

## Double Vision as a Pictorial Depth Cue

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### Abstract

*'Double images' are a little-noticed feature of human binocular vision caused by non-convergence of the eyes outside of the point of fixation. Double vision, or psychological diplopia, is closely linked to the perception of depth in natural vision as its' perceived properties vary depending on proximity of the stimulus to the viewer. Very little attention, however, has been paid to double images in art or in scientific studies of pictorial depth. Double images have rarely been depicted and do not appear among the list of commonly cited monocular depth cues. In this study we discuss some attempts by artists to capture the doubled appearance of objects in pictures, and some of the relevant scientific work on double vision. We then present the results of a study designed to test whether the inclusion of double images in two-dimensional pictures can enhance the illusion of three-dimensional space. Our results suggest that double images can significantly enhance depth perception in pictures when combined with other depth cues such as blur. We conclude that double images could be added to the list of depth cues available to those wanting to create a greater sense of depth in pictures.*

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## 1. Double vision and art

Artists have various techniques at their disposal for conveying a sense of depth in pictures. These include occlusion, shading and shadows, relative size within the picture plane, and various kinds of perspective. Through skillful use of these techniques the artist can create a highly convincing illusion of three-dimensional space on a two-dimensional surface (Pirenne, 1970). These so called ‘pictorial depth cues’ have also been of long-standing interest to scientists studying visual perception, and there is a well-established list of such cues to be found in standard texts on vision (Palmer, 1999).

Pictorial depth cues, however, suffer from the limitation that they are monocular, that is, they present image of the world as it appears to one eye only. Very few attempts have been made to represent the binocular aspects of human vision in pictures. David Hockney (2001) is among those suggesting Paul Cézanne (1839-1906) was the first artist to experiment with capturing the world the way most of us see it — with two eyes. But the artist who most thoroughly investigated the pictorial implications of binocular vision was Evan Walters (1893-1951). Born and educated in Wales, Walters enjoyed early success as a rather conventional portraitist and observer of Welsh life (Plummer, 2011). In the mid 1930s, at the height of his career, he experienced a visual revelation. Seated by the fire and gazing absent-mindedly at the flames he suddenly became aware of the doubled appearance of his own boot. Walters realized such ‘double images’ were a common feature of binocular vision and he soon became deeply absorbed in the technical problems associated with depicting them (Meinel, 1973).

Walters spent much of the remainder of his career analyzing his own visual sensations and experimenting with various ways of depicting what he saw. This resulted in a large body paintings, drawings, and watercolours, which are now rarely exhibited, and an unpublished book setting out his theories entitled *The Third Dimension*. Walters’ obsession with depicting these aspects of visual perception had a disastrous effect on his career. Patrons were reluctant to invest in his unfamiliar style and commissions

soon dried up; exhibitions of his double vision paintings failed to yield any sales and he died in relative obscurity.

[Insert Fig. 1 here]

In a painting such as ‘Self Portrait with Candles’ (Fig. 1) we can see how Walters attempted to record what he called the ‘physical act of vision’ (Meinel, undated). His face is rendered relatively precisely, while the surrounding areas are painted in a looser way, with broader brush strokes. As with many paintings of this period, Walters is attempting to differentiate between the sharply perceived point of fixation and the far less clearly perceived peripheral visual field. He observed that naturally occurring double images were seen either in the margins of the visual field or immediately in front of or behind what he called the ‘focal plane’. The double images occurring outside this focal plane are therefore necessarily less sharp. They are also semi-transparent, a property of double images that Walters considered extremely important.

We owe a great debt to Walters’ former partner Erna Meinel for promoting a wider understanding of his work. After Walters’ death Meinel published a paper describing his methods (Meinel, 1973) and wrote a well-informed book summarizing its’ theoretical underpinning, which sadly was also never published (Meinel, undated). Meinel’s writings offer both a first hand account of the artists’ thinking process and corroboration of his findings in contemporary vision science research. In this she benefitted from intimate acquaintance with Walters himself and her own scientific training.

