schweinhart and Essock (2013) note, another, less direct way to study the idiosyncrasies of visual perception is to study the characteristics of content produced *for* the visual system. Art, and in particular realistic art, presents an enhanced version of the various biases in natural scene statistics, including the $1/f$ linear reduction in amplitude with spatial frequency (Graham & Field, 2007). Schweinhart and Essock (2013) were the first to compare the relative magnitude of the orientation bias within art and the nature it imitates. They derived and validated a computational approach to orientation analysis in which they rotated circular-cropped, band-pass restricted, Fourier transformed images in 3° increments and passed them through horizontal and vertical filters at each increment, revealing the spectral amplitude across a wide range of orientations. The images being compared were either natural scenes or artists' renditions of those same scenes. Using this process, they found two primary results. First, the art exhibited slightly exaggerated orientation anisotropy relative to the natural scenes. Second, they showed that artists "over-regularize" the content they produce relative to the scenes from which they produce them, in the sense that orientation anisotropy was more regular across spatial frequencies in the artists' paintings than in the natural scenes.

Art is a special example of material constructed *for* the visual system, but in fact we modern (W.E.I.R.D., in the parlance of Henrich, Heine, & Norenzayan, 2010) humans are constantly surrounded by material designed for us, and have been since the onset of the industrial revolution. Spatial frequency analysis of the so-called "carpentered" world of modernity consists of more information in the horizontal and vertical orientations than oblique, especially at lower to middle range spatial frequencies (Switkes, Mayer, & Sloand, 1978). With the advent of the technological revolution, modern humans live not only in a carpentered world, but a *digital* world. Whether digital scenes – that is, scenes consisting of screens presenting various types of content to the viewer - exhibit even more exaggerated orientation anisotropy relative to urban and natural scenes remains unknown.

This is the aim of the present study. Borrowing the analytical technique of Schweinhart and Essock (2013), this work compares the orientation anisotropy found within natural, urban, and digital scenes. If exaggerated O.A. is found, it will lend support to the claim that experience with screen media may have the potential to alter aspects of basic visual perception.

Methods

Data Collection

Digital photographs (N = 50, resolution: 5184 x 2916) of natural (n = 9), urban (i.e. cityscapes, n = 11), and digital scenes (n = 30) were taken using a Canon digital camera, model EOS 60D. Images were analyzed as .CR2 files (Canon's proprietary "raw" image format), effectively preventing any pre-processing accomplished by the camera's intrinsic software from corrupting the subsequent analysis. Natural scenes were photographed in the Nature Preserve on Binghamton University campus, a robust natural wooded area containing a variety of natural features. Urban scenes were photographed in downtown Binghamton, NY, a modest urban area, replete with high-rise buildings and busy streets. Care was taken with each of these scene types to avoid including images containing close-up views of people's faces.

Digital scenes all contained an iPad against the backdrop of a wooden table (only a very small portion of the table remained after circular aperture cropping, see Figure 6). An iPad was chosen because tablets are increasing in popularity, especially for entertainment purposes, and because like most digital content media presentations including television and traditional computers, they present their content within a rectangular physical frame. The frame (i.e. the rectangular interior of the tablet was partially included in the to-be-analyzed images for two reasons. First, I intended to analyze the orientation anisotropy of *digital scenes*, not screenshots of digital content, as the former represents the information available to the visual system at the retinal catch. Second, the frame itself is likely an important source of orientation anisotropy presented to the visual system, and so excluding it from analysis would likely underestimate the degree to which digital scenes exhibit this pattern. Importantly, digital scenes analyzed here contained a variety of content types, including video games (n = 15), realistic videos containing live actors (*n* = 9), and cartoons (*n* = 6). The photographs were systematically taken every two minutes during a 12 year old's free play with the iPad, to avoid selection bias from the experimenters.

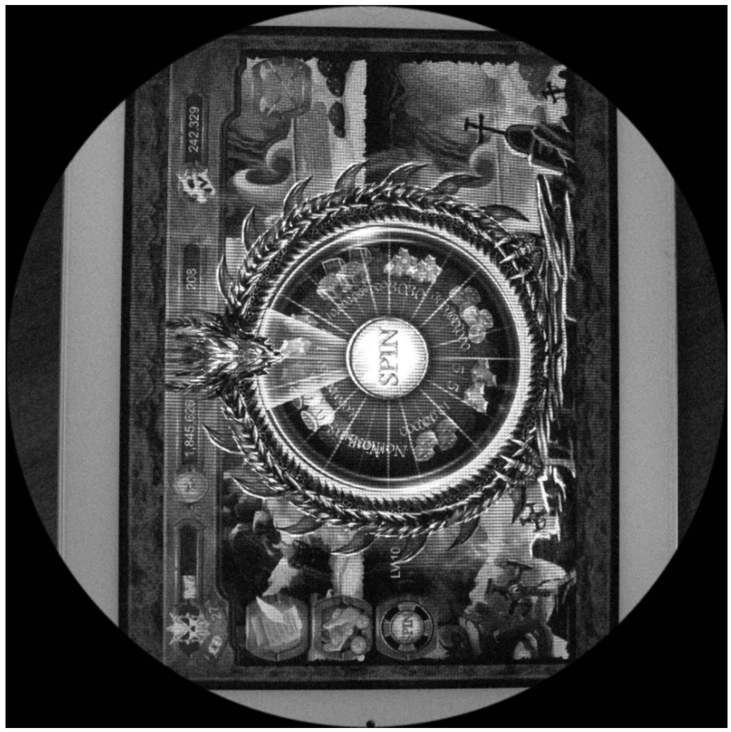


Figure 6. A gray-scaled, circularly cropped image. Images similar to this were produced and filtered during analysis. The black area around the circle was not analyzed, but was included to show the extent of the cropping. This 90° rotated image, and 30 differently oriented images like it, was produced during the analysis of a single digital scene.

It was necessary for all images – natural, urban, and digital – to assume a particular "viewing distance" in order to perform the analyses. We adopted a viewing distance of 45cm, as this is a typical "arms' length" viewing distance for a tablet computer. Importantly, because images were not band-pass filtered by spatial frequency, assumed viewing distance should not impact orientation amplitude to a significant extent.

Image Processing

Schweinhart and Essock (2013) designed a computational method that avoids many of the errors implicit in other methods for analyzing amplitude as a function of orientation, and this method was adapted for the current work (see Schweinhart &Essock, 2013 for extensive comparison of this method to others). The main difference in the current analysis is that our orientation analysis was not separated by spatial frequency, as the current work is primarily concerned with amplitude as a function of overall orientation, not over-regularization. The color photographs were first converted to grayscale using the intrinsic MATLAB function (0.29*R + 0.58*G +0.11*B). Then, the images were cropped with a circular aperture 2048 pixels in diameter. The edge of each circle was linearly ramped to mean luminance over an 8 pixel distance to avoid artifacts resulting from the sharp luminance discontinuity defining the border of the circle. A Fast Fourier Transform (FFT) was then performed on the edge, and the resultant amplitude spectrum was passed through a horizontal and vertical filter. Passing the amplitude spectra of the images through horizontal and vertical filters avoids any anisotropic artifacts related to the square shape of individual pixels. Next, the original image was rotated 3° using the intrinsic MATLAB function imrotate, which Schweinhart and Essock (2013) showed was comparable to a much more laborious method involving camera rotation when the preventative measures described above were taken. This process was iterated until the image was rotated 180°, effectively covering the entire range of orientations in each image. See Figure 6 for a schematic of this process.

