The synoptic art experience

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Abstract

At the start of the 20th century, Moritz von Rohr invented the synopter: a device that removes 3D depth cues that arise from binocular disparities and vergence. In the absence of these visual cues, the observer is less aware of the physical flatness of the picture. This results in a surprisingly increased depth impression of pictorial space, historically known as the 'plastic effect'.

In this paper we present a practical design to produce a synopter and explore which elements of a painting influence the plastic effect. In the first experiment we showed 22 different paintings to a total of 35 observers, and found that they rate the synoptic effect rather consistent over the various paintings. Subsequent analyses indicated that at least three pictorial cues were relevant for the synoptic effect: figure-ground contrast, compositional depth and shadows. In experiment 2, we used manipulated pictures where we tried to strengthen or weaken these cues. In all three cases we found at least one effect, which confirmed our hypothesis. We also found substantial individual differences: some observers experience little effect, while others are very surprised by the effect. A stereo acuity test revealed that these differences could not be attributed to how well disparities are detected.

Lastly, we informally tested our newly designed synopter in musea and found similar idiosyncratic appraisal. But the device also turned out to facilitate discussions among visitors.

Introduction

Viewing a picture confronts our visual system with a paradoxical situation. What we see *in* the picture is often a three dimensional space (pictorial space), whereas what we see *at* the picture is a flat surface containing pigments or pixels. We are generally aware of this duality although we normally only experience one of the two percepts at once. Which of these percepts prevails depends on the visual cues that make up the 3D (pictorial space) or 2D (physical surface) presentations. For example, when looking at a De Kooning, we might immediately notice the thick paint on the canvas and in combination with the absence of pictorial depth cues we will be more aware of the physical surface than of the pictorial space. On the other hand, a more conventional painting with rich depth cues and smoothly varnished surface will likely put us more in the pictorial space mode.

A simple trick to decrease the awareness of the surface is to close one eye. This idea enters psychological literature with an observation of Claparède (1904) but was known long before, most notably by Da Vinci (1888). In his notebooks he more then once mentions closing one eye to change the perception of depth. For example, when looking at the real scene, it helps to close one eye to make it more pictorial, which was recently confirmed experimentally (Wijntjes, 2014). Da Vinci also acknowledges that this trick works in the other direction:

> It is impossible that painted objects should appear in such relief as to resemble those reflected in the mirror[1], although both are seen on a flat surface, unless they are seen with only one eye; and the reason is that two eyes see one object behind another [...]

Although Da Vinci argued that the visual resemblance between reality and pictures is optimal when closing one eye, this does not necessarily mean that he was aware that a picture itself appears different when closing one eye with respect to binocular viewing. Claparède (1904) is often credited to be the first explicitly describing the paradox in this observation: For real objects, depth perception is greatly reduced when closing one eye, but for image perception the opposite occurs ("c'est le contraire qui a lieu: la vision monoculaire est stéréoscopique"). Some years before Claparède, Ebbinghaus (1902) had also described this phenomenon. Interestingly, he explicitly referred to 'Kunstkenner' (art connaisseurs) looking with one eye occluded

[1] Da Vinci very often notes that using a mirror is helpful in many painting problems.

by the palm of their hand resulting in “canals, avenues and porticoes that stretch themselves clearly in the direction of the observer, instead of the upright direction of painting. The illusion of depth is much stronger with one eye than with binocular viewing.”[2].

Although the *pictorial* depth cues are similar for monocular and binocular viewing, the depth cues for the *physical surface* differ substantially. With two eyes, binocular disparity, vergence and accomodation make the flatness of the physical surface accessible to the visual system, whereas for monocular viewing disparity and vergence information is absent. Interestingly, and possibly counterintuitive (hence the ‘paradox’), the perception of the flatness of the physical surface seems to penetrate the perception of pictorial space. The general consensus that emerged after subsequent discussions of Ames (1925) and Schlosberg (1941) is that the primary reason for the effect to emerge is the ability to ‘localise’ the physical surface. Here, ‘localisation’ should be understood in the general sense, so both the location of the surface in space but also the loci making up the geometry of the surface (which is generally flat). Both Ames (1925) and Schlosberg (1941) describe various ways of perturbing the perception of the physical surface. These descriptions largely overlap. We will discuss these solutions together with an overview of viewing devices that could be used for these purposes. The list provided by Ames (1925) is used, but we rearranged the order somewhat.

1. **Monocular viewing**. We already discussed this solution above. Zoth describes a simple device that facilitates monocular viewing, which he called the ‘Plastoscope’ (Zoth, 1916). It consists of a conical tube of 8 cm long, with perimeters of 11 and 8 cm at the ends. The tube was to be made from half stiff leather and the inside should be covered with black velvet. At the smallest side, an aperture can be placed, Zoth recommends a 18 by 12 mm rectangle. In figure 1a a replica is presented that we produced from cardboard and velvet. For reference, a ruler is shown.

2. **The iconoscope**. The invention of the telestereoscope (e.g., von Helmholtz, 1924), that enhances depth perception of real scenes by virtually increasing the interocular distance, triggered the inventions of a device that minimised the interocular difference, which is known

[2]Our rather loose translation of ”Wenn mann ein einsprechend gemaltes Bild einäugig oder wie die Kunstkenner durch die hohle Hand betrachtet, so geht es auseinander, wie man sagt, d.h. die Wasserflächen, Alleen, Säulenhallen erstrecken sich sichtlich von dem Beschauer fort statt von unten nach oben, wie sie gemalt sind; die Illusion kommt dem Eindruck der Körperlichkeit wesentlich naher als bei zweiäugiger Betrachtung.”

as Javal's Iconoscope (Ames, 1925). It somewhat resembles the synopter, which we will discuss later, although the Iconoscope still results in some binocular disparities.

3. **Viewing a picture at a large distance**. For a picture surface that is far away, binocular disparity, vergence and accommodation are too inaccurate to signal the flatness of the surfaces. There is no specific device that can help here, but of course the common cinema experience, where observers are located far away from the screen is a typical example.

4. **Looking through a small hole of 2 mm.** Reducing the size of the pupil increases the depth of field. The 'artificial pupil' is a well known method in vision science often used to maintain the pupil size constant under a wide variety of illumination conditions. Hennessy, Iida, Shiina, and Leibowitz (1976) showed that with decreasing pupil sizes, accommodation stops to depend on the stimulus distance after a certain pupil size. At 2 mm the results were already very similar to smallest size of 0.5 mm. This effect implies that the distance and shape of the picture surface cannot be accurately signalled for an artificially small pupil of 2 mm.

5. **Changing the accommodation of the eyes.** Various viewing devices (including contemporary head mounted displays) make use of a lens to project the image optically farther away, e.g. at infinity. Most notably, the verant[3] lens (Holt, 1904) that von Rohr designed for Carl Zeiss is very suited for this task. In figure 1c an original verant lens is shown that we mounted in a plywood casing. This can be used for monocular viewing of pictures or movies. Although the verant lens is very suitable to increase monocular stereopsis (see next section for an explanation of this terminology), it was more commonly used in stereoscopes. Another class of viewing devices that relies on lens optics which were actually frequently used for single picture viewing are zograscopes and graphoscopes (Kemp, 1990). The difference between these devices is that the zograscope makes use of a mirror. Both devices make use of convex lenses that cancel out binocular disparity, vergence and accommodation cues (Koenderink, Wijntjes, & Van Doorn, 2013). Figure 1d shows both a classic graphoscope and our own version, while in figure 1e a traditional zograscope can be seen.

[3] From 'verus', i.e. 'true'

6. **Changing the convergence.** The lenses used in graphoscopes and zograscopes effectively put the lines of sight parallel, similar to a scene at infinity. Instead of a convex lens, it is also possible to use two pairs of prisms as Ames proposed. Hill (1898) had proposed two ways of adjusting the vergence to be parallel: by mirrors and with prisms (figure 1f).

7. **Blur the image in one eye** Stereo acuity degrades when the retinal images of both eyes are blurred (Westheimer & Mckee, 1980). It is likely that stereo acuity depends on the weakest link and that blurring the image in only one eye yields a similar acuity decrease. However, the sharp image in the other eye will dominate the percept (Levelt, 1966) and it might well be that the monocular blurring goes unnoticed.

8. **Looking through a mirror.** This method appears a little controversial. We can distinguish between two types of mirrors: flat and concave.

