Mondrian, eye movements, and the oblique effect

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Abstract. Observers prefer Mondrian’s paintings in their original orientation compared to when rotated—“the oblique effect” (Latto et al, 2000 Perception 29 981–987). We tested whether eye movements could provide any insight into this aesthetic bias. While recording fixation duration and saccade length, we presented eight Mondrian paintings dated 1921–1944 on a CRT in either their original or seven rotated positions to ten observers who used a Likert scale to report how (dis)pleasing they found each image. We report on eye-movement patterns from nine pairs of images that had a significant orientation effect. During the 20 s scans, fixation durations increased linearly, more so for pleasing images than for non-pleasing images. Moreover, saccade distances oscillated over the viewing interval, with larger saccade-distance oscillations for the pleasing images than the non-pleasing images. Both of these findings agree with earlier work by Nodine et al (1993 Leonardo 26 219–227), and confirm that as an abstract painting becomes more aesthetically pleasing, it shows both a greater amount of divergent/specific types of image exploration and balance. Thus, any increase in visual fluency in localizing vertical and horizontal versus oblique lines can lead to an increase in the aesthetic pleasure of viewing Mondrian’s work.

1 Introduction

In 2000, Latto et al extended the psychophysical ‘oblique effect’ phenomenon, otherwise known as ‘meridional anisotropy’, to the field of aesthetics. The psychophysical oblique effect, coined by Stuart Appelle (1972), is the principle that “our perception of oblique or diagonal lines is slightly inferior to our perception of horizontal and vertical lines” (Latto et al 2000). The later abstract paintings (1921–1944) by Piet Mondrian contain only horizontal and vertical lines (even when the paintings are tilted 45° in a lozenge), which Latto and colleagues had observers rate for their pleasingness in either their original or rotated positions. They found observers preferred the original (ie horizontal and vertical line) positions. We measured observer’s eye movements while they viewed either original or rotated Mondrians to discern if low-level, unconscious, behaviors (such as involuntary eye movements) were related to the phenomenon of the aesthetic oblique effect.

For example, Berlyne (1971) theorized that aesthetic evaluation is based on two types of visual exploration, one being global or diverse exploration and the other being specific information gathering (Locher et al 2007; Locher and Nodine 1987; Molnar 1981; Nodine et al 1993). Specific exploratory behavior occurs when a state of perceptual or epistemic curiosity is created in an observer by uncertainty concerning the information content of an object or event. The function of specific exploration is to obtain information about the object to relieve this uncertainty. On the other hand, diversive exploration is used to “seek out stimulation, regardless of content or source, that has appealing collative properties” (Berlyne 1971, page 100). These two types of exploration might be evident in differing eye-movement saccade lengths and fixation durations depending on whether a Mondrian painting was presented in its (preferred) original or (non-preferred) rotated position.

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Mondrian was preoccupied with the specific proportions of his colored regions and their relationship to his bold horizontal and vertical lines (Nodine and McGinnis 1983). Locher et al (2005) altered compositions by Mondrian by swapping the colors in the colored regions. This altered the amount of each color (since each colored region differed in size), which, the researchers claimed, changed the perceived weight of the areas and thus the location of the balance centers of the compositions. They showed that manipulating these regions of original Mondrians influenced observer’s perception and evaluation of his work. Since Mondrian was conscious of creating balance and harmony in his works, we claim that such effects can be detected in observer’s patterns of eye movements. We hypothesize that, compared to non-preferred images, preferred images should appear more balanced and therefore produce more stable viewing over the viewing period. Thus, fixation dwell-times should be longer as the viewing period progresses for pleasant compared to unpleasant images. It is important to realize that pleasant and unpleasant images are simply rotations of each other, leaving no a priori reason to expect differences in dwell times, other than increased balance (Locher et al 2005). We also hypothesize that Berlyne’s theory of diversive/specific pattern of visual exploration (1971) is correct. We intend to verify this by showing that observers fluctuate more between long and short saccade lengths with pleasant compared to unpleasant images.