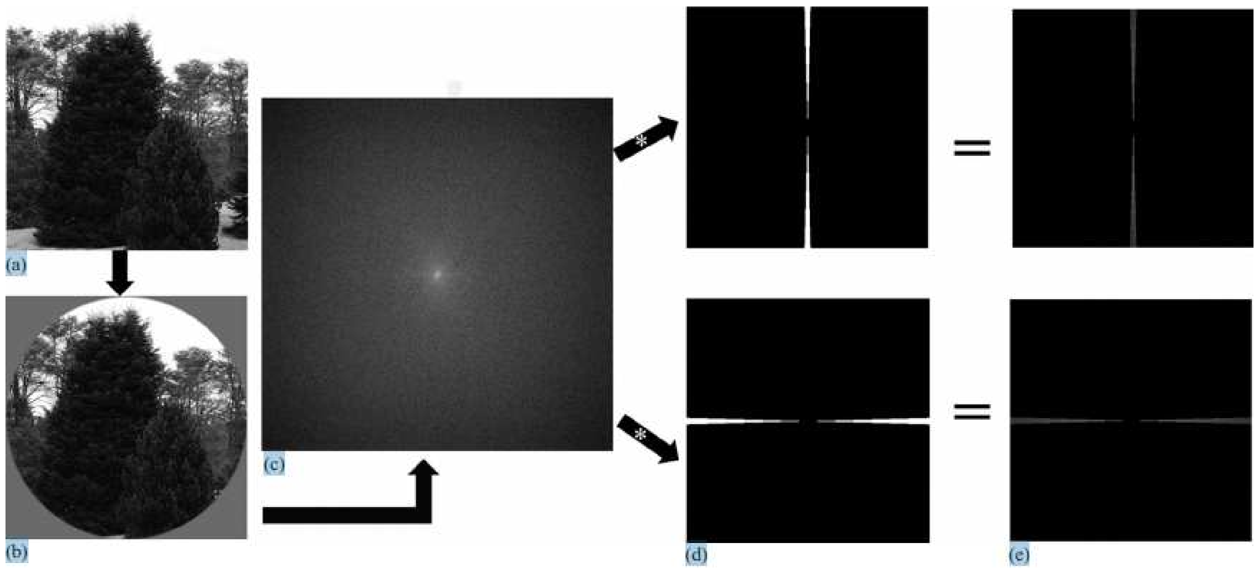


Figure 6. A schematic of the orientation analysis. The same analysis was conducted on natural, urban and digital scenes. Images were first (a) gray-scaled and (b) circularly cropped. A fast Fourier transform wass performed on the cropped image, producing an (c) amplitude spectrum. This spectrum was convolved with (d) horizontal and vertical filters, each 3° wide, and the resulting (e) filtered spectra at each orientation were saved. The original image was then rotated 3° and the process was repeated until all orientations are analyzed (adapted from Schweinhart & Essock 2013).

A vector of 62 amplitudes (one at each of 60 orientations, plus 0° and 90° again, to index measurement error due to the computational rotation) was produced from this process, and these served as baseline data for analysis. Measurement error was extremely minimal (i.e. less than 0.0001%). Amplitude values were then normalized within each image, such that each orientation's amplitude value was divided by the amplitude at horizontal (which was the greatest value for almost all images). Normalization was necessary because overall luminance differences within images would otherwise mask between-image differences, and for this reason normalized values were used in all analyses.

Results

The orientation anisotropy pattern typical of natural scenes was found in each image type, albeit to different respects. The distribution of normalized amplitude for all images peaks around horizontal and vertical and drops as orientation approaches 45° and 135°. One-way ANOVAs were used to evaluate the relative orientation anisotropy in the, with individual photos serving as the analogue for "subject" in the error term of each analysis. Two dependent measures were utilized to index the differences between image types: 1) Average normalized amplitude, which indexes the degree to which amplitude is isotropic with respect to orientation, and 2) Canonical-to-Oblique ratio, or the ratio of the amplitude of the canonical orientations (horizontal and vertical) to the amplitude of the oblique orientations (hereafter "C:O").

Average Normalized Amplitude

Average normalized amplitude varied significantly as a function of image type, $F(4,44) = 5.04$, $p = 0.002$. This difference was primarily driven by the differences between natural scenes and the other types of images, though a clear difference was also apparent between cityscapes and digital scenes. A separate ANOVA containing only the 3 types of digital scenes showed no difference between digital scene types ($F(4,44) = 0.24$, $p = 0.78$). Figure 7 clearly shows the qualitative difference between natural, urban, and digital scenes in terms of the shape of the curve describing the relation between normalized amplitude and orientation.