   Flat mirrors have been used extensively by artists and Da Vinci promotes using a mirror to transform the real world into something more pictorial. In order to get a sense of flatness for the reflected scene, the observer should be able to see either the mirror surface, or the edges. In the latter case, the use of a mirror is similar to using a frame, which has indeed been shown to flatten a real scene (Eby & Braunstein, 1995). Furthermore, flat mirrors are used in the zograscope, as we believe for purely practical reasons. Although there do not seem to be straightforward reasons why a flat mirror would enhance the depth impression, Higashiyama and Shimono (2012) found that observers did experience this. It should be noted that Ames alluded to a different flat mirror setup than Higashiyama and Shimono (2012): the mirror in Ames' description is half translucent, with a blackened mask behind it, and with an extra aperture between the mirror and the picture. This results in confusing disparities that arise from four different depths (mirror edge, background edge behind mirror, aperture and picture plane) which plausibly perturbs localising the picture surface. This is conceptually very similar to a recently introduced display add-on from a company called dioVision that makes use of a patented (Heine, 2009) curved frame (figure 1h).

   The use of convex mirrors is more straightforward since it works similar to the graphoscope and zograscope. The casing of the snapscope, shown in figure 1g, literally promotes giving a ‘striking stereoscopic effect’.

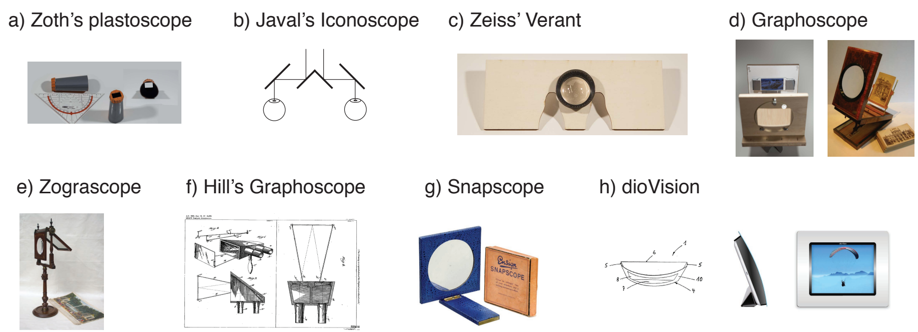

Figure 1: Overview of viewing devices that enhance pictorial depth.

Although the lists of both Ames (1925) and Schlosberg (1941) seem to be rather extensive, neither one mentions the viewing device that is the topic of the current paper: the synopter. von Rohr (1907), who at that time worked for Carl Zeiss, patented an optical invention to give both eyes the same viewpoint. It appears that the synopter was introduced to vision science by Koenderink, van Doorn, and Kappers (1994). Although for many of the viewing devices described above it is easy to retrieve a picture from the internet, we found it impossible to find one of a synopter. This probably means that either is was not put in production at all, or was highly unpopular, unlike the graphoscope and zograscope. This may be due to the increased popularity of stereoscopic devices around 1900, while the graphoscope and zograscope date back to at least a century earlier. Relatively recently, Black (2006) filed a patent concerning a head mounted version of the synopter. In this patent, Black argues that the original synopter never gained popularity due to the high cost. In figure 2, the original patent drawings are shown of three different designs. We will discuss these designs in more detail later but for now it is interesting to view the three left most drawings. Here, the projected eyes are illustrated and it can be clearly seen what the designs accomplish: the first two versions (A and B) position both virtual eyes at the same viewpoint and the last design translates the left eye behind the right eye. Thus the first two seem to remove all binocular disparities, while the last may only cause some uninformative disparities due to the different retinal sizes. Before continuing our discussion of the synopter design, we will first shortly review the theoretical background concerning the aforementioned depth enhancements.

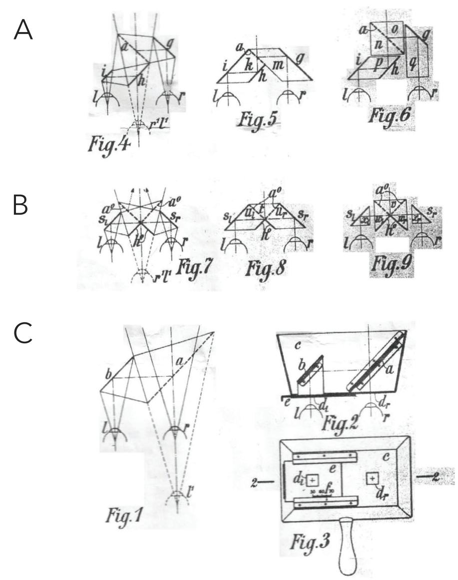

Figure 2: Original images from von Rohrs' patent claim. We have reshuffled the figures to match the order of figure 3 which uses a similar labeling A-C. The labelling 'Fig.4' etc refers to the original patent. Von Rohr drew the basic optics of the three designs in the left column. The drawings in the middle and right column are practical implementations of these three types.

The 'plastic' effect

In the literature, the enhanced depth impression is often referred to as the 'plastic effect' or 'monocular stereopsis'. The word 'plastic' might not sound very intuitive, but reading Schlosberg (1941) ("the person stands out clearly, and plastic space can be seen between him and the background") may clarify the word use. In German, the word 'plastic' also refers to sculpture: the flat picture is transformed into a three dimensional sculpture. Therefore, we could say that the plastic effect has a double connotation: it refers to the space between objects, and it refers to the (sculpted) objects themselves. The term 'monocular stereopsis' refers to the originally greek meaning of 'stereopsis' meaning something like solidity or solidness (referring to the three dimensionality). Thus, stereopsis does not imply binocular disparities, although terms like ‘stereoscopic vision’ often do refer to this. Since the meaning of stereopsis turns out to be ambiguous, and because monocular stereopsis refers to viewing with one eye (which is not always the case in Ames’ list), we will use the term plastic effect. An extra argument for using the term plastic effect is the double connotation of space and shape enhancement, which in our view are indeed the most dominant qualitative differences between normal viewing, and plastic viewing.

The conventional explanation of the plastic effect is that under normal viewing conditions, the flatness that is encoded by the physiological cues diminishes the depth of the pictorial space. Removing these flatness cues makes the pictorial content more ‘plastic’, more articulated in depth. This is how most authors (e.g., Eaton, 1919; Ames, 1925; Schlosberg, 1941; Hochberg, 1962) explain the effect. Although introspective reports are relatively abundant, there are only few experimental studies on the plastic effect. Two studies on pictorial relief showed that for both the synopter (Koenderink et al., 1994) and zograscope (Koenderink et al., 2013) the depth increased for most observers. These data are in line with a cue integration process where cues of both the physical and pictorial space are combined in some weighted average fashion. If the physical surface is difficult to perceive because the cues like binocular disparity are absent, then only monocular cues contribute to the percept. Recently, Vishwanath and Hibbard (2013) challenged this hypothesis. They performed an experiment in which observers had to adjust the cross-section of a rendered (textured, no shading) cylinder. Contrary to Koenderink et al. (1994) they found no difference in depth scaling between observers looking monocularly through an aperture, and binocular viewing. Nevertheless, they did find various other qualitative differences between normal binocular viewing and ‘plastic’ viewing that conform well with the introspective reports found in earlier literature. These findings point into an interesting but at the same time puzzling direction: the plastic effect seems to occur in a qualitative manner without a quantitative increase in depth, or in their words: “perceiving a stronger impression of stereopsis is not the same thing as perceiving a greater magnitude of depth”. The alternative explanation provided by Vishwanath (2014) is that of ‘absolute depth scaling’. Although most depth cues specify relative depth, there are three cues that specify absolute depth: binocular convergence, vertical disparity, and accommodation. Monocular viewing through an aperture cancels out the first two absolute depth cues and leaves accommodation unaffected. The ‘absolute depth scaling’ idea conjectures that the accommodation signal in isolation is now attributed to the pictorial space, instead of the picture surface. If we generalise this concept it means that the visual system can encode the absolute depth of a picture with a set of cues. If this set is reduced up to a certain amount, the residual cues are attributed to the pictorial objects and this attribution causes the plastic effect.

Plasticity and the perception of art

Whichever theory will prove to be correct, they all share the commonality that perception of the pictures' surface influences the perception of pictorial space. Until now we have primarily focused on what occurs outside pictorial space: how the perception of the surface can be modified by the list of possibilities provided by Ames (1925) and Schlosberg (1941). The number of studies on the plastic effect is relatively low, and studies that experimentally address the influence of the pictorial content on the plastic effect are practically inexistent. In their mirror study, Higashiyama and Shimono (2012) used 11 photographs and report without much detail that "pictures for which the plastic effect was well detected contained ample depth cues". Vishwanath and Hibbard (2013) used six different photographs but also did not report detailed information about differences between the stimuli. However, they did address the contribution of a few depth cues by image blurring and an effect that removed smooth gradients while maintaining hard contrast edges. Both effects were reported to have a significant impact on the plastic effect. Lastly, there is abundant historical evidence that a special type of picture was very popular for zograscopic use: coloured engravings (Kaldenbach, 1985; Blake, 2003). Typical examples show a mirrored upper caption, anticipating on the mirror of the zograscope. Typical names for these engravings are 'Guckkastenblatt' (German), 'Vue Perspective' (French) or 'Perspective view' (English); note that the latter is too generic to perform effective internet search. Although these pictures were specifically produced to optimise the plastic effect, their style is not representative for an optimal pictorial design because they are too confined to the medium: engraving. There is very little shading, hardly any rendering of material properties and colours are mostly homogenous. This style is optimal for efficient production, but hardly refers to depth cues that are normally present in paintings and photographs, except for linear perspective.

