Can artistic methods be used to improve the perception of depth in pictures? An investigation into two methods

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Abstract

This PhD research investigates two artistic imaging methods based on modeling human visual experience, Vision-Space and Fovography, in order to ascertain whether they are better able to represent pictorial depth than conventional imaging methods, based on geometrical perspective.

The way we subjectively perceive visual space and depth is still not fully understood and there is still debate about what is the best way to represent the three-dimensional world on a two-dimensional plane. Photographs and computer-generated pictures generally use some form of linear perspective, which has also been employed to some extent historically by artists to produce images that approximate scenes in the visual world (Kubovy, 1987). Many scientists have argued linear perspective is the optimum and accurate way to record visual space (Pirenne, 1970). However, it has also been observed there are limitations to these imaging methods in that the experience of visual space does not correspond faithfully to structure of images produced with conventional linear perspective methods (Kemp, 1990). Cameras, for example, do not discriminate between the central and peripheral areas of the visual field as human eyes do, and cameras can generally only capture a relatively narrow portion of the visual field (Kingslake, 1992).

The Vision-Space and Fovography imaging methods are derived from painterly insights about human vision, while also drawing on insights gained by recent vision scientists about the structure of visual awareness. For the Vision-Space imaging method, this involves applying the spatial radial arrangement of disorder based on Koenderink's (2001) two-dimensional log-polar transform of how visual information could appear across the visual field in order to enhance depth perception. Conventional imaging system pictures, by contrast, often rely on depth of field blur to mimic human visual depth (Mather and Smith, 2002; Mauderer et al., 2014). Meanwhile, the Fovography imaging method represents the full scope of the binocular human visual field within a given picture area, using a method derived from analysis of art historical works and the phenomenal structure of the visual field (Pepperell and Haertel, 2014).

Through investigating both artistic approaches using a variety of quantitative and qualitative methods, this research found that both Vision-Space and Fovography pictures offered significant improvements in perceived depth. Moreover, in some cases they also improved the feeling of being ‘factored into’ (present in) the picture, and directing the viewer’s attention to a given area more reliably than conventional imaging methods.

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Definitions of technical terms

Algorithm	Mathematical formula used to carry out a set of operations.
Artistic methods of Vision-Space and Fovography	The methods and techniques used by artists to record their visual perception of a given scene, some of which draw on vision science theories.
Attention bulge	The expansion of perceived space around a proposed fixation point in a Fovography picture.
Area of interest	A defined area of a picture in which eye tracking data is analysed.
‘Conventional’ and ‘normal’ pictures	Pictures generated by optical devices such as cameras (photographs) and computer generated renders based on geometrical perspective.
Conventional imaging systems	Geometrical camera and computer aided design (CAD) technologies.
Complete Vision-Space and Fovography pictures	Pictures produced combining multiple artistic effects as specified in each theory, as opposed to using each effect in isolation.
Compression image effect	The peripheral area of a picture is increasingly squashed relative to a specified fixation point within the centre.
Falloff value	A level of intensity that the image effect of spatial radial disorder is assigned to a picture.
Improved directional focus	A measure of the speed and duration of an observer’s fixation on a planned focus location in the picture, with more rapid fixation and longer duration being positive.
Improved object proximity	A measure of the observer’s ability to understand differences in the apparent presence of distance between the locations of objects that surround the planned focus location.

Improved observer relation	A measure of the observer’s sense of feeling ‘factored into’ (present in) the scene owing to having an increased understanding of the apparent presence of distance to a planned focus location.
Improved perception of depth	A measure of the observer’s judgment of distance between a specified fixation point in a picture and the rest of the image space, with an increase in the apparent presence of distance being positive.
Linear perspective	A mathematical method of projecting a 2D image of a 3D scene from a given viewpoint based on the principle that light paths travel in straight lines.
Log-polar disordered transform	Disorder that originates from a focus point, where the amount of disorder increases as a function of distance.
Matching closer to natural vision	A measure of the perceived realism within a picture as judged by an observer, specifically how closely it matches the first-person experience of seeing the world.
Natural vision	First-person experience of perceiving the world.
Perceptual image effects	Components of artistic methods based on intuitive insights taken from visual artists and vision scientists engaged in exploring the experience of visual awareness.
Planned focus location (Vision-Space) and Intended focus area (Fovography)	Both imaging methods assume a fixation point on a given area or object in order to simulate the point of view of an observer looking at a given point in space.
Post-production tool	Propriety digital imaging software which creates a novel way of representing visual experience.
Property value	The level of intensity that an image effect is assigned to a picture.
Saliency	A measure of the relative prominence of a given object or area within a picture.