In Meinel’s and Walters’ view the inclusion of double images in pictures can significantly enhance the illusion of depth (Walters, 1940). Like others, they recognised that a flat picture can never fully replicate fully three-dimensional space (Wade and Ono, 2012). In natural vision double images are seen separately by each eye and outside the ‘focal plane’, whereas in paintings the double images are seen in central vision and on the same plane as the point of fixation. ‘Nevertheless’ Meinel says, ‘whether it be through memory or through some other cause, one can feel a

positive if diminished depth sensation on seeing a double image in a picture, a response that may be described as ‘stereoscopic-like’. Consequently, it can be claimed that double images so seen are correlated to their natural prototypes, not only in appearance, but also in the sense of space and distance they arouse. These responses are most marked when painted double images are configured by the viewer in their relationship to the focal area.’ (Meinel, undated)

[Insert Fig. 2 here]

My (Pepperell’s) own experiments with depicting double images bear out many of Walters’ and Meinel’s findings. Fig. 2 shows a still life painting in which the point of fixation is the upper right group of red petals in the centre of the image. The rendering of the picture frame and plaster bust behind the flowers is intended to evoke the way those objects are perceived in actual vision, which is substantially different from how they appear in a photograph taken from the same vantage point (see Fig. 3). In this painting the frame and bust are distinctly doubled and fuzzy compared to the much sharper flowers, which is an approximation of how they appear in vision.

[Insert Fig. 3 here]

## **2. Double images and depth perception**

Although we are not usually aware of it, when we view a scene with binocular vision we see two slightly different images at the same time. These disparate images are projected on identical parts of the retinae of each eye and combined, or fused, by the visual system to produce a singular visual experience. In normal vision, the fused images contribute to the phenomenon of stereopsis, which is often described in terms of enhanced sensation of depth. In fact, only 5% of the total visual field is fused (Agarwal and Blake, 2010). Objects seen outside this point of fusion, and beyond a zone of tolerance known as Panum’s fusional area, will appear doubled due to the images being located at different points on the retinae of each eye. Double images will also generally appear less distinct as they are seen in the peripheral field or outside the point of focus (Ogle, 1964).

The fact that the visual system uses fused disparity as a source of depth information has been long known (Berends et al., 2001) However, it has also been recognised that unfused or doubled images can convey spatial information. Early vision researchers, such as Helmholtz (Wilcox, 2009) and Hering (1942) showed full fusion is not essential for stereopsis, and that double images in themselves can produce a sense of depth. Later research revealed subtleties in the way this information is used. Ogle (1952a, 1952b, 1953) demonstrated that objects seen within Panum's area are treated differently from those located further away from the fixation plane, which led to him to propose the existence of two different processes. The disparity occurring within Panum's area produces what he called 'patent' stereopsis, which allows us to detect fine spatial differences with relatively reliability and precision. Outside this area a coarser form of disparity leads to what he called 'qualitative' stereopsis, which provides more approximate information about depth. Subsequent studies have supported Ogle's findings about non-fused stereopsis (Westheimer and Tansman, 1956; Mitchell, 1966a; Blakemore, 1970; Siderov and Harwerth, 1993; Wilcox and Allison, 2009), showing the processes to be tolerant to great differences in content between the stimuli presented to each eye (Mitchell, 1969), and how they are grounded in neurophysiology (Poggio and Fischer, 1977; Neri, 2005).

The visual system can also generate stereopsis from scenes when a nearer object occludes a further object such that one eye sees part of the scene that is not available to the other — a phenomenon first noted by Leonardo da Vinci and now known as 'da Vince Stereopsis' (Nakajama and Shimojo, 1990). These so-called unpaired images have since been extensively studied and have been shown to occur not only under artificial laboratory conditions but also in real life settings (Wilcox and Lakra, 2007; Harris and Wilcox, 2009).