The study presented here specifically focusses on the perception of paintings. This is interesting for two reasons. Firstly, as we discussed above, there is little known about the contribution of pictorial cues on the plastic effect. Zoth (1916) observed that the plastic effect even works for 'schlechte' (poor) pictures. However, it seems likely that for some pictures the plastic effect is stronger than for others. Indeed, there must at least be some potential for depth increase in the composition. The psychological literature offers ample overviews of the common pictorial depth cues that create an impression of pictorial spaciousness. One way to approach the investigation of the dependence of the plastic effect on these canonical depth cues is to independently manipulate each of them, and their combinations. Instead of taking this traditional psychological approach we took a more explorative approach. The rationale behind this is that the pictorial techniques that facilitate the plastic effect may not be completely covered by an a priori list of psychological depth cues. Furthermore, the use of paintings as stimuli is interesting because long before depth perception was studied by psychologists, it was one of the major topics of investigation among painters. Paintings are not accidental like snap shot pictures. Instead, they are often the result of thorough contemplation. Furthermore, painters are free to create views that are nowhere to be found in reality, yet make perfect sense to our visual system. Therefore, paintings are a rich and inexhaustible source for the study of visual perception.

The second reason to use paintings is the very reason that the synopter was actually designed to be used in art galleries. Zoth (1916) and many others referred mostly to viewing art which makes plastic effect devices historically closely intertwined with the appreciation of art. The purpose of the current paper is not only the investigation of the plastic effect with respect to different paintings, but also to describe the design of a synopter that can be used in art galleries and musea. By giving access to a simple synopter design, we modestly intend to revive the use of the synopter as it was originally intended. Nowadays, museum visitors are assisted by audio tours that help them with the iconographical analysis of paintings. The information may also contain some references to the pictorial techniques but it does not offer an explicitly deeper experience of pictorial space. The synopter is designed to do exactly that, which could make it a unique additive for a rewarding museum visit.

The optics and design of a synopter

Fields of view for various designs

Paintings come in a wide range of sizes and museum visitors look at them from various viewing distances. This means that the field of view can vary quite substantially. To get an idea for viewing angles: if a painting is 1 meter wide and viewed at 2 meters distance the field of view is 28°. In the original patent of the synopter, von Rohr presented three designs, as shown in figure

2. We calculated the optics to verify these three designs and quantify the viewing angles, which is shown in figure 3. An important free parameter is the distance between the eye and the closest mirror, which we set at 20 mm. Furthermore, we used an average of 65 mm inter-ocular distance. Based on these two parameters, the three different designs result in three different viewing angles of 21°, 29° and 35°, respectively. We will shortly describe the three designs.

Design A was previously used in psychophysical experiments (Koenderink et al., 1994). Main advantage is that it is easy to construct and that the optical path lengths for both eyes are equal. Disadvantage is the limited field of view.

In design B, the relatively small field of view is increased almost by a factor 1.5 in comparison to design A. This design is the smallest of all three but has one major disadvantage. As can be seen in figure 3B, the central mirrors are split in two: one section is half translucent and the other is a full mirror. Since the intersection between these two types of mirrors will always have some physical separation, there will be a line visible in the centre of the visual field. Especially when producing a low cost product, it is very difficult to overcome the problem of a visible vertical line. That this design has the smallest size was likely the reason that Black (2006) used this design in his patent for a head mounted version of the synopter.

The last design has the largest viewing angle but has one significant disadvantage over the other two designs: the optical path lengths of both eyes are different. The absolute optical path length (length that light travels from the image to the eye) of the left eye is 65 mm (the interocular distance) longer than the right eye. This implies that objects should be positioned at a sufficiently large distance to make the relative retinal size differences small. For a viewing distance of 1.5 meter, the relative size difference is about 4%. We choose to work out this design because it offers the largest field of view, together with a relatively easy construction. It appears that also von Rohr saw most potential in this design since he presented an actual practical casing for the optics (figure 2C, right).

Mirror characteristics

An ideal half mirror transmits and reflects exactly half of the incident light equally at all wavelengths. In other words, the ideal half mirror should transmit as a neutral density filter. High quality 'beamsplitters' are generally quite expensive, in the order of 100 Euro's. For academic equipment, these costs are not uncommon, but for a commercially available synopter we

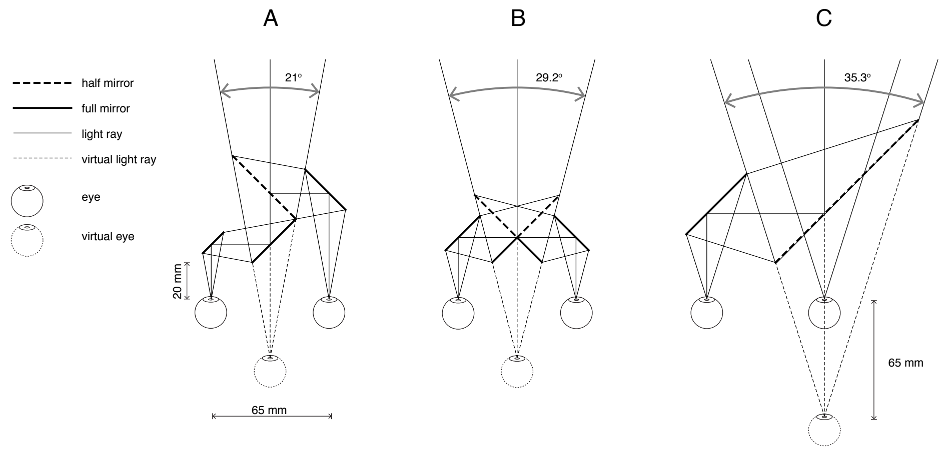

Figure 3: Overview of three different synopter designs by von Rohr. We recalculated the optics and found for a fixed distance of 20 mm to the closest mirror three different fields of view, ranging from 21° to 35.3°

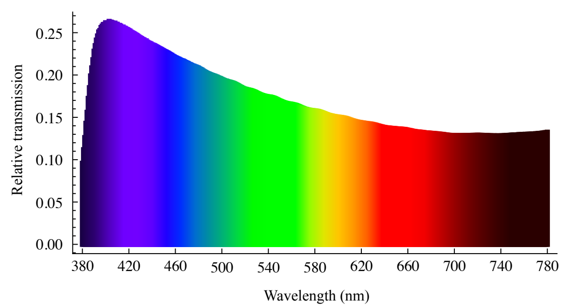

Figure 4: Transmission spectrum of a perspex half mirror.

found this too high. Therefore, we explored the use of more affordable half mirrors made from perspex. We measured the transmission and reflectance spectra with a radiospectrometer and found that these mirrors perform relatively poorly. The average transmission of the mirror is only about 17% and gives a blueish tint as can be seen in figure 4. Furthermore, we measured the average reflection to be about 60% (i.e. some substantial loss of light due to scattering) and the average reflection of the full mirror on the left eye to be 83%. Thus, the total light reaching the left eye is 50% and the right eye 17 %, which means that the net light ratio between the two eyes is 1:3. It should be noted that we a posteriori measured the spectra. Looking at these numbers beforehand would possibly have made us doubt to continue with these perspex mirrors. However, we did not know this at the time of the experiments, and still found that our newly designed synopter worked rather well (see the experiments section). At first sight one might expect that the unequal brightness values in both eyes have a positive influence on the plastic effect. It is possible that unequal brightness values perturb the correspondence problem similar to blurring one eye (see previous overview techniques). However, the mirrors already remove binocular disparities. Therefore it is rather unpredictable what the effect is of unequal brightness values.