Spatial radial disorder	A mathematically-generated disorder effect distributed through the picture relative to a focus point using X, Y and Z axis's to suggest three-dimensional spatial depths.
Spatial radial blur	A digitally generated blur effect distributed through the picture relative to a focus point using X, Y and Z axis's to suggest three-dimensional spatial depths.
Three-dimensional space	Comprising of height, width and depth dimensions (X, Y and Z axis's).
Two-dimensional space	Comprising of height and width in the same plane (X, Y axis's).
Viewing advantages	Claims hypothesised through more accurately conveying visual space then geometrical perspective depictions.
Visual space	The represented physical view perceived within the scope of natural vision or captured by a camera.

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1 Introduction and overview

In the three-dimensional world we perceive objects in space using a number of different depth cues; such as binocular disparity, motion parallax, accommodation, blurring, relative height, occlusion, shadows, texture gradients, familiar size and relative size (Palmer, 1999). This thesis examines the use of artistic methods to improve the perception of depth in pictures, where visual space is depicted on a two-dimensional surface. When visual space is represented in a picture, it generally has less sense of depth than in the real world because we are aware of the flatness of the picture surface. As the psychologist Julian Hochberg noted:

> Regardless of how realistically a trompe l'oeil painter reproduces his scene, no matter how high the fidelity of a photograph, neither the painting nor the photograph can be mistaken for the scene itself if the plane of the picture is effectively localised over its entire surface.
> (Hochberg, 1962, p.39)

The longest established pictorial method developed to rationalise visual space perceived first-hand in the real world is known as 'linear perspective' (Kemp, 1990). Kubovy (1986, p.1) describes linear perspective as a geometrically accurate way to organise the layout of objects relative to a specified fixation point within the picture. The result, as Kubovy notes: was that "...perspective gave Renaissance artists the means to produce a compelling illusion of depth". Filippo Brunelleschi (1377-1446) is credited with pioneering the development of linear perspective at the beginning of the Renaissance, which he publicly demonstrated using a peepshow device (Arnheim, 1974, 1978). His demonstration involved using a panel painting of the Baptistery in Florence, which was observed from the rear through a small hole made in the panel as a reflection in a mirror held opposite at arm's length. When the mirror was removed the viewer was able to see the real Baptistery and compare it directly to the representation he painted. According to a contemporary account by the writer Manetti, the result was a compelling illusion of depth and realism (Kubovy, 1986). However, it was Leon Battista Alberti (1404 - 1472) who first formalised the theory of linear perspective in his short work 'On Painting' (Alberti, 1991, originally published 1435). He described the way orthogonal parallel lines converge to a single point in the distance, known as a vanishing point in a picture, and that objects drawn should appear closer together and smaller the nearer they are to this point. On this basis the scaling of objects could be mathematically calculated to make the depth of the painting look convincing.

Using the theory of linear perspective, Leonardo da Vinci developed a glass tracing drawing method through the invention of the perspectograph. This device had a viewing slot at the front and held a pane of glass behind which an image of the world could be traced in linear perspective. This was one of many Renaissance training aids used to improve the accuracy of represented depth cues (Hochberg, 1962). Such methods allowed artists to create a more realistic representation of space (real and imaginary) and to some extent overcome the lack of physical depth which is an inherent limitation of two-dimensional pictures (Kemp, 1990). Gibson (1961, 1966) reported that if the tracing glass was perfectly flat and transparent, the observer would be able to view the environment as if the glass were not there: allowing the same distribution of environmental information carried in the light (optic array) to pass through and enter the eye when tracing the scene. Providing the viewer of the subsequent picture was located at the same position as the artist, they would also see the same pattern of light. However, if the painting is then viewed from a different distance and orientation than when it was drawn, i.e. the point of central projection, then the optic array produced by the picture would no longer provide a true representation of the physical scene. This limitation on the accuracy of pictorial depth cues is discussed by Pirenne (1970). He shows that pictures are often observed from incorrect viewpoints which give them a changed central projection, so the light information entering the eye would no longer relate to the perspective information depicted. With corresponding visual information being absent from a picture, the perception of spatial relations are said to be disrupted from that of the original physical scene. Even though the representation of the space is distorted, Pirenne (1970, p.96) notes that one is still able to read the information more or less effortlessly.