1.1 The psychophysical oblique effect: Meridional anisotropy
Perhaps the earliest mention of the oblique effect was by Mach who found that observers were more accurate at matching a line parallel to a horizontal or vertical comparison line than to an oblique line (Mach 1861, cited in Westheimer 2003). Likewise, Jastrow found that observers required to reproduce visually presented lines were markedly superior with horizontal and vertical stimuli than with oblique stimuli (Jastrow 1893, cited in Appelle 1972). Higgins and Stultz (1949) also found that observers had 20% higher visual acuity when lines passing through their visual field were horizontal or vertical than when they were oblique.

Behavioral evidence from animal studies has also supported the notion of an oblique effect. For example, goldfish were trained to discriminate between either horizontal and vertical rectangles or between left and right oblique rectangles. The latter group required twice as many training trials, suggesting inferiority in the perception of oblique orientations (Mackintosh and Sutherland 1964; see Appelle 1972 for a more complete review of animal literature).

Neurophysiological research was used in an attempt to determine where in the visual system the oblique effect, also known as meridional anisotropy, originates. Mitchell et al (1966) eliminated optics as the source of the oblique effect, and concluded that its origin must lie in the retina and/or higher visual pathways. Evidence from animal studies has shown that there are more cortical V1 orientation detectors for horizontal and vertical lines than for oblique lines (Latto et al 2000). More recently, Westheimer (2003) concluded that the neural locus existed in more central processing as opposed to the primary visual cortex. (For a counter-example see Heeley and Buchanan-Smith 1994.) In that eye movements rely on both low- and high-level processes—that is, involuntary and voluntary movements—it is possible that determining how scan paths differentially process vertical and horizontal images from oblique ones might be instructive.

1.2 The aesthetic oblique effect and Mondrian
Latto et al (2000) claimed that the psychophysical oblique effect may give rise to an aesthetic oblique effect, which is the notion that we prefer vertical and horizontal lines over oblique lines. They examined the aesthetic oblique effect using the abstract art of Piet Mondrian (1872 – 1944), whose oeuvre during the first half of the 20th century
permanently shaped modern art. Mondrian pioneered the Neoplastic art movement and over his lifespan developed a style that was completely abstract. Eventually, Mondrian abandoned all representation of natural form, quoting Cezanne who said “Beauty in art is created, not by the objects of representation but by the relationships of line and color” (Esman 1994, page 337). He therefore used only black horizontal and vertical lines, and three primary colors: red, yellow, and blue. Mondrian felt so strongly about using only horizontal and vertical lines, that, when a fellow artist of the De Stijl movement, Theo van Doesburg, insisted on using diagonals, Mondrian broke off their friendship and left the movement (Esman 1994, page 332).

Ultimately, Mondrian’s “familiar style of geometric abstraction has had an extraordinary influence both on the plastic arts themselves and on the world of commercial art and design” (Esman 1994, page 325). This may be because he had both an excellent understanding of aesthetics and of how images are processed by our visual system. “[Mondrian] seems to have been deliberately isolating and simplifying the features of stimuli in the attempt to identify the elementary particles of human perception” (Latto et al 2000, page 981). In essence, he may have understood that there was an aesthetic oblique effect even before it was scientifically investigated.