Changizi (2009) has argued that the function of stereo vision in evolutionary terms had less to do with gathering depth information than allowing us to see through or beyond objects that might otherwise obscure our view. Although somewhat speculative, his claim is that early human ancestors evolved in vegetation-rich environments, where grasses or tree leaves would have constantly obscured distant

objects. Having two eyes positioned at different points on the head enables one eye to see something through a gap in the leaves that the other eye can't, on condition that the size of the average gap in foliage a creature would encounter is correctly proportional to the size of the gap between the eyes. The result is what Changizi calls a kind of 'X-ray vision' in which the transparency effect caused by the image from one eye being partially overlaid on a different image from the other allows the viewer in effect to see through or behind objects, much as Walters had observed and documented in his own vision.

Despite our being largely unaware of their appearance in everyday visual experience, doubled or unpaired images are a rich source of information about the spatial properties of the world we see. Yet, perhaps because we have paid so little attention to them in natural vision, they have hardly ever been represented in pictures.

### **3. Stereo vision and pictorial depth**

Because we can so readily see depth in pictures we tend to be blasé about how extraordinary, and even faintly illogical, this ability is. Except in those cases where we are fooled by a *tromp l'oeil* image or optical illusion, when we look at a picture we are aware we see a flat surface while at the same time we are aware of perceptible depth. Pictures, therefore, give us two contrary sets of cues: those that tell us about the two-dimensionality of the picture surface and those that tell us about the three-dimensionality of the depicted subject (Pirenne, 1970).

Artists have been continually and deeply fascinated by the problem of how to depict the experience of a three-dimensional world on a two-dimensional surface (Kemp 1990). After lengthy study, Leonardo da Vinci came to the conclusion that the task of rendering in two dimensions from one eye's point of view what is seen in three dimensions by two eyes is simply impossible, and one has to accept the limitations of pictures and make do with the best approximation (Wade et al., 2001).

But the fact is that we do get a strong sense of space and depth from pictures, even if it is qualitatively different from that experienced in natural vision (Koenderink et al.

2012), and this has encouraged artists to experiment with ways of improving the spatial qualities of their images in the hope of getting ever closer to replicating what we see. One of the ways of doing this, as artists discovered, was to conceal those properties of the picture that reinforce its flatness and highlight those that suggest depth. And among the most effective methods of achieving this was to inhibit binocular viewing of the picture.

According to Livingstone (2002), it was common practice in previous centuries to hang a curtain containing a small peephole in front of a painting. By looking at the painting through this hole the viewer obtained an enhanced sense of depth from the picture being viewed. The reason is that the peephole view suppresses visual cues which tell the viewer it is a flat image — cues like the frame, the surface reflectivity, and in particular the binocular disparity resulting from seeing the painting with two eyes. This suppression allows the pictorial depth cues such as shading, occlusion, and perspective greater prominence, and presents them in a way consistent with the monocular viewing condition (Ciuffreda and Engber, 2002). Indeed, until quite recently paper tubes were often used by art lovers to enhance the spatial illusion of pictures in galleries (Ames, 1925; Schlosberg, 1941). Later studies have confirmed scientifically the effectiveness of monocular viewing of images in strengthening perceived depth, a phenomenon now known as ‘monocular stereopsis’ (Koenderink, 1994).

The use of double images in pictures as a way of enhancing perceptible depth has rarely been discussed in the scientific literature, and has barely been experimented with in art. The exception, of course, is the work of Meinel and Walters cited here. Double images do not appear among the commonly cited pictorial depth cues (Melcher and Cavanagh, 2011), probably because they hardly ever appear in pictures. Yet on the face of it incorporating these common, if overlooked, features of visual experience would be an obvious way to return some of the stereoscopic information that by general consent normal pictures lack, thereby enhancing the sense of depth they elicit when viewed with two eyes. This is certainly what Walters claimed, but as far as we can tell it has never been tested.