In theories of visual perception the function of the human visual system is often compared to the mechanics of cameras and their arrangements of lenses and plates. For example, Palmer (1999) compares the optical structure of the eye to the lens found in the camera (Figure 1.1). Both have a variable sized aperture and clear lens, resulting in light from the environment being projected upside-down and focused onto a light sensitive material, in the case of the eye this being the retina and in the camera the film or plate.

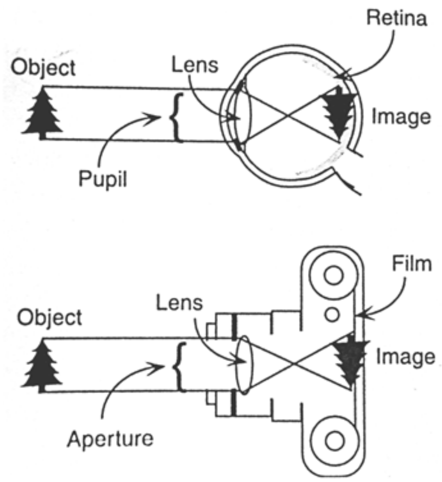


Figure 1.1. Illustrated comparison between the eye and the camera lens (Palmer, 1999).

However, despite these similarities between the camera and the eye, which might suggest that the image in natural vision is analogous to taking a photograph, there are significant differences between the way images are projected and detected in both cases: For example, camera lens systems are specifically designed to produce flat pictures with central projections (which have roughly equal focus and clarity across the whole picture), whereas the eyes optical system images an approximate central projection of physical space onto the curved surface of the retina, with the central area (the fovea) being the most exact (Pirenne, 1970). Furthermore, due to the arrangement of light sensitive cells in the eye, in which the greatest number are concentrated in the central area, the retinal image loses sharpness towards the periphery (Snowden et al., 2006). It is also discussed by Pirenne (1970) that the retinal image loses sharpness towards the periphery but, as a result of continuous eye movements which allow attention parts of the scene within the fovea (facilitating the most accurate visual detail) and accommodation which brings near and far parts of the scene being looked at into sharp focus, an extended clear detailed scene is experienced in natural vision. The difference in purpose between photographs and the retinal image are reported by Pirenne (1970, p.50) as the reason why the photographic camera is not similar to the eye: photographs duplicate physical space to be seen with sharp detail throughout and retinal images link events together in the process of seeing. As Pirenne notes: “Consequently there is no reason why photographs should mimic the peculiarities of the retinal image”.

The main idea explored in this research is the way artistic methods can be used to make pictures that are closer to the natural visual experience than that generated by optical devices such as cameras. More specifically, the research addresses the question of how the perception of depth can be improved in pictures. Traditionally the linear perspective method has been widely used to represent depth, and has often been regarded as the most accurate method (Pirenne, 1970). However, a number of artists and other researchers have questioned whether a model of vision based purely on optical geometry is indeed the best way to create a convincing sense of depth in pictures (Herdman, 1854; Rauschenbach, 1982; Pepperell and Haertel 2014). This research has involved a study of the differences between the way visual space is depicted in conventional geometrical perspective pictures and the way humans perceive depth naturally.