Latto et al (2000) examined the aesthetics underlying Mondrian’s work by relating it to the oblique effect. They showed thirty observers sixty-four images of Mondrian’s paintings taken from 1921 to 1944. There were eight initial paintings, four with horizontal and vertical frames, and four with oblique (ie lozenge) frames, and they rotated each image seven times at 45° intervals. Half of the rotations created oblique components or lines (45°, 135°, 225°, and 315°), while the other half created horizontal and vertical components or lines (original orientation, 90°, 180°, 270°). They showed each image for 5 s and asked observers to rate each on a 1–7 point scale of aesthetic pleasingness. They found a significant main effect for component orientation, such that observers rated images with horizontal and vertical components as more aesthetically pleasing than images with oblique components. They also found a significant main effect for rotation. The original orientation was preferred over rotated versions, specifically over all rotations that produced oblique components. They concluded that there were two factors that reduced the appeal of Mondrian paintings, one being rotation per se and how that might have affected the overall balance of the painting, and the other was the introduction of obliquely oriented components (Latto et al 2000, page 984). They concluded that “we prefer horizontal and vertical lines because they are perceptually more powerful” and therefore more effectively processed by our visual system (Latto et al 2000, page 986). Although they found that horizontal and vertical lines were more aesthetically pleasing than oblique lines, they did not obtain any direct evidence why this is so. Our objective is to extend the research of Latto et al (2000) by including eye-tracking measurements to investigate the underlying causes of the aesthetic oblique effect.

1.3 Eye tracking, perceptual fluency, and Berlyne’s aesthetic evaluation

Eye movements are marked by saccades which are quick jumps about three times per second from one fixation point to another. Commands for horizontal saccades are controlled by premotor neurons in the pons and medulla, while commands for vertical movements are controlled by premotor neurons in the rostral midbrain. There is no specific neural structure that controls oblique saccades; instead, they are produced by a combination of the horizontal and vertical areas (Sparks 2002). These anatomical distinctions suggest that horizontal and vertical saccades may be more natural and efficient, which may explain why horizontal and vertical lines are easier to detect. This may also be what makes them more aesthetically pleasing. For example, Reber et al (2004) propose that the perception of beauty arises from the perceptual fluency
of an observer’s processing experience. Perceptual fluency is defined as a subjective experience reflecting the ease with which we are able to process an image. According to Winkielman et al (2003), processing fluency is hedonically marked, such that the more fluent an observer’s processing experience the more positive his/her aesthetic response. Thus, any increase in visual fluency in localizing vertical and horizontal versus oblique lines can lead to an increase in the aesthetic pleasure of viewing Mondrian’s work.

Testing such notions is novel in the field of eye tracking and there are no previous studies relating eye movements to the aesthetic oblique effect. However, earlier research has shown that there is a higher concentration of specialized receptor cells in the fovea region, and that meridional anisotropy or the oblique effect decreases as you move away from the fovea (Mansfield and Ronner 1977). This suggests that, since eye tracking measures placement of the fovea, it could potentially determine underlying oblique effect mechanisms. For example, since oblique lines require more processing, rotated Mondrian paintings may show a greater concentration of fixations along their oblique lines than Mondrian paintings containing only vertical and horizontal lines.

One way to approach this topic is to examine how eye movements relate to judging aesthetically pleasing works of art. Berlyne (1971) concluded that aesthetic evaluations are based on two types of visual exploration, one being global or diverse exploration and the other being specific information gathering (Locher 1996; Locher and Nodine 1987; Molnar 1981). Diverse exploration is characterized by short dwell times, or eye fixations that are under 300 ms, after which a saccade is made. Specific exploration is characterized by long swells, or eye fixations that last for more than 450 ms, after which shorter-length saccades are made (Nodine et al 1993). Berlyne concluded that to make aesthetic judgments our eyes follow an oscillating pattern of long and short saccades. Initially we exhibit global exploration through fixations of short duration (short dwells and long saccades), followed by a period of more specific, information-gathering fixations of longer duration (and short saccades). This pattern repeats itself as the eyes search for specific areas of interest to focus on. Berlyne concluded that this pattern of short and long saccade lengths represents high variation in exploration, which is crucial for judging images as aesthetically pleasing (Noton and Stark 1971; Stark and Ellis 1999). In our experiment, observers see the same pictures only rotated, thus the null hypothesis is that there should be no difference in the amplitude of saccade-length fluctuations. Thus, accentuation in saccade length oscillations occurring more so with pleasing than with less pleasing images would strongly support Berlyne’s (1971) diversive/specific theory.