## 4. Study

We designed a study to test whether the inclusion of double images in pictures enhances the perceptible sense of depth compared to pictures without double images. We created a set of stimuli containing a red square surrounded by white dots on a black background (see Fig. 4). The background included a foreshortened ‘floor’, which suggests the square and its immediate surroundings are set back in space from the lower foreground area in the image. Four versions of the stimuli were created: A) red square on dotted background with no effect, B) red square on dotted background where the background is blurred, C) red square on a dotted background where the dots are doubled around the periphery of the square and, finally, D) red square on a dotted background with doubled dots and blur.

[Insert Fig. 4 here]

The appearance of the double images — their degree and angle of separation and transparency — was modelled as closely as possible on observation of actually perceived doubling. We sought to eliminate pictorial depth cues that might add to or confuse the depth perception attributable to the double images, such as shadow or size relation, but chose to include blur since relative indistinctness is a feature of naturally occurring double images. It’s well known that blur is an effective depth cue in natural vision (Mather, 1996) and that it occurs frequently as a pictorial depth cue (Nguyen et al., 2005). As noted by Meinel above, double images normally appear out the point of focus, so defocus is a natural corollary to the double image effect (Mather and Smith, 2000).

As this was the first study on pictorial double vision we chose to conduct a qualitative experiment to see if there were any initial effects in response to the various conditions. The participants were undergraduate fine art students (10 female and 5 male; aged 20-40 with an average age of 23) all of whom had good or corrected binocular eyesight. The stimuli were presented on a 27-inch iMac screen with brightness set to maximum and with constant ambient lighting in the room. The pictures were shown in horizontally aligned pairs in all six possible combinations: A-



B: *no effect vs. blurred background*; A-C: *no effect vs. doubled*; A-D: *no effect vs. doubled with blur*; C-D: *doubled vs. doubled with blur*; D-B: *doubled and blurred vs. blurred*, and B-C: *blurred vs. doubled*. The pairs were presented in random order. Each picture was 26 x 17 cm in size. Participants were seated approximately 80 cm from the screen. The duration of the presentation was not limited, and participants could decide when they wanted to proceed to the next pair.

Participants were asked by the investigator to describe any differences they noted between the paired pictures and, if they noted any, to describe the effect of the differences. The investigator offered no prompts on the subject of depth perception. Participants' responses were recorded as audio data, transcribed as text, and then analysed for comments about depth perception.

## 5. Results

Interviews lasted between 3 and 15 minutes, with the average being about 5 minutes. The results for each condition were as follows:

A-B: In the 'no effect vs. blur' condition the background was reported as being "*out of focus*" suggesting that the square and background appeared to occupy different depth planes in the blurred condition. Depth related comments included the terms "*floating*", "*coming forward more*" or "*in the middle of the room*". This is consistent with depth enhancing effect of blur noted above.

A-C: In the 'no effect vs. doubled' condition, double vision had little effect in enhancing depth. Only 4 of 15 participants spoke about the doubling as suggesting depth or having binocular qualities, offering comments such as "[...] *it's obviously 3D* [...]"; "[...] *it looks like crosseyed* [...]"; "[...] *it's almost like a sculpture* [...]"; "[...] *it jumps out more* [...]"). Two participants reported the doubling was a distraction and actually made the square seem less prominent. The remaining participants noted properties not specifically related to depth, talking instead about the way the doubled image was "*interesting*" or "*rich in information*".

A-D: When participants were presented with a comparison between ‘no effect vs. doubled with blur’, 10 of the 15 reported the square in the effected state as being more “*out standing*”. One participant reported the reverse effect, in which the doubled dots appeared to create a white frame around the square, which gave it a flattened appearance.

C-D: The comparison of ‘doubled vs. doubled with blur’ evoked similar responses as the A-B ‘no effect vs. blur’ condition. The majority (11 participants) reported the square as being closer when the stimuli was doubled and blurred compared to doubling alone. The remaining four did not mention depth.