Artists and technologists have evolved a number of methods and techniques for realistically representing depth in pictures, including exploiting monocular depth cues, stereoscopic devices, and depth of field blur. Some of these are based on natural properties of human vision, but some achieve their effects in other ways. It is widely accepted that we use the disparity between our two eyes to judge spatial depth, a phenomenon known as binocular disparity (Ogle, 1964). However, artists are generally unable to rely on information from binocular disparity to create a sense of depth as linear perspective pictures are almost always made from a single eye's point of view Kubovy (1986). Even so, artists have still been able to create a strong sense of depth using other cues such as shading, occlusion, size diminution, etc. For some researchers the role of stereoscopic information has been overestimated, and our ability to judge depth from purely monocular sources has been studied. For example, in the paper 'Space Perception in Pictures' Koenderink et al. (2011) examined the way we are able to derive depth from flat pictures. They noted:

> Apparently we deal with a very basic ability of the human mind, namely the ability to generate three-dimensional geometrical structures automatically, in proto–awareness, and to do so, on the basis of mere pictorial cues. Neither binocular disparity, nor movement parallax, etc., are involved. (Koenderink et al., 2011, p.7)

It has long been know that by viewing a picture through a lens or a hole using one eye, apparent depth is created by preventing the picture frame from being seen (Ames, 1925). Furthermore, by suppressing the visual cues formed from using two eyes, such as binocular disparity, a picture will appear less flat (Livingstone, 2002). Ciuffreda and Engber (2002) also suggested that monocular viewing conditions enhance pictorial depth cues, such as occlusion, shading, perspective, etc. which investigations by Koenderink et al. (1994) confirmed using a synopter (a device which creates a similar effect to closing an eye), with monocular perceived depth increases when looking at a painting described as 'monocular stereopsis'. A further study by Koenderink et al. (2013) which allowed the two eye observation of pictures using a device called a zograscope (a lens which produces a cyclopean view from both eyes instead of looking through a single peephole or synopter), also saw participants experiencing a strong sense of depth which was significantly larger than experienced in natural vision.

Stereoscopic imaging techniques that produce binocular disparity information have been shown to increase the sensation of depth within a picture viewed with two eyes (Wagner et al., 1992). This method produces depth by mimicking the presentation of disparate images on the two retinas of the viewers' eyes in natural vision. When binocular disparity is introduced appropriate to the objects in the scene, the observer is more able to view the scene rather than the flat two-dimensional object that the picture is (Hochberg, 1962). Three-dimensional films derived from stereoscopic photography have become more popular over recent years, with the release of "Avatar" in 2009 being a global box office success. In addition, studies have shown that stereoscopic pictures are preferred over conventional pictures (IJsselsteijn et al. 1998; Freeman and Avons, 2000). However, studies have also shown increased eye-strain and fatigue whilst viewing stereoscopic images over non-stereoscopic ones (Mitsuhashi, 1996; IJsselsteijn et al., 2000).

The use of depth of field blur as a depth cue in human vision is widely accepted (Atchinson and Smith, 2000; Mather and Smith 2002; Ciuffreda et al., 2007). The blur formed in a retinal image is described by Mather and Smith (2002) as showing the optical limitations of the eyes which produces the same effect as depth of field blur found in optical pictures; that being "...objects nearer or farther than the plane of fixation are blurred by an amount that depends on their relative distance from the fixation plane" (Mather and Smith, 2002, p.1). Conventional imaging system pictures often rely on depth of field blur to mimic human visual depth, which Mauderer et al. (2014)

suggests can produce a sensation of depth in pictures through representing the depth of field limitations of the eye. In addition, Nefs (2012) demonstrated that the effect of depth of field blur is an important perceptual depth cue in pictures even though it is unable to give absolute measures of distance.

Photographs (geometrical lens-based pictures) generally depict a scene that crops or excludes the peripheral part of the observer's visual field, which discounts much of the first-person perspective seen in the human peripheral field (Pepperell and Burleigh, 2014). A more natural looking photograph is said to be produced when the camera's focal length is approximate to the diagonal length of the film or sensor; this being a focal length of 50mm for a standard 35mm film (Kingslake, 1992). For the purposes of this research, a normal photograph is understood as being shot using a camera with a 35mm sensor and 50mm lens which captures an area that subtends 43 degrees laterally (Pepperell and Haertel, 2014), therefore only a portion of the human visual field (which is approximately 135 degrees vertically and 200 degrees laterally (Hershenson, 1999) is contained in these photographs. This excludes close proximity objects and the viewer's body from pictures along with the ability to adopt a first-person relationship to surrounding objects (Stanghellini, 2009).