In an effort to replicate Latto et al’s (2000) findings, we predict that observers will prefer images with horizontally and vertically oriented components over images that are oriented on the oblique. To extend Latto et al’s (2000) findings, our eye movement scans should reveal saccade lengths with greater oscillations while viewing pleasing versus less pleasing pictures in agreement with Berlyne’s (1971) diversive/specific theory. There should also be a greater concentration of fixations along rotated Mondrian’s oblique lines supporting the Reber et al (2004) and Winkielman et al (2003) work regarding perceptual fluency. Moreover, dwell times should increase more while viewing pleasant versus unpleasant images, in that these images should evoke more balance (Locher et al 2005).

2 Experiments 1 and 2
2.1 Methods
2.1.1 Participants. Thirty Wake Forest University undergraduate students (thirteen males), with normal or corrected vision participated in the first experiment in exchange for course credit. Ten additional students (four males) participated in the second experiment.
We did not analyze gender differences in either experiment because of the small number of observers. Ages ranged from 18 to 24 years with a mean age of 20 years. None of the observers had a college-level art course, and only three observers in the first study and none in the second study were familiar with Mondrian’s work.

2.1.2 Stimuli and apparatus. Eight color images of Mondrian’s paintings—all oil on canvas—adopted from Latto et al (2000) were used as visual stimuli. Each painting consisted of only horizontal and vertical lines and colored regions, and had sides of equal length. As in the Latto et al (2000) study, to control for frame orientation, four paintings had horizontal and vertical frames: Composition in a Square (1929); Broadway Boogie-Woogie (1942–1943); Composition with Red, Blue and Yellow (1930); Composition with Red, Yellow and Blue (1927); and four had oblique frames: Composition I with Blue and Yellow (Lozenge) (1925); Composition with Two Lines (1931); Victory Boogie-Woogie (1943–1944, unfinished); Composition in a Lozenge (1925). Each painting was rotated seven times at 45° intervals, creating eight different images, four with only horizontal/vertical components (original, 90°, 180°, 270° rotations) and four with only oblique components (45°, 135°, 225°, and 315° rotations). Thus, a total of sixty-four images were presented to each observer.

In the first (pleasingness rating) experiment, thirty observers were shown as a group the sixty-four images, where the order of the images was determined by a Latin-Square configuration. The images were projected onto an overhead screen by an automatically run Power Point presentation. Image size differed (ranging from 11.1 deg × 11.1 deg to 14.3 deg × 14.3 deg), depending on where an observer was seated in the room.

In the second (eye tracking) experiment, the sixty-four images were presented in a single random order in an automatically run Power Point slide-show. The images were standardized in size [ie horizontal and vertical frames (16.3 deg × 16.3 deg) and oblique frames (22.6 deg × 22.6 deg)], and presented to observers individually on an IBM computer CRT.

We fit an Applied Science Laboratories model 501 eye-tracking device (series 6000; with a temporal resolution of 120 Hz) onto each observer’s head and calibrated it to their gaze. The device recorded their eye movements as they viewed the paintings.

2.1.3 Procedure. As in the original Latto et al (2000) study, in the first experiment each image was presented for only 5 s. Each observer rated each image on paper on a 1–7 scale of pleasingness; where 1 represented ‘not at all pleasing’, 4 represented ‘neutral’, and 7 represented ‘extremely pleasing’. This scale was chosen as it was found to positively correlate with scales of likeability and preferability (Russell and George 1990). Observers were encouraged to use the whole range of the scale. They were not told that the images would be shown in several rotations; however, upon debriefing, they were asked if they realized this was the case. Most reported that this became obvious after the first few slides, yet most were unaware which compositions were the originals. None said that the repetition of (rotated) images affected their scoring.