D-B: A strong effect was found in the ‘doubled and blurred vs. blurred’ condition. In this case 11 of the 15 participants reported the combined effect of doubling and blur was greater than blur alone, reporting the red square as standing further out from the background. One participant even remarked that the doubling effect appeared to depict “*two-eyes-perspective*”. Three participants judged the square to be more outstanding in the blur only condition, and one participant did not mention depth at all.

B-C: Double vision fared worst when compared to the blurred background. In this ‘blurred vs. doubled’ condition only one participant perceived the square as more spatially prominent when set on a doubled background compared with a blurred one. Participants volunteered comments about the way the blurred background helps to “*emphasize*” the red square or to give “*more depth*” or “*three- dimensionality*” to the picture.

The two graphics (Fig. 5 and 6) illustrate the main result of the interviews and provide samples of depth-related comments.

[Insert Fig. 5 and 6 here]

## **6. Discussion**

We hypothesised that pictures containing double vision in combination with blur would elicit a greater sense of perceived depth compared to pictures without double images. Our results support this hypothesis. We have shown that double images combined with blur elicit stronger perceptions of depth than blur alone. This initial study suggests that double images may indeed provide us with an effective and as yet unexploited pictorial depth cue, as Walters and Meinel claimed.

One reason that double images combined with blur may be an effective depth cue is that they are either consciously or unconsciously associated in the mind of the viewer with the double images seen in natural vision, although only one participant explicitly mentioned this. Double images may therefore help to inhibit the flatness cues in the picture and promote the depth cues.

Although these initial results are encouraging there are a number of factors that need further consideration and exploration. First, as noted, the participants in this case were undergraduate fine art students. It is possible that owing to their training, visual preferences, and perhaps even personality type may have affected their receptivity to this novel form of stimuli. It will be interesting, therefore, to extend the study to a wider social group. Second, in this study we did not direct or measure the participants' fixation within the area of the presentation screen. According to Meinel the depth effect should be strongest when fixation is on the non-doubled object as doubled images never coincide with the point of fixation in natural vision. However, the fact that the enhanced perception of depth was strong even though the participants could wander around the stimuli at will argues for the robustness of the effect. Further studies using eye tracking and directed fixation may reveal the extent to which the effect is gaze contingent. It would also be useful to test the differences between binocular and monocular viewing of double image stimuli, which is a variable not examined here. Meanwhile, Ogle (1952a) showed that double vision stimuli are most effective when presented in short exposure times, indicating that duration may be another factor to investigate. As the authors observed in their own vision, double images are also fleeting and transient, and it may be that animated stimuli would better convey these properties than still images.

It is worth noting that the creation of double vision stimuli presents a number of challenges. First, like many visual phenomena, depth perception varies from person to person (Westermann and Cribbin, 1998) and this may apply to double vision as much as anything else. Also, some people may adapt more quickly to the double vision cues than others (Mitchell, 1966b). Furthermore, as noted above, double vision is never seen directly in natural vision. If we try to look at or arrest a double image it either disappears, or changes, or the visual system tried to fuse both images (Bruce et al., 2010). Likewise, in natural vision double images never appear in isolation from other depth cues such as occlusion, size variance, and defocus, and so studying double vision on its own is very difficult, and perhaps not desirable. For experimental purposes, double vision stimuli need to be sufficiently realistic so as to be meaningful to the participant but sufficiently abstract to control for all the other variables that might affect the results. Further work is needed here to better understand the phenomenal appearance of double vision so as to most effectively harness it for experimental purposes.

Including double vision effects in pictorial information may have a number of useful applications. It's widely recognised that depth judgements in images are adversely affected by the flatness of screens (Domini et al., 2011; Watt et al., 2002). The addition of double vision as a further depth cue might help to counter this. The finding that double vision is most efficacious when combined with blur coincides with other research (Hoffman and Banks, 2010; Held et al., 2012) showing that blur can aid depth discrimination performance. Wang et al. (2011) meanwhile, demonstrated that adding blur in three-dimensional images can lessen the visual discomfort associated with coarse disparity and can improve the depth perception. Accounting for double vision, therefore, may also prove important to those engaged in designing effective and comfortable 3D capture and display systems. Finally, for artists double vision is an as yet largely unexplored aspect of visual perception to be exploited pictorially. It offers a naturalistic way of expressing depth and proximity within the picture plane, and can create a greater sense of involvement on the part of the viewer with the work of art.