There have been attempts to optically replicate a closer human visual experience, using panoramic photographs and wide angle lenses such as the fisheye (Kingslake, 1992). However, both of these techniques only address the full scope of the visual field and not the perceptual phenomena experienced in natural vision. Some of these perceptual phenomena include objects being enlarged when they are fixated on (Suzuki and Cavanagh, 1997) and double vision (diplopia) caused by retinal images of the same object being outside of Panum's fusional area and so cannot be fused together (Agarwal and Blake, 2010).

More recent advances in technology have enabled a number of creative visual field imaging technologies, such as Quick Time VR (New World Designs, 2004) which uses multiple (batched) photographs stitched together. This approach is similar to panoramic photography, except that these photographs are taken at points through a 360 degree rotation, allowing the observer to virtually navigate within the scene (Precision, 1999). In a related way, the video technology known as Condition One

(Condition One, 2013) allows the viewer to interact with and adjust the viewing angle of a playing video, in order to see surrounding information which was out of frame. Both of these imaging technologies make further efforts to include the full scope of the human visual field.

All the methods described above are ways of creating a sense of depth in pictures, some of which are based on mimicking features of natural vision. Despite this, there are still large differences in the way conventional imaging technologies record visual information and depth compared to the way humans achieve the same task. This includes the much larger field of view experienced by humans (Hershenson, 1999), and the greater sense of depth we perceive than is available in geometrical perspective pictures (Kemp, 1990).

The purpose of this research is to examine some of these differences and evaluate whether alternative methods of depicting visual space developed by artists can produce a more convincing sense of depth by modelling their representations more closely on natural vision. The basic approach is to use quantitative and qualitative methods, to compare geometrical perspective pictures produced using conventional imaging methods against pictures adjusted using artistic methods, based more closely on the structure of natural vision.

1.1 Background to the research project

This research project was a response to a call put out in 2011 by Cardiff Metropolitan University to undergo the following research, and was supported through a Knowledge Economy Skills Scholarship program and the European Social Fund.

> A quantitative and qualitative examination of the effectiveness of a new three-dimensional graphical representation technique.

The research was originally focused around the Vision-Space imaging method developed by the artist-researcher John Jupe, which creates a novel way of representing visual experience using digital imaging technology known as a post-production tool (Jupe, 2002). Jupe trained at the Slade School of Art, UCL, where he was introduced to a rigorous method of artistic observation as taught in the school. He went on to develop a theory about the nature of visual perception based on his artistic work, and sought to develop this as a commercially viable technology for use in imaging media. The Vision-Space imaging method claims to discard the centuries-old convention of relying on linear perspective or geometrical lens-based models of vision. Instead Jupe (2002) hypothesises that Vision-Space pictures simulate much more closely the actual phenomenal experience of seeing and spatial awareness, using for example what he terms ‘disorder’ instead of blur to replicate peripheral vision to create depth cues.

To undertake this research project a cross-disciplinary supervisory team collaborated at Cardiff Metropolitan University which included Professor Robert Pepperell, also an artist-researcher who studies visual perception and consciousness, Professor Steven Gill, a product design researcher and Dr Darren Walker, a cognitive phycologist. The research aimed to evaluate the user response to the Vision-Space pictures in comparison to their corresponding geometrical perspective pictures in the early development phase of the imaging technology. It was proposed that this would be best achieved through developing experimental methodologies which empirically explore the experience of depth in pictures, which also meant learning statistical analysis methods.

After initial background research into the Vision-Space imaging theory, a collaboration was formed with Dr Maarten Wijntjes, a vision scientist at Perceptual Labs, Technology University Delft. This involved visiting him where quantitative experimental methodologies were developed to explore the relief and relative sizing of objects in Vision-Space pictures in comparison to their corresponding geometrical perspective pictures. These experiments were founded on previous methods to probe pictorial depth, developed by vision scientists Jan Koenderink and Andrea van Doorn, also based at Perceptual Labs.

Even though preliminary vision science studies carried out at Delft seemed promising at the time, they proved problematic because the method developed by Koenderink and colleagues required consistency between spatial proportions in the comparator pictures studied, whereas Vision-Space image effects transformed the shape and size of picture space content, which made direct comparison difficult. Nevertheless, as my background was in product design and education this experience at Delft contributed to my development as a researcher combining science knowledge with vison knowledge to design psychophysical experiments. Following this experience, on my return to Cardiff I designed two alternative experiments which involved qualitative comparisons between Vision-Space and geometrical perspective pictures in order to overcome the negated preliminary experiments.