Experiment 2 differed in several significant ways from experiment 1, and therefore also from Latto et al’s (2000) original study. In the second (eye-tracking) experiment, each observer’s chin was placed on a chin-rest and the observers were instructed to remain as still as possible for the duration of the experiment. A visual calibration was done by showing observers a slide on the CRT screen with the numbers 1–9 dispersed across three rows. They were instructed to focus on each number, one at a time, while we calibrated their gaze. Observers then focused on a fixation point in the middle of the CRT screen. After 10 s, an image was shown for 20 s duration, during which time we tracked their eye movements. This extended viewing time was necessary to collect enough dwell time and differing saccade-length data. After the picture viewing period,
there was a 10 s inter-stimulus interval (ISI) during which the observers refixed on the middle point of the screen. During the ISI observers verbally rated the previous image on the 7-point scale of aesthetic pleasingness. This process continued until all sixty-four images were viewed and rated. The entire experiment took approximately 35 min. Again, observers were encouraged to use the whole range of the scale, and were not told the images would be shown in multiple rotations. Yet, during debriefing the observers reported that many of the images were rotations but they were unaware which were originals, and did not feel the repetition of (rotated) images affected their scoring.

3 Experiment 1
3.1 Results
3.1.1 Pleasingness ratings. We ran a one-way within-subjects ANOVA, comparing each original image to each of the seven rotated versions. In agreement with Latto et al (2000), we found observers rated pictures composed of horizontal/vertical lines as more aesthetically pleasing than pictures composed of oblique lines ($M_{\bar{3}}$: 47, $SEM_{\bar{3}}$: 218 versus $M_{\bar{3}}$: 29, $SEM_{\bar{3}}$: 201, respectively; $F_{1,4} = 4.628$, $p < 0.05$). A series of $t$-tests revealed that the original orientation ($M_{\bar{3}}$: 51, $SEM_{\bar{3}}$: 186) was significantly greater than all of the oblique orientations ($45^\circ$: $M_{\bar{3}}$: 37, $SEM_{\bar{3}}$: 187, $t_{29} = 2.135$, $p < 0.05$; $135^\circ$: $M = 3.18$, $SEM = 0.203$, $t_{29} = 2.332$, $p < 0.05$; $225^\circ$: $M = 3.29$, $SEM = 0.198$, $t_{29} = 2.287$, $p < 0.05$; $315^\circ$: $M = 3.31$, $SEM = 0.216$, $t_{29} = 2.089$, $p < 0.05$; all one-tailed). However, the original orientation was statistically insignificantly different from all of the images with horizontal/vertical lines ($p > 0.05$). These findings confirm Latto et al's (2000) main finding, and demonstrate an aesthetic oblique effect. An eye-movement experiment was thereby conducted to determine the underlying cause of the phenomenon.

4 Experiment 2
4.1 Results
4.1.1 Pleasingness ratings. Figure 1 (top) shows the raw scores for pleasingness rating and standard deviations for each of the ten observers on the 1–7 scale for all sixty-four images. Figure 1 (bottom) shows the raw scores and standard deviations for all ten observers, this time parsed by the sixty-four images in the order they were shown. The mean rating in these graphs was 3.89 ($\pm 1.37$ SD), slightly lower than an average score of 4. Since, for any given image, observers varied considerably in their ratings, we transformed all of the 1–7 pleasingness ratings for each image to standardized $z$-scores to normalize the data. Everything that was statistically significant with the $z$-scores was also significant with the raw data.

Using $z$-scores, we ran seven paired-samples $t$-tests (one for each image) comparing each original image to each of its seven rotations. From these $t$-tests we found nine pairs of images that were statistically significantly different on pleasingness ratings from each other. As predicted by Latto et al (2000), in six cases an original was more pleasing than a rotated version, but in three cases a rotated image was more pleasing than the original (figure 2). These data do not fully support the oblique effect phenomenon found in our first study. Observers did not consistently prefer paintings by Mondrian when they were in their original orientation or when they had only horizontal and vertical lines. This may be due to the fact that the images in the second experiment were, on average, 66% larger than in the first experiment. Also, the viewing duration in the second experiment was four times that of the first experiment (20 s versus 5 s). We increased the size of the images so that saccades of significantly different length could be obtained. We increased the duration in the second experiment, so that dwell times of different extent could be obtained. Changing these parameters could have altered
Figure 1. The average raw pleasingness score for each observer (top) and for each of the sixty-four images (bottom). Error bars represent standard deviations.