As an extra check and for clarifying purposes, we also made photographs through both viewing apertures, which are presented in figure 5. As can be seen, the right eye indeed shows a bluish tint, that we already predicted from the transmission spectrum. The pictures through the synopter were taken with the same shutter/iso/diaphragm settings so the relative image brightness difference is roughly indicative for the actual relative brightness difference. Indeed, the right eye receives a darker image than the left eye. If figure 5A is cross fused, it can be seen that there are no disparities, except the reflection of the nose hole in the mirror (see figure 6) in the left eye image. This makes it extra clear that the synopter itself does not introduce disparities. In figure 5B, we have put a toy giraffe in the scene. It is clearly visible that the position of the giraffe does not change with respect to the background for both images. If the synopter is removed (figure 5C), both images have equal brightness *and* the giraffe has markedly different positions. Cross fusing this last image pair will result in a strong stereoscopic impression where the giraffe comes forward, although the painting itself maintains its flatness. It should be noted that the field of view on the pictures is less than the actual field of view due to camera limitations.

3D design

The housing of the optical system was designed to be easily reproducible. We chose a box-shaped design which can be produced with a laser cutter. We include the production drawings as supplementary material to this paper. Our current models are cut from 3 mm thick cardboard. A significant drawback of this material is that it gets charred in the laser cutting process. A good alternative is using plywood. To shield ambient light at the eyes we also made an eyecup. This can be produced from any deformable material

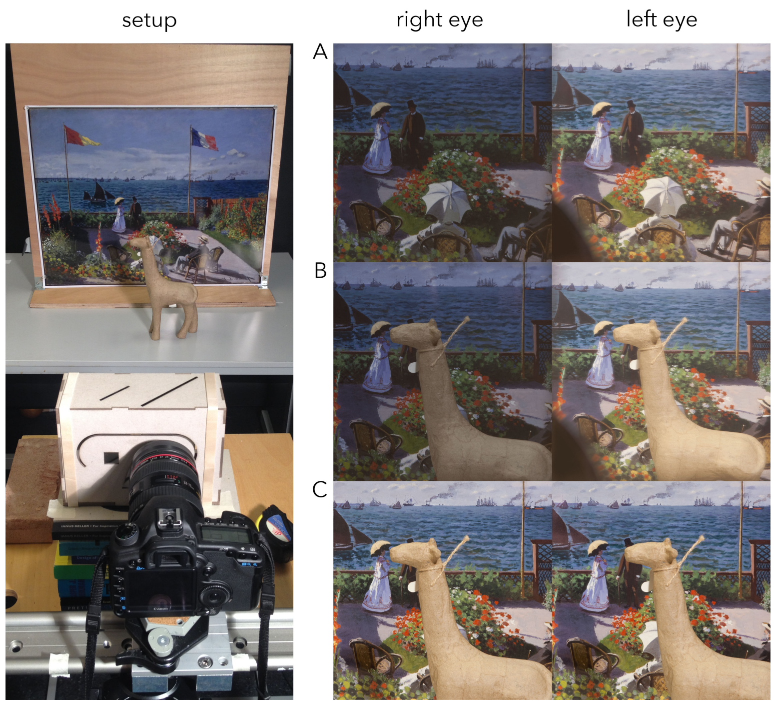

Figure 5: Left: the setup we used to make the photographs through both peepholes of the synopter. The camera was on a slider, so two parallel pictures were made with a 6.5 cm lateral translation difference. Right: right-left image pairs are shown. The placement of the right picture on the left side and vice versa was on purpose, to allow visual cross fusion for the trained reader. A) pictures through the synopter without the giraffe object. The images differ in brightness and color, as predicted by the mirror characteristics. B) Same images but now with a toy giraffe in front to validate that there is no parallax between the two eyes. C) Images taken without the synopter. The relative position of the giraffe in the right eye image (shown left) remains unchanged, but in the left eye a paralactic displacement is visible. Cross fusion will reveal a clear binocular stereoscopic impression.

like rubber or cork. In figure 6 an 'exploded view' is shown. On top two slits can be seen that contain the mirrors.

Figure 6: The left column shows renderings of the model, including an 'exploded view'. The middle and right columns show photographs of the synopter used in this research.

Experiment 1

The first experiment consists of data collected during a course given by the first author of this paper (MW). The main purpose of this experiment was to verify whether the plastic effect shows a certain degree of consistency with respect to various paintings. The experiments were performed by students[4]. The students consisted of two groups (A and B) that each chose different paintings and used different participants. Originally, there was also a third group but they made use of many copy righted materials including photographs. The overall results were similar to the other groups but will not be reported here.

[4] All students were notified that they could participate in co-authoring this paper when they agreed to help with discussing the manuscript and help with developing supplementary material. Two students agreed, the others appear in the acknowledgements.

Methods

Participants

All observers were fellow students or friends of the (student) experimenters. Mean age was about 20 years old. Observers were excluded if they reported to be stereo blind. Groups A and B performed the experiments with 15 and 20 observers, respectively. Thus, a total of 35 observers participated in the first experiment.

Stimuli

The two student groups were instructed to select their stimuli from the Rijksmuseum website (www.rijksmuseum.nl) where the first author already had made a pre selection. In general the images were selected to ascertain a variety of depth cues and scene types, although it is difficult to do this in a systematic manner. Group A used 15 stimuli and group B used 9 stimuli. An overview of the paintings is presented in table 1. As can be seen, two paintings were used by both groups, yielding a total stimulus set of 22 different paintings.

Apparatus

The synopter has been described in the previous section. The paintings and photographs were shown on a computer screen. Screen sizes were approximately 30-40 inch diameter and viewing distances were approximately 1.5 m.

Procedure

The task of the observers was to assess the strength of the synoptic effect. The mechanism behind the synopter was briefly explained and one or two example images were shown. All presentation orders were randomised per observer. Each observer saw only one presentation of each image. The observer was instructed to compare viewing with and without the synopter. While viewing, observers could freely switch between looking through the synopter and free viewing. Observers estimated the effect on a scale from 1 to 9 (group A) or 1 to 7 (groups B).

Table 1: Overview of paintings used in the experiments. 1A and 1B refer to the two different sets in experiment 1. * indicates that this painting was edited in experiment 2. In the supplementary material a table is included with links to the original works at the Rijksmuseum website. [...] indicates a cropped title due to space limitations.

#	Experiment	Artist	Title	Year
1	$(1A, 2^*)$	Rembrandt	Man in Oriental Dress	1653
2	$(1A)$	W.C. Heda	Still Life with a Gilt Cup	1635
3	$(1A, 2)$	F.C. van Dijck	Still Life with Cheese	1615
4	$(1A, 2^*)$	van Gogh	Self-portrait	1887
5	$(1A, 2)$	P. Claesz.	Still Life with a Turkey Pie	1627
6	$(1A, 2^*)$	Breitner	The Singel Bridge [...]	1896
7	$(1A, 2^*)$	J. Israëls	Children of the Sea	1872
8	$(1A)$	Appel	The Square Man	1951
9	$(1A, 1B, 2^*)$	Breitner	Girl in a White Kimono	1894
10	$(1A, 2)$	Kruseman	Portrait of Alida Christina Assink	1833
11	$(1A, 1B, 2^*)$	Voogd	Italian Landscape [...]	1807
12	$(1A, 2^*)$	Coorte	Still Life with Asparagus	1697
13	$(1A, 2)$	Ruisdael	The Windmill [...]	1668 - 1670
14	$(1A, 2^*)$	Post	View of Olinda, Brazil	1662
15	$(1A, 2^*)$	d' Eyck	Still Life with Books in a Niche	1442 - 1445
16	$(1B, 2)$	Vroom	Dutch Ships Running [...]	1617
17	$(1B, 2)$	Sande Bakhuyzen	The Artist Painting a Cow [...]	1850
18	$(1B, 2)$	Gabriël	Duck nests	ca. 1890
19	$(1B, 2)$	Springer	The Zuiderhavendijk, Enkhuizen	1868
20	$(1B, 2^*)$	Weissenbruch	Wooded View near Barbizon	1900
21	$(1B, 2^*)$	Potter	Four Cows in a Meadow	1651
22	$(1B, 2^*)$	Maris	Ducks	ca. 1880

Results

Internal consistency

To assess how similar observers scored on the stimulus set, we calculated Cronbach's alpha values. This statistic is generally used to quantify the internal consistency of a group of raters. In the context of our research this metric is used to assess whether the effect of the synopter depends on the pictorial content. The values we found for the two groups were 0.87 and 0.72, respectively. As a comparison, random input ($N = 1000$ for 15 observers and 18 paintings) gives a mean Cronbach's alpha value of -0.17 with a standard deviation of 0.56. Thus, values were well above chance level. To quantify if there were any outliers, we correlated all observers with the group means and defined an outlier as someone who correlated negatively with the group mean. We found 0 and 4 outliers in groups A and B, respectively. We removed this data from the subsequent analysis. New Cronbach's alpha values were 0.87 and 0.86, respectively.