Shortly after the conclusion of the second Vision-Space experiment, at the mid-point in the research the collaborative relationship between Jupe and Cardiff Metropolitan University ended. However, there was a second imaging method being developed by Robert Pepperell, based on his own artistic insights, which too included the phenomenal experience of seeing and challenged the idea of pictures based on geometrical perspective as the best method to depict depth in pictures. This meant that the research project was able to progress, with the Fovography imaging theory being investigated in a number of further experiments, whilst incorporating what had been learnt from previous Vision-Space experiments. However, because the theory behind Fovography differs to that relating to Vision-Space, additional background research needed to be undertaken in respect of the Fovography imaging method (Pepperell and Burleigh, 2014). Furthermore, an extended period was spent learning the Fovography imaging processes which involved picture construction and many image modifying procedures prior to developing new experiments for its study.

This research therefore examines two different imaging theories that challenge the idea that conventionally generated pictures are the best method to depict depth. Fundamentally important to both imaging methods is that they discard conventional linear perspective or geometrical lens-based models of vision in favour of intuitive insights taken from visual artists and vision scientists engaged in exploring the experience of visual awareness.

1.1.1 Overview of Vision-Space pictures

This research began by exploring Vision-Space pictures which differ in structure from conventional pictures in that they use a radial computational structure, based on Koenderink's (2001) two-dimensional log-polar disordered transform of how visual information may appear across the visual field, in order to enhance depth perception (Figure 1.2).

Figure 1.2. Vision-Space pictures present an unambiguous central fixation object (Television screen) within the claimed spatial qualities of spatial radial disorder.

Whilst conventional imaging methods are often reliant on depth of field blur to mimic human vision, Koenderink and van Doorn (1999, 2000) propose that visual information could be disordered across the visual field. They suggest that when spatial detail is removed from a picture using disorder rather than blur less structure is lost. As Baker and Donne note:

> When individual pixels are merged together into a single pixel, data is lost, whereas when pixels are disordered, more picture information is preserved. (Baker and Donne, 2010, p.3)

This theory was extended by Koenderink (2001) into a bespoke algorithm for John Jupe; detailing an X and Y axis spatial disorder that originated from a focus point using a log-polar transform, where the amount of disorder used is a function of distance. The distribution of disorder across the picture was based on the two-dimensional self-similar sunflower model which Koenderink and van Doorn (1978) had proposed as a basis for the increased distribution of contrast across the human visual field from a fixation. It is this computational formula that underpins the unique Vision-Space arrangement of spatial radial disorder (also set out from a central fixation), incorporating the additional ‘Z’ axis to suggest three-dimensional spatial depths. Through the use of a Vision-Space post-production tool, the visual quality of disorder is added to a geometrical perspective picture as spatial radial disorder along with other perceptual image effects to produce a Vision-Space picture.

Jupe also claims from his painterly insights that peripheral visual information in a picture is easier to understand when it is offset in a clockwise rotation by a number of degrees, and that central visual information should remain vertical. In addition, his depictions of visual space suggest a stretch in the Y axis to elongate the peripheral visual information, and a stretch in the X axis to widen the central fixation area. Jupe claims that this artistic insight encourages a further increase in the perception of depth as it allows additional discordance between central visual information being accurately fixated on and peripheral visual information.

When a photograph or computer generated picture is reprocessed with spatial radial disorder and other perceptual image effects, Jupe hypothesises a number of viewing advantages. These being that the observer feels increasingly ‘factored into’ (present in) the picture when viewing a planned focus location. It is from this planned focus location at the centre point of spatial radial disorder that the observable realism of a picture is said to better represent the first-person experience of perceiving the world. Accordingly, proximity judgements between objects and the perception of depth are claimed to be improved (Jupe, 2005).