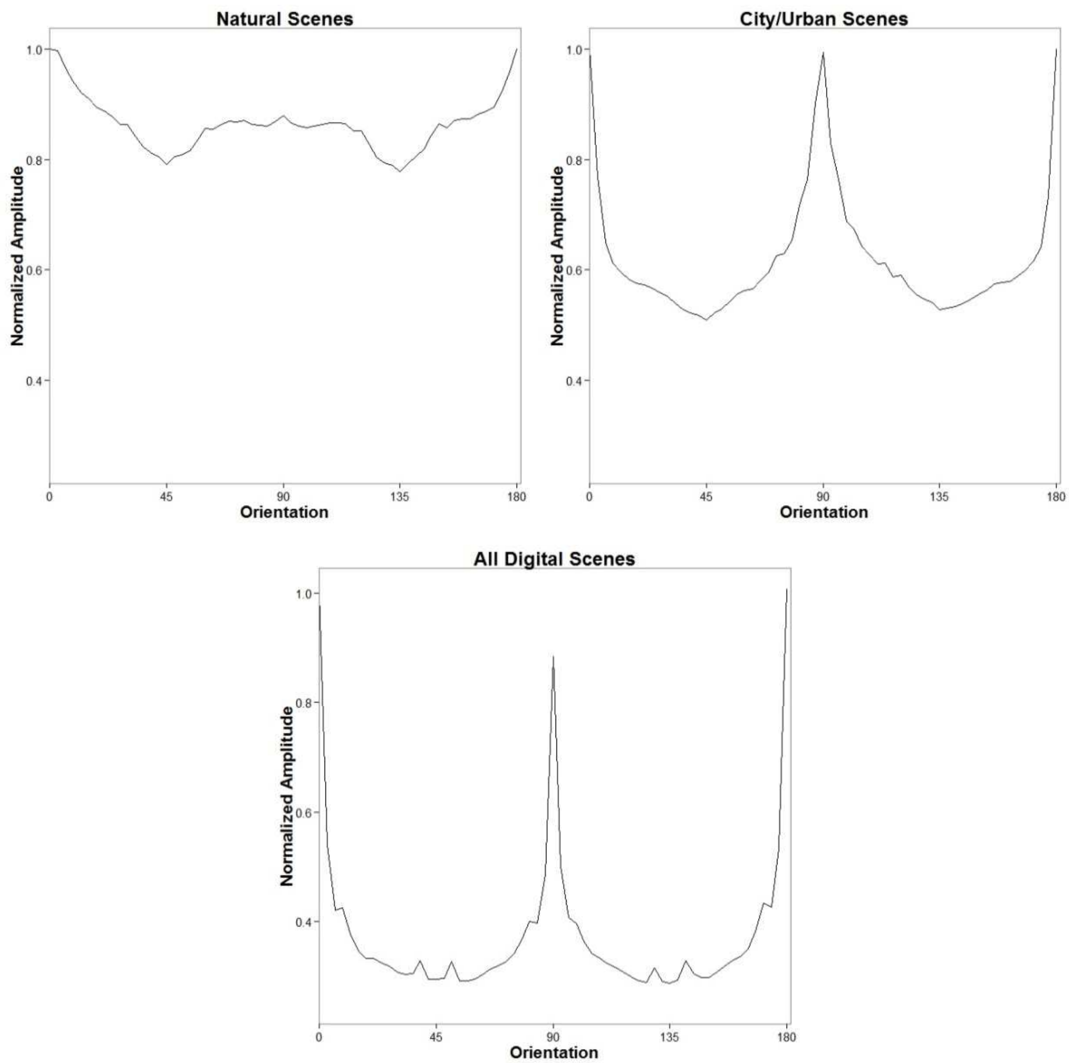


Figure 8. Normalized amplitude as a function of orientation across scene types. Amplitude values were normalized within each image, such that the value for horizontal was set to 1.0, and other values Natural scenes display the orientation anisotropy characteristic of complex natural images, with slight peaks at 0° and 90° and troughs at 45° and 135°. City scenes show an exaggerated anisotropic pattern, likely reflecting the so-called "carpentered" aspects of urban environments. And even relative to the exaggerated pattern found in urban scenes, analysis digital scenes revealed a significantly greater degree of orientation anisotropy.

A secondary statistic capable of indexing orientation anisotropy is C:O, or canonical to oblique ratio ($[Amp_{0^\circ} + Amp_{90^\circ}/2]/[Amp_{45^\circ}+Amp_{135^\circ}/2]$, Schweinhart & Essock, 2013). Replicating results reported elsewhere, our corpus of images revealed a much smaller difference between horizontal and vertical orientations than between canonical and oblique orientations (i.e. the H>V>>O pattern). A main effect of image type was also found within our analysis of C:O, F (4,44) = 9.46, $p < 0.00001$, indicating that different image types possessed different degrees of anisotropy. Two of the three digital image types (Realistic and Videogames) possessed C:O greater than 3.0. City and digital cartoon images revealed C:O just under 2.0. The C:O found for natural scenes revealed a much subtler bias (see Table 1. for exact values). Evaluating these differences in light of the orientation anisotropy graphs above suggests that these similar city and cartoon C:O values emerged for different reasons. For the urban images, there was relatively more oblique energy, leading to a larger denominator in the ratio, whereas for the digital-cartoon images, there was slightly less vertical energy than in other digital image types, leading to a smaller numerator.

Table 1

Canonical to Oblique Ratio by Image Type

Image Type	**C:O**
Nature Scenes	1.198
City/Urban	1.922
Digital-Realistic	3.236
Digital-Videogames	3.153
Digital-Cartoons	1.818
Digital - All	2.735

Discussion

We aimed to discover whether scenes dominated by digital content possessed caricatured orientation anisotropy relative to natural scenes and the so-called "carpentered world" of modern cities. In this regard, both qualitative (graphical) and quantitative (inferential/statistical) evidence converged on the affirmative. All image types evaluated in the current work showed the characteristic orientation anisotropy reported elsewhere in the literature (for a review, see Hansen & Essock, 2004). We extend this literature by showing this pattern is exaggerated in the urban scenes relative to natural scenes, and even more exaggerated in the digital scenes relative to the other classes.

The current study is another example of how content created for the human aesthetic often exhibits properties that match or exceed the perceptual expectations of the visual system, as Schweinhart and Essock (2013) showed in their analysis of paintings. Given the ubiquity of this sort of content in the modern visual landscape, it is important for researchers to characterize the changing visual ecology of modernity. Other aspects of the digital experience were clearly either designed or exapted to attract viewers' attention, and caricatured orientation anisotropy may enhance this effect.

An important caveat to our results is that the framing border of the monitor (in this case, the tablet) likely contributed to the enhanced orientation anisotropy found in our images. We cannot claim based on our data that all digital *content* presents caricatured orientation anisotropy, only digital *scenes*; in fact, given the ever-increasing diversity of content available online, such a broad characterization would be hubristic. Even if such a characterization were reasonable in theory, digital content is not presented to the visual system in this way. Monitors are ubiquitous, and while these frames vary in size, global orientation (landscape vs. portrait), and other perceptual dimensions, they do not vary much from their typical rectangular shape. It was therefore important to include the framing border of the tablet in our analyses, as few naturalistic viewing scenarios would position the viewer at such a close distance from the screen that the border was not present in their visual field. In this sense, our analyses, and in fact all analyses of natural scene statistics, are “pre-perceptual”; they avoid assumptions about salience and attention, and focus instead on the purely physical input the visual system receives.

The frame itself may even conscript attentional processing in a manner lending itself to aesthetic experience; consider Mondrian’s paintings. Plumhoff and Schirillo (2009) measured subject’s eye movements during free viewing of rotated Mondrian paintings and correlated the patterns of their eye movements with their aesthetic judgments. Not only did subjects prefer the canonically oriented Mondrian paintings, dominated as they are by horizontal and vertical lines and completed rectangles, but eye movement data indicated that participants’ fixation durations and saccadic oscillations both correlated with the global orientation (and therefore, aesthetic rating) of the paintings. When viewing images rated as aesthetically pleasing, fixation durations increased with a steeper linear ramp, and saccades oscillated over shorter distances.

As we learn more about the inherent biases of visual perception – how malleable they are, whether they derive from experience-expectant or experience-dependent plasticity, whether and how they scale with stimulus complexity - we will also understand how this changing visual environment impacts the developing visual system. Such an understanding will also alter our concept of the human aesthetic, and whether a universal basis for aesthetics is possible in theory or practice. While it is true that orientation anisotropy is reflected in the visual nervous system (e.g. Li, Peterson, & Freeman, 2003), the fact that top-down perceptual biases "whiten" nature's orientation anisotropy (Essock et al., 2009; Hansen & Essock, 2004; Haun et al, 2006; Kim et al., 2010) keeps open the question of whether the differences observed between image types in the current work are sufficient to significantly alter visual processing either in the short- or long-term. Experiment 3 in this dissertation is designed to broach the short-term question by evaluating the impact of this sort of caricatured visual experience on the visual oblique effect. Future research may profitably investigate how generalizable the current findings are with respect to other digital content devices, such as smart phones and televisions, as well as the extent to which screen media presentations are caricatured in other perceptual domains.

Experiment 3: Mind-Craft: Increasing the Oblique Effect with Videogame Play

The various processes underpinning visual perception derive their idiosyncrasises at least in part as a function of experience with the statistics of visual scenes (Geisler, 2008). For example, the visual environment contains an enormous amount of information about the relation between proximity and contour orientation, and the visual system appears to use this information optimally during contour interpolation (Geisler, Perry, Super, & Gallogly, 2001). Experience continuously updates the perceptual system, especially during youth, when exuberant learning takes place as a function of enhanced plasticity and a weaker knowledge base. However, this process does not eventuate at puberty; even older children and teenagers show “immature” contour processing relative to adults, and the visual system’s model of the world is continually updated into adulthood (Hadad, Maurer, & Lewis, 2010; Hipp, Dickerson, Moser, & Gerhardstein, 2014; Kovacs, Kozma, Feher, & Benedek, 1999). Absent such experience, entire aspects of visual perception can remain immature or even fail to develop altogether, especially if this experience is depreciated during critical developmental periods. For example, cats reared with no experience with visual contours of a particular orientation lose the ability to perceive these contours (Callaway & Katz, 1991).