Pictorial style

Since we found that observers rated the effect consistently, we wanted to understand what exactly determines the effect. Since we used unmodified images we did not control for any image cues. In this section we will present the ordering of the stimuli according to the mean responses and will analyse these in the discussion section.

We normalised all answers per observers and used these data to calculate means and medians. Because the (normalised) data is bounded one cannot assume normal distributions. Therefore, the median would be a better statistic to quantify the overall effect per painting. However, because the data is also discrete (whole numbers), the median will also be discrete and thus miss some subtle difference between paintings. Therefore, we ordered the data according to the mean values (white line) but also displayed the median values (black line) for reference. The data is shown in figures 7 and 8. To get an idea of the variance we plotted box whisker graphs that denote the four quartiles, i.e. the whiskers each represent 25% of the responses, the box represent 50% of the responses. Using a standard deviation or likewise statistic would not be suitable because of the aforementioned boundedness.

Figures 7 and 8 show the average responses per picture, where thumbnail versions represent the stimuli. By coincidence, the groups choose two overlapping paintings that can be used to roughly compare the data between groups. These paintings are indicated by the dashed boxes. Overall there

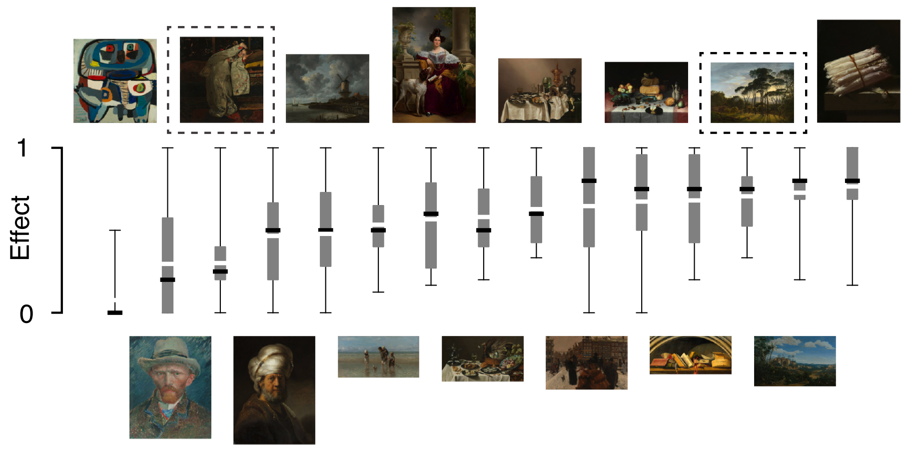

Figure 7: Results of group 1 ($N = 15$) shown in a box whisker plot. The grey bar denotes the second and third quartiles (i.e. 50% of the responses), the 'whiskers' denote the maximum scores. The black lines indicate the median values and the white lines the mean values. The paintings were ordered with respect to the means (white lines). Each painting is shown in thumbnail format at the specific data points. The dashed boxes denote paintings that were also measured in the other group, which can be used as inter group comparison.

seems to be a considerable amount of variance between and within paintings. The effect of the synopter is for some paintings convincingly higher than for other paintings. Importantly, the overlapping paintings between the groups give a consistent impression. When we compare the groups, we see that 'Italian Landscape with Umbrella Pines' by Hendrik de Voogd is in all groups rated very high while 'Girl in white kimono' by Breitner is rated very low in groups 1 and 2. Thus, besides the internal consistency as revealed by the Cronbach alpha values, there also is a certain consistency between the two groups.

Discussion

Our first question was whether the synoptic effect was consistent between different observers while varying from one painting to another. If so, that would imply that pictorial content contributes to the synoptic effect. Indeed, we found that the internal consistency was significant as quantified by the

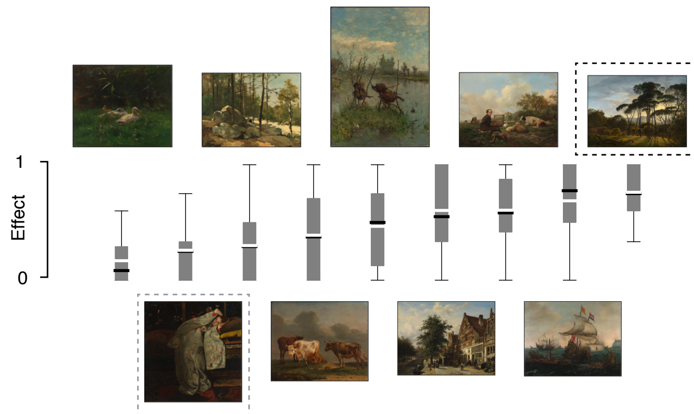

Figure 8: Results of group 2 ($N = 20$) shown in a box whisker plot. For an explanation see caption of figure 7.

Cronbach alpha values. Thus, there was agreement between observers about the strength of the synoptic effect with respect to the various paintings.

Which cues are important for the synoptic experience is difficult to determine. A standard approach would be to analyse all paintings in terms of textbook depth cues and model the data with a linear system. Although this sounds attractive, the depth cue combination literature does not offer a complete system that covers all possibilities of generating depth in pictures. Therefore, we chose to analyse the results in a more explorative way without performing any modelling. Because this study is the first of its kind in relating the pictorial content (pictorial cues) to the plastic effect, this explorative approach appears more sensible than using a model of which a complete and formal description is still to be developed.

First painting set

The first group included a Karel Appel painting which, in line with the Cobra style, does not include many depth cues. Indeed, observers rated this painting to be the weakest of all. Perhaps surprisingly, the next three paintings in the ordered presentation of figure 7 were all portraits. Although close together in rank order, it should be noted that the average values between the van Gogh and Rembrandt differs substantially. This difference can either be due to the higher degree of shading contrast in the Rembrandt, or the contrast between foreground and background: the background of the van Gogh has a similar luminance as the face itself. The full body portrait of Breitner (Girl in White Kimono), can be compared with a somewhat similar scene painted by Kruseman (Portrait of Alida Christina Assink) which is four positions higher in the rank order. In the latter there is clearly more to see, so the chance that something 'stands out' in depth is a priori higher. However, besides being more complex, the scene is also more articulated in depth than the Kimono girl who seems to blend in with the pillows behind her. Next we see that four still life paintings all end up quite high in the overall ranking. All of them contain many objects and are shaded very explicitly. Except for the book scene, they also contain a ground plane (the table) which may serve as a cue for depth perception. The street scene of Breitner is painted in a very rough style without much detail. Hardly any shading is present here, but linear perspective is clearly present. In the top 3 we find two landscape paintings and one still life. Both landscapes are clearly organised in layers, with a foreground and a background that contrasts with the landscape painting of the mill which is rated 5th. The asparagus are clearly painted with skill, they even appear somewhat translucent[5]. But it is difficult to compare this painting with the others. At first sight, it appears as a single, well shaded object with a black background. As such, it is similar to the much lower rated portret of Rembrandt. However, we may also regard the asparagus as individual objects that occlude one another. Furthermore, the collection as a whole occludes parts of the table, most notably at the edge. This layered, occluded composition is also found in the other paintings that score high.

We conclude that for painting set 1, various cues (from shading to perspective) may have contributed to the results but there seems to be an additional role for figure-ground segregation. In the analysis of painting set 2 we put extra emphasis on this cue.

Second painting set

In addition to the general rating task, group 2 had asked the observers to indicate in which part of the painting the synoptic effect was particularly strong. The observers indicated the areas by circling it with a pencil on a small printed icon of the painting. We manually fitted ellipses around the sketched circlings and plotted them in figure 9. As can be seen, the number of ellipses (numbers on top of images) increases in approximately the same order as the synoptic effect. To understand the role of figure-ground contrast

[5] Although this could have been caused by zinc white turning translucent over time