## **7. Conclusion**

The use of double vision as a pictorial depth cue has received very little attention in art or science. Yet the results obtained here suggest that under certain conditions double images may have a significant impact on perceived depth in pictures. Much further work is needed to replicate these results, to determine the possible impact of other variables, and to better understand the perceptual phenomenon itself. Yet we can envisage a time when double vision will take its place among the far better established pictorial depth cues. If this were to happen it would be a testament to the pioneering work of Evan Walters and Erna Meinel.

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Kemp 1990



## Figures



Figure 1. Evan Walters, *Self Portrait with Candle*, c. 1939, Oil on canvas, City & County of Swansea: Glynn Vivian Art Gallery Collection.



Figure 2. Robert Pepperell, *Studio Painting 10*, 2011, Oil and sand on canvas. Note the doubling and relative softness of the frame and bust behind the flowers, which were the point of fixation.



Figure 3. Photograph by Robert Pepperell, 2011, showing still life scene photographed with 24 mm lens from the same vantage point as the painting in Fig. 2.

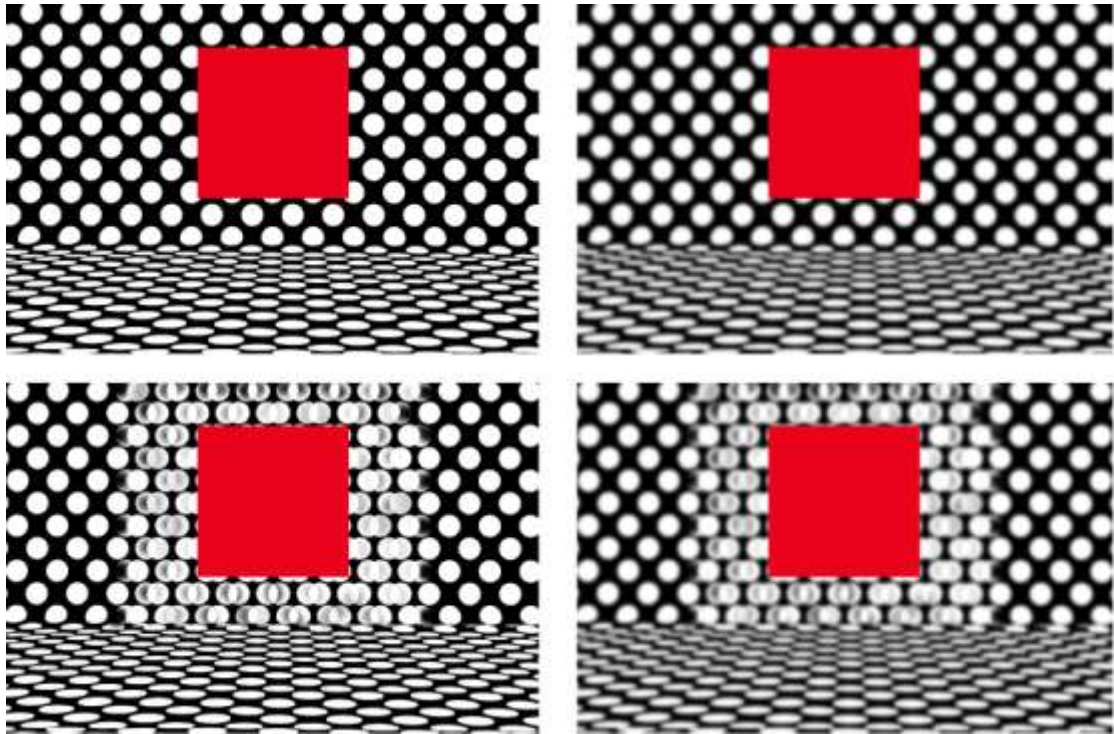


Figure 4. The four conditions of stimuli used in the study. Top left (A) red square on dotted background with no effect; Top right (B) red square on dotted background where the background is blurred; Bottom left (C) red square on a dotted background where the dots are doubled around the periphery of the square; Bottom right (D) red square on a dotted background with doubled dots and blur.