Just as information absence is reflected in the absence of processing, the inherent statistical biases in visual scenes also manifest perceptually. This is the case with the visual oblique effect, in which orientation anisotropy in natural scenes (Coppola, Purves, McCoy, & Purves, 1998; Schweinhart & Essock, 2013; Experiment 2, this volume) contributes to an anisotropy in processing, both perceptually (Fang, Bauer, Held, & Gwiazda, 1997; Field, Hayes, & Hess, 1993; also see Experiment 1, this volume) and physiologically (Bosking, Zhang, Schofield, & Fitzpatrick, 1997; Furmanski & Engel, 2000; Li, Peterson, & Freeman, 2003).

An important result from Yao and colleagues (2007) speaks to the robustness of cortical coding of visual scenes. In this study, cats were either exposed to movies of natural scenes, white noise, or flashed bar stimuli. Cortical neuron response reliability only improved during natural scene viewing, and not with the less information-rich visual stimulation. Importantly for the current work, this effect lasted for several minutes after the movies were turned off, suggesting that the visual system not only adapts "on-the-fly" to information-rich scenes, but also that the statistics of these scenes persist as a memory trace reflecting past experience. Just which mechanism is responsible for this effect remains unclear, though modification of existing horizontal connectivity in primary and secondary visual cortex seems the most plausible candidate (Loffler, 2008; Stettler, Das, Bennett, & Gilbert, 2002).

This interpretation seems especially likely given research speaking to the necessity of stimulus complexity for visual learning of the sort mediated by horizontal connectivity in early visual cortex (Cass, & Spehar, 2005; Gilbert, Das, Ito, Kapadia, & Westheimer, 1996). Almost all studies of basic contrast sensitivity, in which Gabor patches of various contrasts are presented to participants within a yes/no detection paradigm, report no perceptual learning. Yet contrast sensitivity improves, albeit only after a considerable number of trials, when collinear flankers are added (Dorais & Sagi, 1997; Adini, Sagi, & Tsodyks, 2002). These studies demonstrate that flankers not only improve contrast sensitivity for foveally-presented targets, but the distance of flanker facilitation can also be modified as a function of experience with the stimulus set. Flankers add informative context to the target patch; in natural scenes, the presence of a collinear element just outside the target's receptive field adds to the likelihood that the target patch is present (Geisler, Perry, Super, & Gallogly, 2001). These sorts of statistical relations between contiguous regions of visual space are encoded by horizontal connections in V1 and V2. Only one result to date contradicts this finding, and only when contrast was held constant across trials (Yu, Klein, & Levi, 2004). It therefore appears that, except under very specific and contrived circumstances, visual perceptual learning requires complexity to proceed.

As Experiment 2 demonstrated, the visual statistics of modern human environments, replete as they are with framed, digital content, are now undergoing a second shift towards enhanced orientation anisotropy. Given that this statistical bias is the pattern putatively responsible for cortical anisotropy (Li, Peterson, & Freeman, 2003) and the visual oblique effect (Keil & Cristóbal, 2000), it remains an open question whether exposure to framed, digital scenes effects alters visual perception. One way to test this would be to use a pre-/post-test paradigm and train participants' visual systems with experimentally controlled, complex stimuli to compare performance on some test of visual perception before and after visual training. However, while such manipulations are useful reductionist methods for revealing the boundary conditions of well-established findings, these methods also lack ecological validity, and no studies have examined the impact of caricatured, framed digital experience on visual perception. As Yao and colleagues (2007) demonstrated, complex natural scenes are encoded much more efficiently than even patterned, complex visual stimuli. Therefore, a complimentary approach to would be to train subjects with the sort of caricatured visual experience common in modern society. With this approach and the results from this volume's previous two experiments in mind, an experiment was designed that attempts to alter the magnitude of the visual oblique effect Appelle, 1972; Experiment 1, this volume) as a function of four uninterrupted hours of focused playing experience with the most popular videogame of all time, Minecraft (Mojang, 2011). Minecraft was chosen due to its pixelated, blocky graphics, its extreme popularity, and because like the other computer games tested in Experiment 2, it exhibited exaggerated orientation anisotropy. Participants in this Minecraft training condition were compared to control subjects instructed simply to limit exposure to screens of all types during the four hours between experimental test sessions. To index experience-mediated changes in the oblique effect, as indexed by the eye tracking method in Experiment 1, I analyzed accuracy and detection speed for horizontal, vertical, and oblique contours. Based on the research discussed above and the results from Experiment 1 and 2 of this volume, I predict that subjects visually trained with Minecraft will display an increased difference between canonical and oblique contours after training, whereas control subjects should show no difference, or even a slight reduction in the magnitude of the oblique effect if they typically spend much of their time viewing and interacting with screen media.

Methods

Participants

Adults participants were college students recruited via university channels and incentivized with class credit (*N* = 20, *Males* = 10, evenly split between experimental and control conditions). Proper consent was obtained from all subjects. Following consent, participants' vision was assessed using a Snellen eye test, and all subjects exhibited normal or corrected-to-normal vision (20/20). If their vision was corrected to normal with contact lenses or glasses, they wore this correction during experiment participation. One subject in the control condition was removed after admitting to playing video/computer games during much of the time between pre- and post-test.

A questionnaire attempting to index participants' typical screen media habits was administered prior to participation. However, the data emerging from this questionnaire proved internally unreliable. Despite this, self-report estimates about number of hours spent interacting with different media sources were preliminarily evaluated within the models presented below. These self-report estimates also did not improve model predictive efficacy, and so were not included in final analysis.

Apparatus

A 120Hz SMI iView X remote eye-tracking system was used to collect gaze data. A 42" High Definition color LCD television (Samsung, 1920 x 1080 resolution) served as the viewing monitor for the experimental data collection. An ASUS VG248QE 24-inch LED-lit Monitor with a 144Hz refresh rate and 1ms pixel response time was used to display videogame training stimuli. A gaming mouse and mousepad was used to offset the strain on the wrists of participants during the four hour training period.