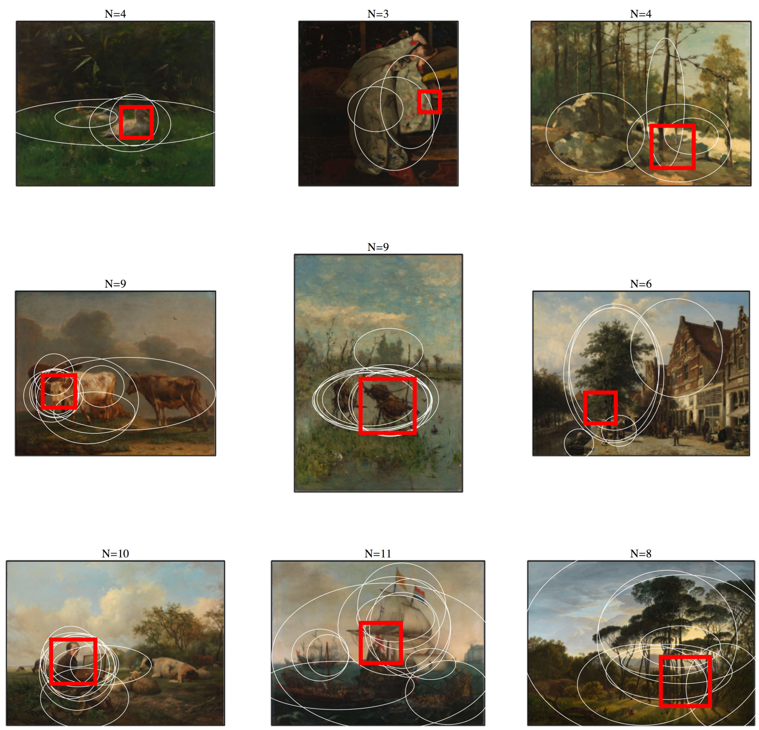

Figure 9: Annotations of observers indicating in which parts of the painting the effect was particularly strong in painting set 2. The images are ordered with respect to synoptic effect (as in figure 8) and N denotes number of annotations made by observers.

we took a closer look at some regions of interest were the annotations were particularly prominent. In figure 9 we highlighted these areas with a red square, results are shown in figure 10.

Interestingly, these areas show various types of figure-ground contrasts. The duck is blended in the grass: similar brush strokes are used for both subject and background. Furthermore, the transition between the breast of the duck and the grass is similar in brightness. Brush stroke similarities can also be found in the next two paintings. Although the brightness between the kimono and background is different, the pattern is highly similar. The same holds for the forest of Weissenbruch, where trees and background are blended by a similar handling of the brush. An opposite example is the Duck Nest of Gabriël where the chick is rendered with thick and directional (van Gogh like) strokes whereas the watery background is painted so thin that we

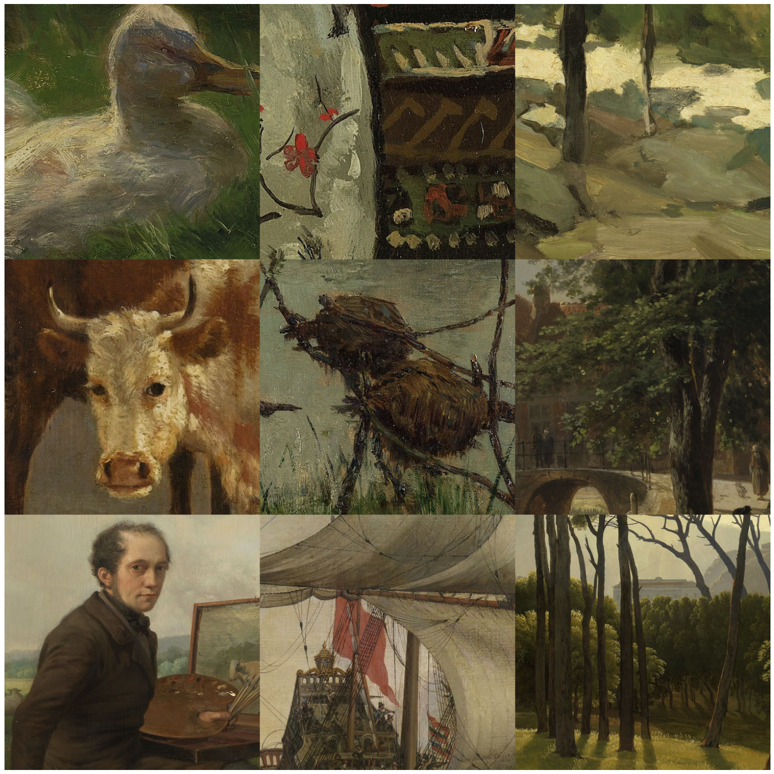

Figure 10: Details of the red squared areas shown in figure 9.

can see the texture of the canvas through it. To a lesser degree we can also see this type of figure ground contrast in the cow head of Potter. However, it is not particularly the brushstroke itself, but the tonal variation with substantial local contrast that renders the hairy head of the cow, contrasting with the darker and more homogeneously rendered background of the air and another cow's body. The foliage of the sixth painting (Zuiderhavendijk by Cornelis Springer), is also depicted in an interesting way: the front leaves are bright and clearly distinguishable with respect to the darker and more vaguely painted foliage on the back. The self portrait of Hendrikus van de Sande Bakhuyzen in a Dutch landscape has a more traditional figure ground segregation accentuated by the atmospheric perspective including the loss of detail for distant objects. The sea battle is not such a clear example of figure-ground segregation. It is certainly present, and there are many occlusions with many objects. Also clear shading gradients on the sails are present. As can be seen in figure 9, the observers themselves were not uniform in choosing a single part of the painting that came forward. Lastly, the Italian Landscape with Pine Trees is full of colour contrast. Also, the textures of the foliage that are partly occluded by the stems on the foreground are different than the textures of the stems themselves.

Our analysis indicates that in both painting sets, there seems to be evidence that figure-ground contrast plays a substantial additional role in the plastic effect, besides the more tradition depth cues like shading, shadowing and perspective. To investigate this more thoroughly, we conducted a second experiment.

Experiment 2

The purpose of the second experiment was twofold. Firstly, we wanted to ascertain the validity of the results found in the first experiment since that was performed by students under conditions that were not optimally controlled. The second reason was to correlate stereo acuity with individual differences and to test the contribution of various pictorial cues. We investigated this by manipulating the original stimuli with photo editing software.

Methods

Participants

30 observers volunteered to participate in this experiment, 18 males and 12 females. Mean age was 32 years with a minimum of 21 and maximum of 59. All observers had normal or corrected to normal vision.

Stimuli

We used a selection of 20 of the 22 paintings used in experiment 1, as can be seen in table 1. We wanted to test various hypotheses concerning the possible contribution of depth cues that we found in the first experiment. Our main focus was to test various forms of figure-ground contrast, as can be seen in the upper two rows of figure 11, where the numbers on the paintings refer to table 1. Two paintings were found suitable for increasing figure-ground contrast by adding defocus blur. Both original paintings (7 and 20) were rated low in experiment 1. In both cases we hypothesised that adding blur to the foreground and background would increase the plastic effect. The second figure-ground contrast we manipulated was that of brush stroke technique. Paintings 1 and 4, both famous self portraits, are rendered in very different brush styles. Both originals scored low in experiment 1. We exchanged their background textures while maintaining the colour statistics. This results in a relatively homogeneous background for van Gogh, and a very directionally textured background for Rembrandt. The third figure-ground contrast was the manipulation of colour. Painting 14 received high scores in experiment 1, and we hypothesised that the removal of colour may decrease the clarity of depth layers and thus decrease the plastic effect.

We called the second cue that we considered 'compositional depth'. To our surprise, painting 6 (Breitner) received high scores in experiment 1, the median score was even the highest of group A. This is surprising because the painting has little shading and shadowing, and also not much contrast between the depth layers. We hypothesised that a potential contributor to the plastic effect could be the number of objects in the space. Because this largely has to do with how the scene is composed, we call it 'compositional depth'. The manipulations we performed were removal of all persons behind the foremost lady in the Breitner (painting 6) and to add many other ducks to the Maris (painting 22). The still life with asparagus (Painting 12) was manipulated differently. The original was rated rather high, which could have several reasons (including shading and contrast) but also the way it is composed. In the original, the asparagus bouquet rests obliquely over the table's edge and leans over an isolated asparagus. The reason behind this compositional choice was likely to create a three dimensional impression. By removing the supporting asparagus, this depth composition is strongly degraded. We hypothesised that this would have a negative impact on the plastic effect.

The last four manipulated paintings are concerned with cast shadows. In painting 15 and 9, these cast shadows resemble the function of drop shadows in graphic design: they serve as a distance cue between object and background. In painting 15 we removed some of the cast shadows, and in painting 9 we added a (drop) shadow. We thus expect a weaker plastic effect in painting 15, and a stronger plastic effect in painting 9. Painting 11 shows long cast shadows that originate at the tree roots. The contrast was adjusted so that these shadows became invisible. As a side effect, the contrast between trees and background also decreased. In painting 21 we performed the opposite transformation.