Figure 2. [In color online, see http://dx.doi.org/10.1068/p6160] The z-score significant differences of pleasingness ratings showing six cases in which the original orientation was preferred to a rotated version, and three cases in which a rotated version was preferred to the original.
our results in unforeseen ways. For example, having more time to scrutinize larger images may have made observers more likely to expand their range of verbal reports, which even a transition to $z$-scores could not remedy. To overcome this limitation, the eye-movement results from the nine pairs of statistically significant differences between image pairs were compared to eye movement results from nine pairs of statistically insignificant differences between image pairs chosen at random. We were able to obtain statistically significant eye-movement results from the nine significant pairs which were not reproducible with the nine insignificant pairs (in all cases $p > 0.23$), lending credence to our findings.

Owing to our relatively small sample size ($n = 10$), we accepted $p < 0.1$ as statistically significant; and only in cases 1 ($p < 0.06$), 5 ($p < 0.035$), and 6 ($p < 0.04$) were horizontal and vertical lines preferred over oblique lines. In cases 2 ($p < 0.063$), 3 ($p < 0.062$), and 4 ($p < 0.076$), originals were preferred over rotated images; however, these rotated versions also contained horizontal and vertical lines. More importantly, in cases 7 ($p < 0.087$), 8 ($p < 0.058$), and 9 ($p < 0.092$) the rotated images were preferred over the originals (note that these $z$-score significant differences are negative). While there were only nine cases where statistical significance was found, Latto et al (2000) did not specify the number of specific pairs that reached statistical significance, and since we were interested in differences in eye-movement patterns for significantly different pairs, we proceeded as follows.

4.1.2 Eye tracking. The eye-tracking data we analyzed took the above nine significant pairs, and their $z$-scores were used to separate each pair of images into ones that were pleasing versus the ones that were not pleasing. We then plotted the eye scans for each of the ten observers on each of the significant eighteen ($9 \times 2$) images. We visually compared these scans to determine where observers fixated on the different images, and whether these ‘areas of interest’ were similar or different. This allowed us to determine if observers focused on different areas of interest in the original versus rotated images (eg see figures 3 and 4). Figure 3 shows the pattern of fixations across all observers for a representative preferred (original) image versus a non-preferred (rotated) image. It is evident that the scan patterns are quite different for the two images. This was tested by placing a virtual $3 \times 3$ grid over each image and tallying the number of fixations per cell in the grid for each image. A $\chi^2$ test revealed a statistically significant difference for the upper-yellow, lower-blue, and adjacent lower-middle-white regions ($\chi^2, 9-\nu = 31.25, 22.72, \text{ and } 16.07$, respectively, $p < 0.05$). While the fixation pattern for the original image follows a broad, upward diagonal slope, the fixation pattern for the rotated image follows more of an L-shaped pattern centered on the middle of the image where observers focused more near the black oblique lines. This suggests
that rotation alone affected observer’s eye movements. It is also notable that stimulus salience did not drive the pattern of eye movements. For example, in the original image there were no fixations located in the upper-left (yellow) square; however, in the rotated version there were quite a few. This suggests that observers are not necessarily looking at the most salient regions, or that what is considered a salient region changes with rotation. Locher et al (2005) has shown that altering the locations of the primary colors of specific Mondrians alters the perceived heaviness of a primary color. Thus, we surmise that not looking at a specific (what might have been salient) area may be related to its new location on the (rotated) canvas. This hypothesis is supported by the eye-movement work of Nodine and McGinnis (1983), where they added an extra rectangle of color to an original Mondrian to shift its pictorial balance.