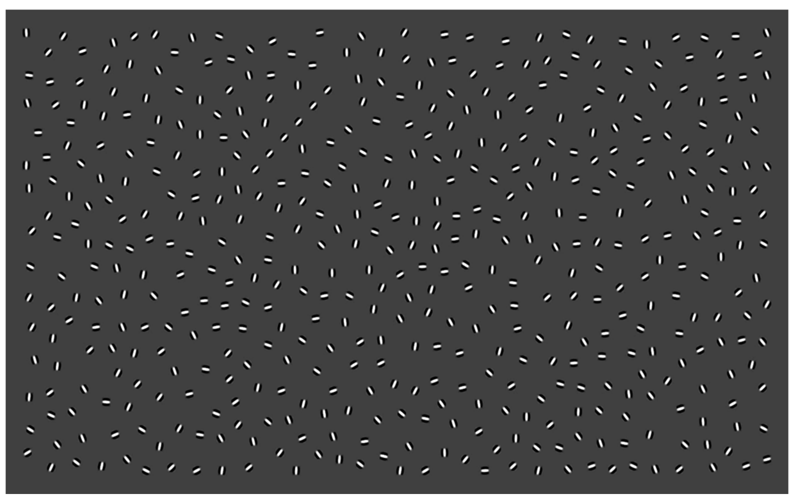
Visual Contour Integration Stimuli

Practice and experimental “contour + noise” stimuli were created within MATLAB, using the Grouping Elements Rendering Toolbox (Demeyer & Machilsen, 2012), which itself relies upon the Psychophysics-3 Toolbox (Brainard, 1997). Standard deviation (σ) of the Gaussian component of the Gabor elements was set at 4 pixels. Spacing between Gabor elements is typically expressed as a multiple of λ, or the wavelength of an individual Gabor element (e.g. Kovács & Julesz, 1993; Hipp et al. 2014). In the present experiment, Gabor patch frequency was set to 0.08 cycles/pixel, the underlying sinusoid obscured by the Gaussian spanned 10 pixels, λ was set to 8 pixels, and spacing between contour elements was set to 50 pixels, .57° or 6.25λ. Patches were modulated from a neutral (50%) grey background.

Contours were comprised of six perfectly collinear Gabor patches, each of which fell on a linear path 270 pixels (4°) in length. Noise patches were randomly oriented about their central axis.

Care was taken to include only images with contours not impinging on the image boundaries, and contours were equally likely to appear in each of the four quadrants of the screen around a 350 pixel by 350 pixel invisible exclusionary zone surrounding the center of the screen. Experimental stimuli were both presented for a maximum of 1000ms, and trials were concluded after 100ms of fixation accrued consecutively (these values were doubled for practice trials so subjects could acclimate to the task demands). Viewing distance was set to 200cm from the television display (25.6°), and lights were turned off except for the television. Only the television illuminated the subject area, as the experimenter computer was hidden from view by a barrier.

Four of the eight practice stimuli were made easier, such that relative noise density (D) was set to 2.0, entailing that the contour elements were twice as dense as the noise elements. This served to make the task trivially easy so that participants could be introduced to the general method of the experiment. Following four trials with $D = 2.0$, four more practice trials with $D = 1.0$ were presented. Everything else about the practice stimuli was identical to the experimental stimulus conditions described above. For the 80 experimental trials, $D = 1.0$, ensuring that trials were as easy as possible while still requiring subjects to use visuospatial integration to find the contour, which would not be the case at greater values (Kovács & Julesz, 1993). See Figure 9 for an example stimulus image.



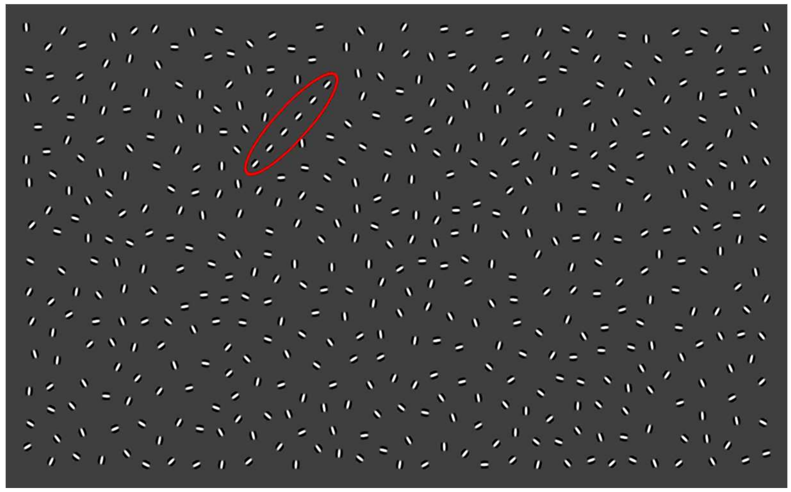


Figure 9. An example stimulus image oblique contour embedded in noise. The contour in the bottom image is highlighted in the same manners as it appeared to participants after a correct trial. Stimuli were identical to those used in Experiment 1.

Videogame Training Condition

The most popular computer game of all time, Minecraft (Mojang, 2011), was presented at full resolution and frame rate on a 1920x1080 high definition monitor. Images from this game were included in Experiment 2 (this volume), and exhibited the enhanced orientation anisotropy characteristic of digital visual scenes. Viewing distance was controlled by participants.

Minecraft (Mojang, 2011) is an extremely popular multi-platform (PC, digital phone, Xbox One) “sandbox survival” game in which players survive by gathering raw materials and building equipment while avoiding interactions with cartoonish zombies and other non-player characters. It is particularly noteworthy for its graphical style, consisting of simple, blocky, cartoonish figures. Minecraft (Mojang, 2011) players can adopt either a first- or a third-person view, though most players adopt the first-person view. Two game-modes, “survival mode” or “creative mode”, are available to players.

Participants in the current experiment could switch back and forth between these modes using a keyboard command, which they were alerted to prior to participation. Survival mode is the more traditional videogame mode, in which players must rush during the in-game "daytime" to construct sufficient materials to survive the night, when creatures come out that can damage the player. Creative mode allows players unlimited access to in-game items and freedom from the physics of the game, allowing them to build whatever they wished without restriction. Both modes contain identical visual graphics and controls.

Control Condition

Participants in the control condition ($n = 10$) were instructed simply to limit use of screens, especially videogames, smartphones, and televisions, for four hours. One participant was dropped from the experiment after admitting to playing smartphone games for a significant portion of the intervening four hours.

Procedure

Pre- and Post-Test

Between three and four pre-test eye tracking sessions were conducted, and three to four more were conducted after the four hours of either training or control time elapsed. If three sessions proceeded without issue or error, the fourth was not conducted; otherwise the three best sessions in terms of calibration accuracy were included in the final analysis. Total participation time spent calibrating and collecting eye tracking averaged about two hours per subject (one hour for pre-test, one hour for post-test).

Before each eye tracking session, subjects were dark-adapted and calibrated using iView calibration software. Calibration was repeated until a criterion accuracy of 1.5° in both the *x* and *y* dimensions was met or exceeded. Calibration was conducted separately for each of the 6-8 sessions for each subject.

A black fixation cross on a grey background preceded stimulus presentation on every trial. An invisible, square area of interest surrounded the fixation cross, and subjects had to fixate for 200ms (350ms during practice) on the cross in order to bring about the next stimulus presentation. In this regard, the experiment was self-paced, although participants tended to proceed quite rapidly through the trials. Experimental participation took approximately 8-10 minutes to conclude once calibration was achieved.

Once the fixation cross was successfully fixated upon for 200ms, the stimulus image appeared for up to 1000ms, or until the subject fixated within a 350 pixel by 350 pixel area of interest surrounding the contour for 100ms. If successful fixation occurred within the 1000ms, a red oval appeared around the contour for 500ms, which served as confirmation for the subject that they had successfully located and fixated upon the contour. After the red oval, an animated .gif image appeared in the center of the screen, depicting a set popular cartoon characters (the “minions” from the film “Despicable Me”). The animated .gif was paired with the sound of the laughing “minions”, serving as a reward. See Figure 2 for a schematic of each trial’s procession.