Experimental design

To avoid a certain response bias, we did not let observers directly identify which of the original or manipulated stimuli evoked the strongest plastic

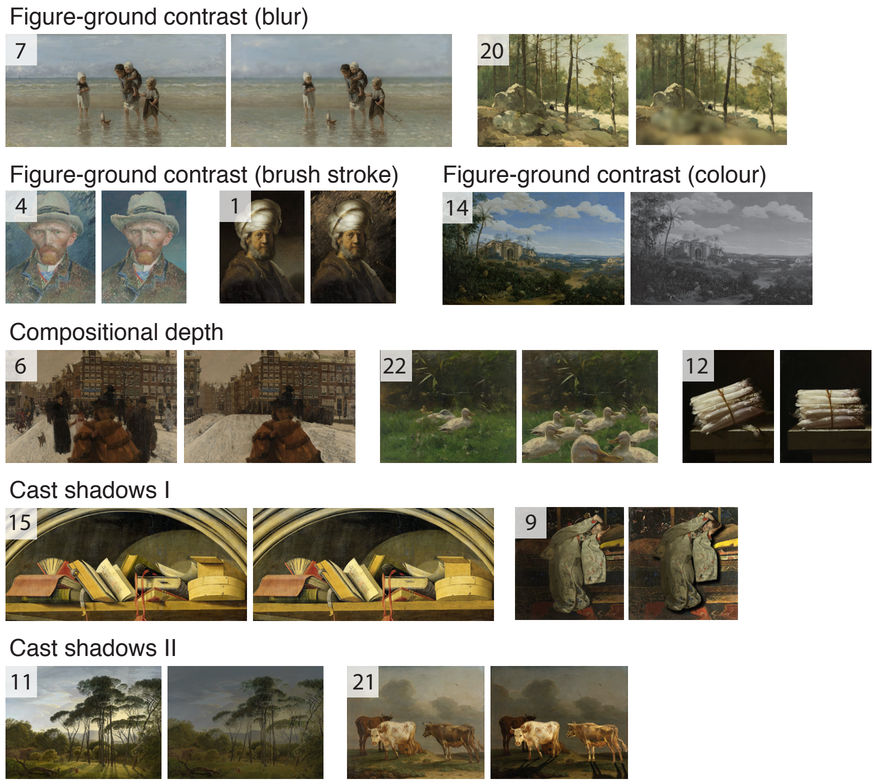

Figure 11: Image manipulations to strengthen (7,20,4,1,22,9,21) or weaken (14,6,12,15,11) the plastic effect.

effect. Instead, we used a between subjects design in which half of the participants was presented with half of the edited and half of the originals, and the opposite stimuli for the other half of the participants. We manipulated 12 of the 20 stimuli, so each group was presented with 6 edited versions, and 14 originals. Thus, the 8 stimuli that were not edited were shown to all observers.

Apparatus and procedure

The same synopter was used as in Experiment 1. Observers viewed the stimuli from 1.5 m distance. Their head position was not restrained, they were sitting behind a table. The screen on which the paintings was presented was a 65 inch (diagonal) Panasonic plasma TV (TX-P65VT30). The resolution of this screen was 1920 by 1080 pixels. The stimuli all had higher resolutions and were down sampled to fit the screen. Although the light was half dimmed, the glossy surface of the screen still reflected some of the surrounding, which was an approximately 30 m^2 lab space in which multiple experimental setups were located.

The observers first gave their informed consent in participating in this experiment and then read the instructions. After reading, they received additional verbal information by the experimenter (MW). The mechanism of the synopter was explained to them, that it removed binocular disparity information and that this could result in a more enhanced experience of pictorial depth. Two practice paintings were shown, a still life (painting 2 from experiment 1) and a scene with birds by Melchior d' Hondecoeter. The plastic effect was briefly discussed and they were informed of the kind of effects they could expect, mainly a more pronounced separation between foreground and background and an increase of relief of individual objects.

We used the Psychophysics Toolbox (Brainard, 1997; Kleiner, Brainard, & Pelli, 2007; Pelli, 1997) for Matlab to program the experiment. Observers were allowed to view each stimulus in their own pace, and could press a key to continue. They were instructed to rate the difference in depth experience between with and without looking through the synopter on a scale between 1 (no difference) to 7 (huge difference). Some observers requested to use non integer values, mostly half integers, to make a finer rating, which was granted. The observers were explicitly informed that it was not abnormal to not see any effect, and that they could simply score everything at 1 if they failed to see any difference.

After finishing the main experiment, stereo acuity was measured using the TNO stereo test. This test allows to measure how accurate binocular disparities are detected, in logarithmic steps from 480 to 15 arc seconds (i.e. from 0.133° to 0.004°).

Results

In figure 12 the mean ratings of each observer is plotted with respect to their individual stereo acuities. Red circles denote outliers, which will be explained later. Since the data is very sparse at most acuity values, we cannot perform regression analysis to quantify if stereo acuity has a positive impact on the plastic effect. Nevertheless, we did perform a (signed) Mann-Witney test on two subsets of 30 and 60 arc seconds stereo acuity. On average, there is an expected decline of plastic effect if stereo acuity is less accurate but this difference was not significant ($p = 0.12$).

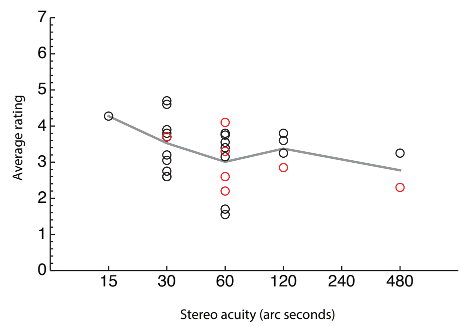

Figure 12: Relation between stereo acuity and overall rating of the plastic effect. Red circles denote participants that correlated negatively with the group means and were discarded in the further analysis.

We performed the consistency analysis on the two separated groups of 15 observers that were presented with the same stimulus set. Again, we found that some observers correlated negatively with the group mean, which were left out of the remaining analysis. These outliers can be identified by the red dots in figure 12. As can be seen, they do not appear overrepresented at low ratings or low stereo acuity. For the remaining observers we found Cronbach alpha values of 0.80 ($n = 12$) and 0.58 ($n = 11$).

In figure 13 the results of image manipulations are presented. Each pair of bars denotes the data from the original (left) en edited (right) stimulus. Mann-Withney tests with directional hypotheses were conducted to quantify significant ($p < 0.05$) differences between original and manipulated, which were found in 5 of the 12 cases as indicated by the asterisk signs.

Discussion

As indicated by the relatively low Cronbach alpha value of 0.58, the individual differences seem rather high. It is a little surprising that in the second experiment, which was conducted under more controlled conditions, the consistency between observers decreased. This can have several reasons. Firstly, participants of both experiments may differ in homogeneity. In the first experiment primarily students participated whereas in the second experiment PhD students, postdocs and faculty participated. A second reason could be the stimulus set. In experiment 1, observers were shown 15 and 9 stimuli, whereas in the second experiment 20 stimuli were used, among which were manipulated versions. Possibly, the configuration of the stimulus

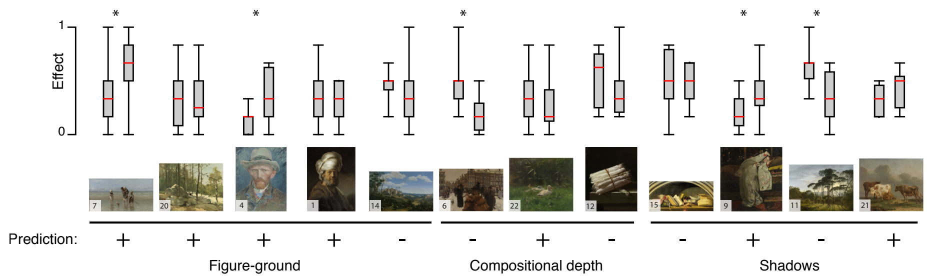

Figure 13: Overview of the effect of various image manipulations on the synoptic experience. Left bars denote the original stimulus, right bars the manipulated versions. The plus and minus signs indicate the expected difference. Originals are shown in thumbnails, the edited version can be seen in figure 11. Significant differences are marked by a '∗'.

set is of influence on the overall consistency. This would explain the large difference between Cronbach alpha values of the two groups of experiment 2, since the only experimental difference was the set of (manipulated) images.

A low internal consistency is not the only type of individual difference that can occur in this type of experiment. Instead of observers disagreeing about which painting evokes the strongest plastic effect, we may also expect that the overall plastic effect differs between observers. We explicitly instructed observers to score low when the synopter did not have much effect. As can be seen in figure 12 there is quite some dispersion, with average ratings ranging from 1.5 to 4.7. We hypothesised that a possible reason behind the individual differences could be stereo acuity, but our data no not confirm this.