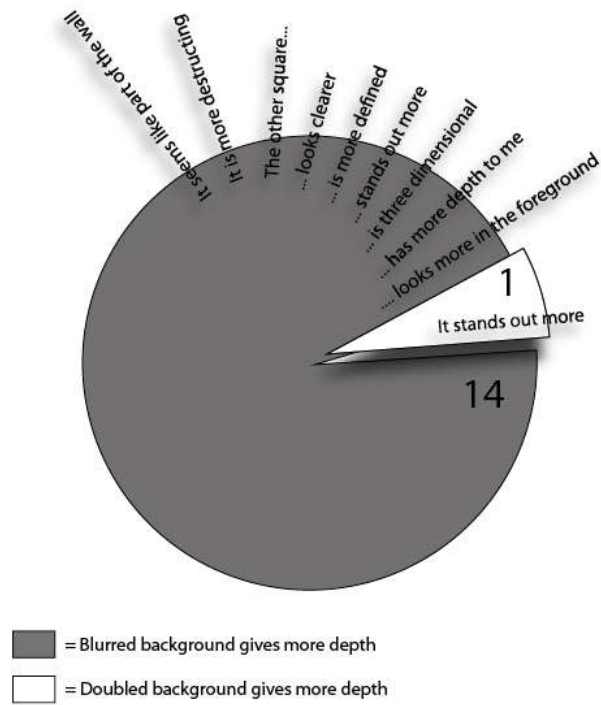


Figure 5. 14 of 15 participants reported that the blurred background gives a greater sense of depth compared with doubling on its own. This demonstrates that doubling alone is insufficient to enhance depth. The comments prefixed by ‘The other square...’ refer to the square on the blurred background.

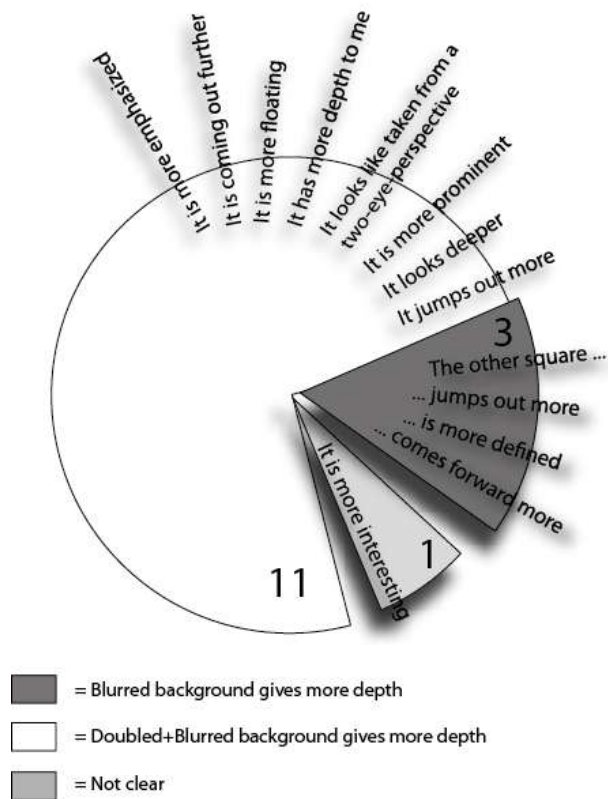


Figure 6. 11 of the 15 participants reported that the doubled and blurred background gave a greater sense of depth than blurred background alone. One participant offered a comment not relevant to depth. The comments prefixed by ‘The other square...’ refer to the square on the blurred background.