Figure 4 shows the scans for one observer for one image and its seven rotations. It again shows that eye scans were strongly affected by rotation. Note once more that there are fixations in the (salient) yellow square in only three of the rotated versions. This figure also shows that there is a great deal of variability among the eye scans for each image, which was a consistent pattern that we found for each observer. For example, in the first (original) image the fixation points are mostly centralized in the large open white space of the painting. In the second image, the pattern of fixations is more variable, and the saccades seem to follow the upper black oblique line, while in the fourth image the eye scan pattern is extremely variable, as the observer jumped all around the image. This diverse pattern of scans is typical of all observers and is further evidence that rotation affected the pattern of eye scans.

Therefore, we ran a $2 \times 9 \times 10$ (pleasingness x cases x proportion of viewing time bins) repeated-measures ANOVA to look for patterns across the duration of the scan. For our independent measure we broke the duration time of each image scan into ten equal bins (10% of fixations in each bin). Our dependent measures were average saccade length and fixation durations. While we hypothesized that the data would fluctuate, we had no a priori knowledge what polynomial would provide the best fit to the data. Therefore, we determined the lowest-level polynomial that was a significant fit to the data, and we plotted this line. We did this for each of the eighteen images of the nine significant pairs. This allowed us to determine the scanning pattern for each image, across the 20 s duration of each scan, and compare the scanning pattern for pleasing versus not pleasing images. Overall, fixation durations increased linearly [not exponentially as Hochberg (1976) describes; see figure 7], where image fixation duration increased more for pleasing (figure 5a, solid line: $y = 0.014x + 0.28$,}$
than non-pleasing images (figure 5b, solid line: $y = 0.004x + 0.32$, $R^2 = 0.28$, $p < 0.046$). These slopes were statistically significantly different ($F_{1,9} = 5.792$, $p < 0.039$).

Moreover, saccade distances oscillated over the viewing interval; with the pleasing image fit being more variable (ie saccade distance oscillations were larger: figure 6a, dashed line: $R^2 = 0.74$) than the non-pleasing image fit (figure 6b, dashed line: $R^2 = 0.80$). These effects were not statistically significant at the linear level, and were significant only when they reached a 5th-order polynomial for the preferred images and a 4th-order polynomial for the non-preferred images.

5 General discussion

The pleasingness data from our first experiment support an aesthetic oblique effect. When we followed the methodology of Latto et al (2000) exactly, observers preferred the original orientation of Mondrian’s paintings over rotated versions. However, this was not always the case in the second experiment, where the preferred paintings did not always have horizontal and vertical components. For example, some of the preferred paintings were rotated versions of the images, and had oblique components. This may, in part, have been due to having a different viewing scenario in the second experiment. To accrue sufficient eye-movement data, the viewing times in the second experiment were longer (20 s versus 5 s), and the images were made approximately 66% larger. These alterations could have expanded the ratings, which may have decreased the possibility of obtaining more statistically significant differences between pairs in the second experiment.
For example, Locher et al. (2007) showed that observers shift their aesthetic ratings when they only had a 100 ms glance at several artworks, compared to when they had unlimited time.

In agreement with Latto et al. (2000) and our first experiment, Haun et al. (2006) were able to show that observer’s preferred horizontally and vertically oriented Mondrians compared to those presented obliquely (which they call a horizontal effect). However, their results were obtained by a different method than that of Latto et al. (2000). They presented all eight versions of each picture (the original and its seven rotations) simultaneously and had observers’ rank-order the images, with ‘1’ indicating the best image and ‘8’ indicating the worst image. Unfortunately, given that we were interested in eye movements made while viewing (and mentally evaluating) each image, we were not able to present all images simultaneously. Yet, we were able to take the nine cases where we did find significant differences between pleasing and non-pleasing images and relate them to our eye-tracking differences.