Figure 10. A time-course schematic of the Minecraft training experiment. Pre-training eye tracking sessions were conducted, followed by four hours of uninterrupted videogame play, concluding with post-training eye tracking. Control participants simply avoided electronics for four hours instead of playing Minecraft.

Analysis

Similar to Experiment 1, data were analyzed using mixed effect modeling (see Experiment 1: Methods for justification of this method over more traditional approaches). Binomial models attempted to predict accuracy, and linear models attempted to predict detection speed on accurate trials, or latency until the onset of the first saccade into the AOI. The lme4 package was used (Bates & Sarkar, 2006) and the ANOVA package was used for model comparison (car package; Fox & Weisberg, 2009) in the R system for statistical computing (R Development Core Team, 2006).

Results

Accuracy

Accuracy was analyzed trial-wise using binomial mixed effect modeling. Trials concluding before maximum time elapsed were considered correct, as this indicated the participant found and fixated on the contour successfully in the allotted time. Comparison within pre- and post-test sessions revealed no accuracy difference as a function of sub-session, nor was there a significant interaction between sub-session and orientation, $p > .05$. This suggests that mere exposure to the experimental stimuli did not influence performance.

Model comparisons and the logic of the current design justified including two fixed effects, the between-subjects effect of condition (Minecraft vs. Control), and the within-subject effects of session (pre-test vs. post-test) and orientation (canonical vs. oblique). No significant difference was found between horizontal and vertical contours in terms of accuracy, and as such these orientations were aggregated for further accuracy analysis as "canonical contours". Backwards selection led to the inclusion of two random effects, accounting for subject and item level error variability.

Canonical contours were detected successfully on 82.8% trials, while oblique contours were detected successfully on 71.9%, leading to a significant main effect of orientation in the model, $z = -4.82$, $p < .00001$. This was the only significant effect in the model. Overall accuracy did not vary by session (pre- vs post-test, $p > 0.05$) nor by condition (Minecraft vs. Control, $p > .05$). Canonical contours were successfully detected on 81.5% of pre-test trials, and 84.4% of post-test trials, and oblique contours were successfully detected on 71.0% of pre-test trials and 72.9% of post-test trials. While these differences trended in the predicted directions, neither of these 2nd order difference effects were statistically significant ($p > .05$). As such, although the main effect of contour orientation (i.e. the oblique effect) replicated the main result from Experiment 1, no accuracy effect relevant to the current experiments research question was obtained.

Detection Speed for Accurate Trials

Detection speed, here considered an index of fluency in attentional allocation was operationalized as latency of the onset of the first saccade terminating in the AOI surrounding the contour. This metric was intended to measure rapidity of attentional allocation, and is likely a more sensitive index of perceptual fluency than accuracy, as the eye tracking experiment itself was designed to be fairly easy. Only trials in which the contour was successfully detected were included in this detection speed analysis (6847 trials across all subjects). Normality of response time data was assessed by evaluating histograms. In contrast with Experiment 1, detection speed data were fairly normally distributed, so untransformed values were analyzed. This may be because a slightly different index of detection speed was used; in Experiment 1, duration of correct trials was used, whereas latency of the first saccade terminating in the AOI was used in the current experiment. These statistical indices overlap considerably, but correct trial duration adds at least a minimum of 100ms to each datapoint, and more than 100ms if the 100ms of consecutive fixations on the contour were interrupted.

Average detection speed across all trials was 319.5ms (*SD* = 131.8). Mean detection speed for horizontal contours was 285.0ms (*SD* = 107.7ms); for vertical contours, 308.5 (*SD* = 122.0); and for oblique contours, 345.6ms (*SD* = 143.9). Figure 10 displays condition means graphically.

Several models were compared, and the eventual model predicting latency included three fixed effects, the between-subjects effect of condition (Minecraft vs. Control), and the within-subject effects of Session (pre-test vs. post-test) and Orientation (canonical vs. oblique). The same two random effects as the accuracy model, subject and item, were also included, as they once again contributed to the model's predictive efficacy. In contrast with the accuracy model, horizontal and vertical contours did differ significantly in terms of detection speed, and so contour orientation remained separated as horizontal, vertical, and oblique.

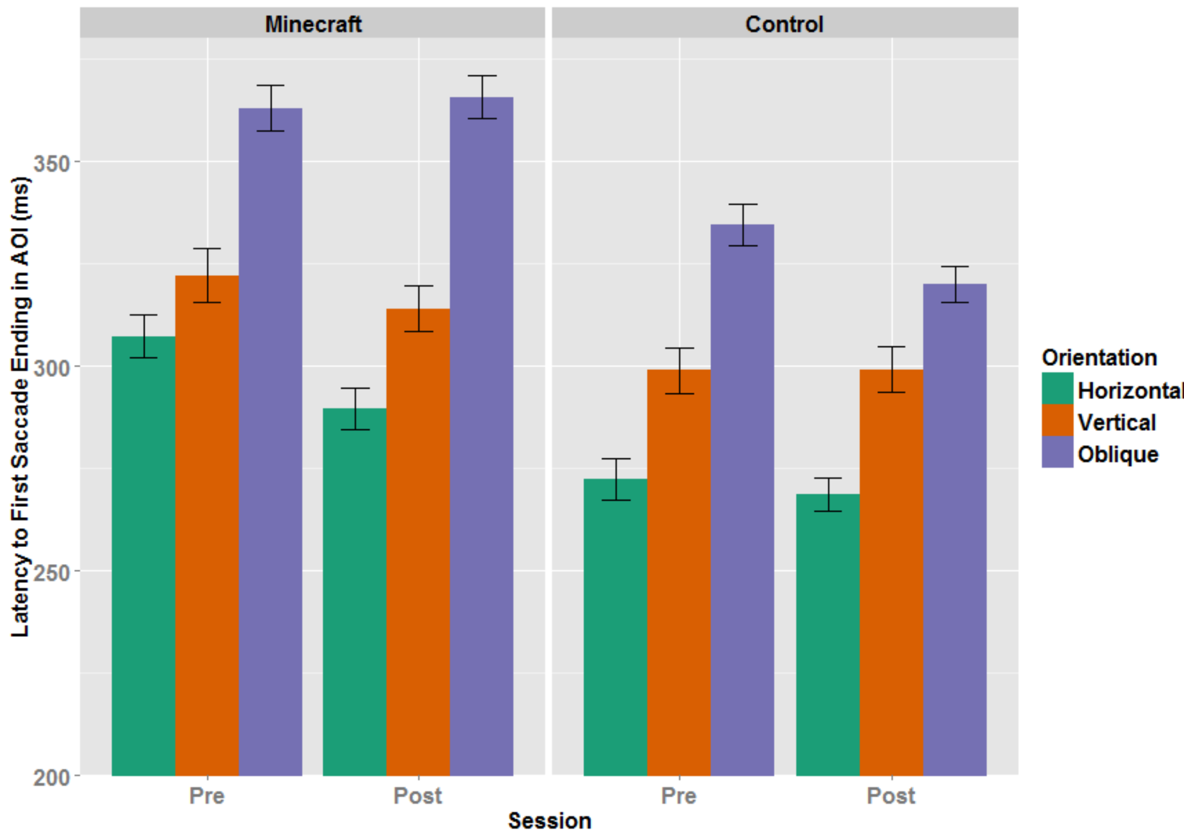


Figure 11. Detection Speed as a function of condition, session, and orientation. Successful detections of horizontal and vertical contours were deployed more quickly after 4 hours of Minecraft training, but not after 4 hours of intervening time with limited use of screen media.