The manipulated paintings were reasonably successful in revealing which pictorial cues are important for the plastic effect. For the interpretation of these results it is important to keep in mind that the absence of a significant difference does not imply that there is no difference[6]. Thus, the absence of an effect for the Weissenbruch (painting 20) does not prove blurring foreground and background ineffective. On the other hand, the significant difference between the original and manipulated Israëls (painting 7) indicates that blurring does have an effect. Our other manipulation of the figure-ground contrast also reveals differential synoptic appraisal: substituting the background of the Rembrandt portrait into the background of the van Gogh portrait increased the depth impression (painting 4), although the reverse

[6]a null hypothesis can in general not be confirmed, only rejected

case showed no effect. Furthermore, removing colour did not have an influence.

As for 'compositional depth', we find that indeed emptying the pictorial space (Breitner, painting 6) reduces the synoptic effect, but that filling in the space with more ducks (painting 22) did not result in an effect increase. We should admit that our manipulation of the duck painting was a bit blunt and possibly the awkward impression it evokes counteracted the potential increase of depth experience. The manipulation we applied to the asparagus (painting 12) was more subtle but also addressed a different type of compositional depth because we changed the apparent attitude of a pictorial object. Although the difference was not significant, it should be noted that there was a substantial difference between the medians in the predicted direction.

Lastly, shadows also contribute to the plastic effect. The first type of shadows were cast shadows against a vertical background, where objects and shadows were not always attached. The bookshelf (painting 15) was not susceptible to removing the cast shadows whereas the Breitner (painting 9) was. This could be due to the manipulations of the bookshelf being too subtle, or too sparse whereas in the Breitner we added one large and rather salient drop shadow. The second type of cast shadows (paintings 11 and 21) are different because they are cast on the ground plane and are clearly attached to the casting objects. That the synoptic experience of the painting with umbrella pine trees was significantly reduced could indeed have to do with the cast shadows. On the other hand, the overall contrast of the trees themselves was also lowered by the manipulations. Addition of shadows on the cows did not have an effect. Among many potential reasons, one of them could be that the manipulation was not realistic enough.

General discussion

In this paper we presented a practical synopter design and measured the strength of the synoptic effect on various paintings. We showed that despite the low optical quality of the mirrors, our design works very well. The experiments revealed that observers tend to agree about which painting evokes a higher plastic effect than another. At the same time we also found considerable individual differences. In this discussion we will shortly reflect on our results and finish with some notes about actual museum use of the synopter.

As reviewed in the introduction, a recent paper by Vishwanath (2014) challenged the theory of the plastic effect. Previously, the plastic effect was considered to occur because the physical depth of the picture interferes with the depth of pictorial space. Vishwanath (2014) opposed this view because he did not find an actual quantitative increase of pictorial shape (Vishwanath & Hibbard, 2013), although others before him did find this (Koenderink et al., 1994, 2013). Our data will not resolve this debate, but the overview of viewing devices given in the introduction in combination with our detailed explanation of the synopter may turn out valuable for future studies on this theory. For example, Vishwanaths theory describes that the plastic effect occurs because of sensory attribution: in his case the accommodation signal is attributed to the pictorial space instead of the picture surface. The reason why the visual system erroneously conducts this attribution is because the other cues that code the absolute distance of the picture surface (vertical disparity and convergence) are absent. Using a modified version of our synopter, it is easy to change parallel vergence to a fixed convergence angle that matches the physical distance of the stimulus picture. This type of experimental manipulations may resolve this theoretical debate.

The data of both experiments show that many pictorial cues determine the strength of the plastic effect. These pictorial cues include, but are not limited to, depth cues. For example, we showed that removing the background crowd of the lady walking on an Amsterdam bridge (painting 6), reduced the plastic effect. In a sense, we removed the affordance of the plastic effect, and this can hardly be called a depth cue. On the other hand, the drop shadow edit (painting 9) was a clear and successful modification of a depth cue. It should also be mentioned that many depth cues are difficult to add or remove from a painting. For example, we tried to get rid of the shading on the books (painting 15) but this turned out to be too difficult. Thus, our image manipulations reveal a few interesting pictorial cues that affect plasticity, but are by no means a complete list. The figure-ground contrast we identified as being effective exists in another style that is ubiquitous in our daily image consumption: photographs with a finite (preferably small) depth of field. This technique is often used by the skilled photographer to accentuate the main subject of the pictorial narrative, but is rarely used by painters. This is likely because this technique was never 'invented' for perceptual purposes, but was simply a side effect of using a lens to speed up the long exposure time of pin hole cameras. Livingstone (2002) argued that a blurred background disrupts the correspondence problem for binocular disparity computations. This implies that the plastic effect may already be present for normal binocular viewing. We mimicked this photographic effect in our image manipulations and found that for one painting the synopter even strengthens this effect. It is worth mentioning that the third student group of experiment 1, of which the data was excluded in this paper due to copy-righted material, used two photos with a very shallow depth of field that were both rated very high.

We have shown that the synoptic effect depends on the picture, but we also found that there are considerable individual differences. Stereo acuity appears not to correlate with susceptibility of the plastic effect, so what determines these larges differences between observers? Firstly, we should consider that we measured the subjective impression of an effect that the observers experience for the first time. Their expectations can be markedly different. During the instructions they were informed that the synopter could produce a similar effect as a 3D picture or movie (in which binocular disparities correlate with pictorial depth). This could have raised their expectations too high, at least for some. Others, that were more sceptical at first may be positively surprised by the synopter actually working. However, the individual differences may also have a totally different cause and it is very difficult to experimentally reveal this. What in any case appears to be a constant factor of these idiosyncrasies is that they also occur outside the lab. During demo events of both the European Conference on Visual Perception and the annual meeting of the Vision Science Society, we also found that more than half of the attendees were immediately enthusiastic while others were disappointed. The effect was for some people so strong that an experienced fellow scientist asked us to measure the disparities between the two images. This person reasoned that since he experienced disparities, there must be actual physical disparities in the stimulation. The introspection of this person is much in line with the theory of Vishwanath (2014) who argues that stereopsis arising from binocular disparities is phenomenologically similar to 'monocular' stereopsis. Furthermore, the introspection nicely illustrates how strong the plastic effect can be.

With the exception of the manipulated paintings from experiment 2, all our experiments could have been conducted in musea. We chose to remain in our lab due to practical reasons but we nevertheless performed quite some informal testing in musea, mostly in the Netherlands. With respect to the stimulus set used in this paper, we found that especially the Breitner (painting 6) was relatively 'disappointing' in reality. Although it is also visible on the electronic reproduction, the actual painting is rendered with very visible, rough brush strokes. This immediately gives an awareness of the picture surface and makes penetration into pictorial depth more difficult than on a computer screen. Furthermore, we found that both our monitor as well as paintings with glass protection were annoying due to the reflections. In this case, the synopter has an opposite effect because it gives the reflection the same disparity as the surface, resulting in perceptual integration instead of the normal segregation we experience when viewing binocularly.

The effect of visibly thick oil paint strokes and reflection on glass plates are the only 'negative'[7] aspects of seeing painting in reality. In general, we enjoyed looking at real paintings much more than the computer images, the effect appeared much stronger. The pictures we used in the experiment were all paintings and did not include very abstract art (except for the Karel Appel). During our museum visits we found that also abstract art can be enjoyed with the synopter, for example we found that a typical Jackson Pollock induced a very spacious impression, like a voluminous cloud of curvilinear lines. On the other hand, during a large Rothko exhibition in Den Haag, we did not see any plastic effect, which is likely due to Rothko's typical smooth gradients. Furthermore, we found that light box photos (in our case a Jeff Wall exhibition) were very compelling.

Visiting a museum with a synopter will doubtlessly attract attention of other visitors. Many people asked why we were looking through this box. Explaining and demonstrating the device resulted again in individual differences: some visitors immediately asked if they could buy it at the museum shop while others politely confessed that they did not see any difference. We found that the synopter activated spontaneous conversations among museum visitors. Instead of the normal iconographic discussion (what does the composition mean) they shift their attention to the perceptual aspects, which may be a valuable addition to the understanding of art. Yet, the threshold of actually using a synopter in a museum is something that deserves future attention. In a paper about the viewing of art with one eye, Ciuffreda and Engber (2002) concluded:

> *One is left with the following dilemma at the art museum. Does one opt to maximise and enhance the visual impact of a painting but to do so at the expense of appearing a bit odd and receiving curious glances from nearby onlookers, or does one perpetuate conventional manners with the resultant loss of artistic visual excitement?*

Although the synopter indeed provokes curious glances, the visual excitement that we observed may resolve the dilemma in favour of von Rohr's invention and would merit actually producing the device. With the open source material we provided in the paper, we hope to contribute to this.

[7] This does not in any way imply a negative appreciation of the art work, it only refers to synoptic effect.

Acknowledgements

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