Most importantly, our evidence supports the diversive/specific hypothesis of exploration proposed by Berlyne (1971). That is, we found greater saccade-length fluctuations for pleasing versus non-pleasing images. In 1976, Hochberg replotted data collected by Antes (1974) of observer’s eye movements while they were viewing aesthetically pleasing works of art, in order to find support for Berlyne’s hypothesis (figure 7). However, unlike Hochberg’s (1976) exponential-decay finding, we found that saccade lengths oscillated over time (figure 6). This may more accurately support the diversive/specific hypothesis. That is, saccade lengths are greatest when the observer is diversively exploring the painting, whereas saccade lengths decrease as the observer focuses on specific areas of interest and uses a more specific pattern of exploration. The oscillating pattern present in our data is evidence for the back-and-forth pattern of diversive/specific exploration proposed by Berlyne (1971). Locher and colleagues (2007) have found that observers rate artwork higher when it is viewed for an unlimited amount of time compared to only glancing at the image (although the two reports are highly correlated). We also found an increase in our ratings on going from experiment 1 to experiment 2. It may be that this additional time allows for oscillations in saccade length to occur.

One potential reason our data may differ from Hochberg’s may be due to the abstract nature of our images. Hochberg used Antes’s (1974) data, which were collected from observers as they viewed realistic images by such artists as Leon Kroll (see figure 8, top).

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**Figure 7.** Hochberg’s representation of the changes in fixation duration (D) and in saccade extent (E) (after Hochberg 1976; data by Antes 1974).
Antes analyzed his data by dividing his paintings into regions of ‘informativeness’ (figure 8, bottom), and examined the proportion of viewing time spent in each region. We did not divide our images into regions of salience because we believed that the abstract nature of the images would automatically draw observers to the most salient regions (black lines and blocks of color). However, this was not always found in our data; for example the yellow square in image 1 was not consistently fixated upon (see figures 3 and 4). Thus, it would be interesting in future studies to examine regions of salience in the Mondrian images to determine how they are affected by rotation.

Such notions are prominent in the work of Leder et al (2004). They consider how early versus later stages of information processing are related to making aesthetic judgments. They might regard involuntary eye movements to be driven by meridional anisotropy and the salience of using primary colors, while voluntary eye movements occur during cognitive appraisal. Thus, the fluctuation in saccade lengths may be the result of integrating voluntary and involuntary eye movements. Likewise, for more pleasing images dwell times increase as viewing time is extended. This agrees with Leder et al's suggestion that these later stages of processing are more cognitive in nature and less perceptual, thus requiring longer fixations as time progresses. Thus, lower processes (ie involuntary eye movements driven by bold horizontal and vertical lines and primary colors) may combine with higher processes (eg reflected in voluntary eye movements to provide exploration) to provide what Mondrian considered aesthetically pleasing works of art. Locher et al (2005) showed how manipulating original Mondrians influenced observer’s perception and evaluation of his work. Thus, we argue that Mondrian’s use of vertical and horizontal lines to create balance in his works is reflected in subtle ways, such as patterns of diversive/specific eye movements. How enhanced saccade-length oscillations relate to paradigms like visual fluency (Winkielman et al 2003) is a promising venue for future study.

Figure 8. Morning on the Cape by Leon Kroll, as used by Antes (1974).
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References
Antes J R, 1974 “The time course of picture viewing” Journal of Experimental Psychology 103 62 – 70
Esman A H, 1994 “Piet Mondrian: The fusion of art and life” Psychoanalysis & Contemporary Thought 17 325 – 344
Heeley D W, Buchanan-Smith H M, 1994 “Evidence for separate, task dependent noise processes in orientation and size perception” Vision Research 34 2059 – 2069
Higgins G C, Stultz K, 1949 “Variation of visual acuity with various test-object orientations and viewing conditions” Journal of the Optical Society of America 40 135 – 137
Mackintosh J, Sutherland N S, 1964 “Visual discrimination in animals” British Medical Bulletin 20 54 – 59

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