Detection speed on correct trials significantly varied as a function of orientation. Horizontal contours were detected faster than vertical contours, $t = 2.60$, $p = .01$, and vertical contours were detected faster than oblique contours, $t = 5.25$, $p < .00001$. A significant interaction was obtained between condition and orientation, $t = 2.33$, $p < .05$, indicating that oblique contours were detected slower overall in the Minecraft condition than the control condition. Importantly for the current project, this 2-way interaction was buttressed by a 3-way interaction between condition, session, and orientation, $t = -2.19$, $p < .05$, indicating that the pre-test to post-test difference between oblique and vertical contours was greater in the Minecraft condition than the control condition. Examining these data graphically (see Figure 10) indicates that detection speed improved for horizontal and vertical detection in the Minecraft condition, but remained constant from pre-to post-test in the control condition. In fact, detection rate of oblique contour actually improved slightly in the control condition between pre- and post- test. Separate analysis in which canonical contours were grouped together for interpretation simplicity replicates and thus supports the veracity of this three-way interaction, , $t = -2.38$, $p < .05$.

Discussion

Based on the results of Experiment 2, in which it was established that digital images contain exaggerated orientation anisotropy relative to other types of images, it was predicted that acute "digital" visual experience in the form of four hours of videogame play would increase the magnitude of the perceptual oblique effect relative to controls who were simply told not to engage with screens for the four hours between eye tracking sessions. Results from the current work are consistent with this interpretation; on average, the perceptual oblique effect, as indexed by differences in the detection speed as a function of orientation, increased when subjects "trained" their visual systems by playing the computer game "Minecraft" (Mojang, 2011) in an otherwise dark room, but not after a simple delay consisting of normal visual experience. In fact, participants in the Minecraft condition gained facility with horizontal orientations after training (*Pre –*

Post = 13ms), whereas the control subjects actually gained facility with oblique contours (*Pre – Post* = 15ms).

While accuracy did vary as a function of orientation, replicating the accuracy effect obtained in Experiment 1, it was not controlled by the three-way interaction (Condition x Session x Orientation) describing the full manipulation in the current experiment. This should not be surprising, as the parameters of our contour stimuli, including the relative contour density (D = 1.0) and straightness of our contours, were designed to make detection fairly easy. Under these conditions, the saccade latency measure is likely more sensitive than raw accuracy for detecting subtle differences in processing. Subjects accurately detected the contour on 77.3% of trials, and so large differences in accuracy were unlikely to be found given the subtle nature of the training manipulation.

Characterizing the detection speed differences presented above as “fluency” effects seems best, as fluency is often cast as “ease of processing” (Alter & Oppenheimer, 2009; Westerman, Lloyd, & Miller 2002). Studies operationalizing perceptual fluency using reaction time report a variety of effect sizes, depending on where in the cognitive stream the putative processes likely occur, with more perceptual manipulations typically engendering more subtle effects (Reber, Wurtz, & Zimmermann, 2004; for a review of how fluency is variously characterized, see Alter & Oppenheimer, 2009). And, while detection speed differences in the 10-15ms range are certainly not enormous, neither was the current manipulation designed to elicit the maximum effect. Instead, this was an exploratory investigation of whether ecologically valid experience with caricatured visual statistics is sufficient to alter a basic aspect of visual processing, at least in the short term.

That four hours of uninterrupted computer game play alters visual processing is interesting, since theory (Ben-Yishai, Bar-Or, & Sompolinsky,1995) and experiment (see Kohn, 2007 for a modern review) suggests that short term adaptation of this sort likely underpins longer-term perceptual statistical learning if inputs are anisotropic and recurring.

The ubiquity of computer games in modern society entails that this training manipulation fits better within the paradigm of cognitive ethology (Kingstone, Smilek, & Eastwood, 2008) than within traditional cognitive psychology. Under this paradigm, experiment design is justified more by questions about how normal experience (rather than well-controlled experimental stimuli) influences cognition. Visual adaptation is certainly not a new phenomenon, but the current work provides a first estimate of the robustness of this process as a function of modern visual experience.

One important aspect of the training manipulation detailed here concerns the volitional, first-person point of view adopted by the game player; the extent to which this controlled the effects reported here remains unclear. It may be that the allocentric perspective adopted by the Minecraft (Mojang, 2011) players in our experiment was critical – certainly this would be predicted from a Gibsonian perspective (for a modern re-publishing of the class work, see Gibson, 2014) in which optic flow (Warren, Kay, Zosh, Duchon, & Sahuc, 2001), not mere static properties of visual scenes, controls perception. Future work may consider testing a variety of stimulus types, or simply having a portion of subjects view the game while not playing it.

Despite these limitations, there is good reason to believe the modest effects reported in the current work underestimate the magnitude of the effect in real world experience. Visual contours in perceptual psychology experiments, including the test experiment reported here, are unlike realistic contours in that they are typically static and constructed of luminance-mediated Gabor patches. Contrasting these contours with the chromatic, dynamic contours that populate realistically experienced natural scenes suggests that the effect reported here suffers a generalization decrement from training to test. Developing a training manipulation that realistically reflects experience with digital scenes was relatively easy compared to the difficulty inherent in designing a similarly ecologically valid test experiment.

Future work will likely refine our understanding of the interplay between visual statistics and visual perception by establishing the boundary conditions under which short-term adaptation under realistic conditions leads to long-term learning. Yao and colleagues (2007) suggest that visual cortex best responds to naturalistic stimuli, and that changes in responsivity likely last beyond the duration of experimental participation. Understanding ecological perception more fully will likely entail testing other aspects of visual perception such as chromatic sensitivity or object recognition individually. Eventually, with advances in methods and knowledge about the processes involved, researchers will likely combine utilize multisensory experimental paradigms aimed at discovering non-linearities in adaptation and learning emergent only when sense data are fully integrated, as they are in everyday experience.

General Discussion

Summary

This volume presents three novel results related to the interplay between the perception of oriented contours and the changing physical world. First, it was demonstrated that a contour-level "oblique effect" (Appelle, 1972) is capable of being indexed by a simple eye tracking paradigm. Horizontal, vertical, and oblique straight-line contours comprised of Gabor patches were embedded amidst equally dense noise. After only 80 trials, and using a method that requires only eye movements, differences in accuracy and detection speed as a function of orientation emerged.

While this general H>V>>O effect has been well-established in perceptual psychology since Appelle's landmark (1972) study, no investigation to date has employed eye tracking as a method; instead they have relied on overt responding by subjects. Most studies require many more trials than the current work, making participation taxing and precluding developmental applications. But beyond mere methodological novelty, this study marks a psychophysically rigorous demonstration that the oblique effect scales to contour-level processing, not simply orientation discrimination. Recent research suggests that despite superficial similarities between the perceptual organizational rules at work within flanker-facilitation tasks (e.g. Polat & Sagi, 1993) and contour integration tasks (Field, Hayes, & Hess, 1993; Hipp, Dickerson, Moser, & Gerhardstein, 2014), the cortical loci of these processes are likely different (Huang, Hess, & Dakin, 2006). Most researchers now believe contour-level proximity and collinearity effects emerge from processing in V2. If this characterization is accurate, then Experiment 1 effectively suggests that an oblique effect also emerges from V2 level processing due to its use of well-established contour detection methodology.

Given relatively recent changes in visual ecology, comparing various visual environments in terms of basic properties is important if we are to understand how perception adapts to these changes. Natural scenes had already been reported to exhibit a degree of orientation anisotropy (e.g. Hancock, Baddeley, & Smith, 1992; Hansen & Essock, 2004). That is, these scenes on average contain more horizontal information than vertical information, and more in both of these canonical orientations than oblique. Yet no studies to date had analyzed the orientation content within digital scenes containing a screen media stimulus. Experiment 2 thus used an adaptation of a cutting-edge computational method established by Schweinhart and Essock (2013) to compare the orientation content contained within three types of image - natural, urban, and digital scenes. Results were unambigious; urban scenes contained exaggerated orientation anisotropy relative to natural scenes, and the digital scenes were even more exaggerated in this regard, containing significantly greater orientation anisotropy than even the urban scenes. While it is likely the framing border of the tablet contributed to the anisotropy found in our analysis of digital scenes, an analysis of only what is on screens without including the screens themselves would likely underestimate the degree of anisotropy the visual system experiences in real-world scenarios involving screen media.

Visual ecology clearly impacts aspects of visual perception, including the magnitude of the oblique effect and other aspects of visual perception (Annis & Frost, 1973; Fang, Bauer, Held, & Gwiazda, 1997). That digital scenes contain caricatured orientation anisotropy even relative to the already exaggerated orientation content in urban scenes led to the prediction that the perceptual oblique effect may be malleable as a function of caricatured visual experience. Such a prediction also fits well with data suggesting about cortical coding of natural scenes (Yao, Shi, Han, Gao, & Dan 2007) and the relation between perceptual learning and stimulus complexity (Dorais & Sagi, 1997; Adini, Sagi, & Tsodyks, 2002). To test this prediction, a pre- post-test training experiment was designed around the methods of Experiment 1. Half of participants spent the four hours of intervening time between eye tracking sessions playing Minecraft (Mojang, 2011) uninterrupted in a dark room, while the other half were instructed to avoid screen media for four hours. Results indicated that detection speed improved for canonical contours relative to oblique contours after computer game training, thereby increasing the magnitude of the oblique effect. This was loosely cast as a "fluency" effect; experience with the caricatured orientation statistics of Minecraft, but not a simple delay with little screen media exposure, increased participants' ease of processing canonical contours relative to oblique contours.

Extrapolating Beyond the Current Data

Several questions emerge from the results described in this volume. First, how likely is it that the sort of short-term adaptation found in Experiment 3 lends itself to longer-term perceptual learning? Both of these functions depend on plasticity, and the role of plasticity in cognitive function is presumably to enable the organism to adaptively utilize statistical regularities in the environment to improve behavior. While adaptation and perceptual learning operate at different time scales, it may be the case that the short-term neural changes giving rise to adaptation guide the development of longer-term plasticity underlying perceptual learning, as is the case in the auditory maps of barn owls (Gutfreund & Knudsen, 2006).

Related to this question of long-term learning, how might the current results impact developing perceptual systems during ontogeny? Given that young children are primary consumers of digital content, what might it mean for their developing visual systems to continuously experience caricatured input? Orientation anisotropy is reflected in the visual cortex; the amount of visual cortical tissue dedicated to horizontal and vertical orientations is greater than oblique-dedicated tissue (Furmanski & Engel, 2000; Li, Peterson, & Freeman, 2003; Mannion, McDonald, & Clifford, 2010). When these results are paired with studies suggesting contour processing undergoes slow, protracted development at least into late adolescence (Hadad, Maurer, & Lewis, 2010; Hipp, Dickerson, Moser, & Gerhardstein, 2014; Kovacs, Kozma, Feher, & Benedek, 1999), it stands to reason that the developing neural/perceptual systems involved in contour processing would be sensitive to and eventually reflect gross anisotropies in the visual environment. This would entail that a child born in modern Manhattan who spends 6-8 hours a day interacting to some degree with screen media would have a very different distribution of orientation-selective visual cortical tissue than a child born in a more “natural”, less anisotropic environment.

A developmental interpretation of the current findings also speaks against Geisler and colleagues (e.g. 2001) who suggest that the near optimal use of proximity and collinearity during contour detection tasks derives mostly from phylogeny. If our visual systems are sensitive to our rearing environment more than our ancestral one, it may be that subjects in Geisler’s series of studies comparing human performance to Bayesian ideal observers were employing their own set of "priors", reflecting not the "natural", ancestral environment, but the modern, caricatured one.

Limitations

The studies represented in this volume are of course not without their inherent limits. Experiment 1, for example, sought to answer a highly specific, and thus limited – question: Can the oblique effect be indexed quickly and reliably using a method requiring no overt responding? While this was confirmed, the boundary conditions of this paradigm have not yet been fully explored. For example, how does contour orientation affect contour detection under conditions of stimulus uncertainty, such as within-contour "jitter" (Field, Hayes, & Hess, 1993) or changes in relative noise density (Hipp, Dickerson, Moser, & Gerhardstein, 2014; Kovács, & Julesz, 1993)? Because this experiment was designed both to serve Experiment 3's design and (separately) as a candidate experiment for a new cognitive development battery capable of working with young children, it was necessarily restricted in terms of how many parameters could remain free to vary.

A second limitation inheres in the set of images analyzed in Experiment 2. While I sought to capture a diverse set of images for orientation analysis, the corpus of natural images tested essentially included only forest scenes, and the urban images were similarly limited to a small city in Upstate New York. Moving forward, future research aimed at better establishing these findings as general should aim for more representative sample images, especially with respect to cities, as urban scenes have not been as extensively studied as so-called "natural" scenes.

Another limitation concerns our method of training in Experiment 3. The Minecraft (Mojang, 2011) training used in this experiment was not created to elicit the maximum effect possible; rather, it was chosen as a representative "digital" visual experience. Adopting the perspective of cognitive ethology entails that the focus will be on humans interacting with naturalistic environments rather than highly controlled experiments. As such, this also implies that in many circumstances the magnitude of the effect found will be smaller than if the manipulation were chosen for purely theoretical purposes. For instance, if instead this experiment measured the oblique effect of participants before and after four hours of viewing oriented bar stimuli, the measured difference in the contour detection task may have been larger. The decision to use Minecraft (Mojang, 2011) as a training stimulus did increase the external validity of the study, but it also likely reduced magnitude of the measured effect. Both approaches – the purely experimental and the ethological – have their merits, and can serve complimentary roles in psychological science.

More generally, orthodox visual psychophysics experiments of the sort presented in this volume are limited by the contrived nature of their stimuli. This is particularly true in contour processing, in which a qualitative gap exists between experimental stimuli and ecologically valid contours. Great methodological strides have been made in pure experimental psychophysics, but the complexity of developing more ecologically valid approaches to stimulus design will require great ingenuity in order to move the field forward.

Despite these limitations, this series of experiments serves as an early step towards enhancing the external validity of visual psychophysics and understanding relation between our increasingly “digital” visual environment and our dynamically adaptive visual perception. With every passing day, screens develop to better capture our attention and encroach deeper into our lives. Studying how human psychology interacts with these new ecological demands can only improve how we relate to our digital creations.

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