1.1.2 Overview of Fovography pictures

The Fovography imaging method aims to proportionally represent the full scope of the binocular human visual field, which is approximately 135 degrees vertically and 200 degrees laterally (Hershenson, 1999). In comparison to the human visual field, a normal photograph taken with a 50mm lens using 35mm film or a sensor subtends to 43 lateral degrees (Pepperell and Haertel, 2014). This rectangular picture format (Figure 1.3) is used in most everyday media types and is unable to contain close proximity objects and peripheral information to the same extent as experienced in human vision.

Figure 1.3. A normal photograph shot using a Canon 5D Mark II DSLR with a full frame (35mm) sensor and 50mm lens, which captures an area that subtends 43 degrees laterally (Pepperell and Haertel, 2014).

Currently, the extended view of a Fovography picture is achieved through shooting multiple photographs, then using image-editing software (Photoshop) they are stitched together (Figure 1.4) and manipulated to produce a larger field of view picture with the scope of visual information found in the human visual field (Figure 1.5).

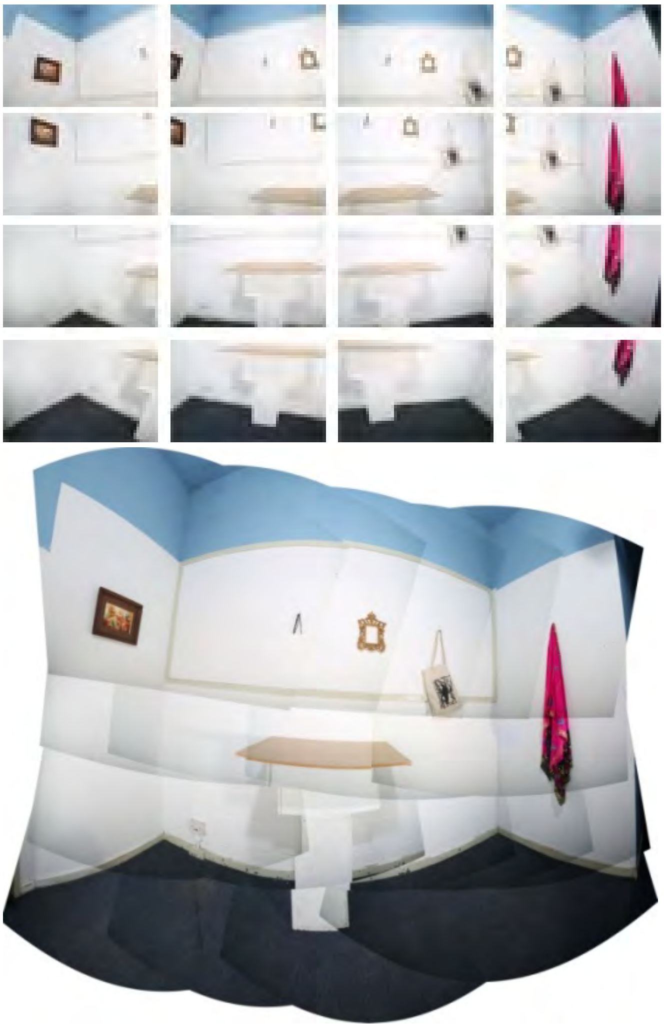


Figure 1.4. Each scene is photographed multiple times, then batch imported and stitched together using photo editing software (Photoshop).

Figure 1.5. Larger field of view picture containing the scope of visual information found in the human visual field.

In order that the human visual field can be accurately represented in the larger field of view picture, using a developed artistic method of representing the visual field in pictures (Pepperell and Haertel, 2014), the proportions of the scene are drawn whilst maintaining a fixation on a staged object. After the completion of this skilled drawing, a line of sight photograph is taken of the fixation object, from the same vantage point that the drawing was made (Figure 1.6).

Figure 1.6. The seated location of the person drawing the table scene, and the corresponding line of sight camera position.

The line of sight photograph is firstly arranged fittingly in the larger field of view picture then, based on the skilled drawing of the scene, the picture is increasingly compressed towards its periphery which is supported by Newsome (1972), whose experiments showed that the perceived size of objects viewed peripherally decrease with eccentricity. Additionally, the fixation area is enlarged similar to how Suzuki and

Cavanagh (1997) describe the expansion of perceived space around a focus of attention (Figure 1.7)

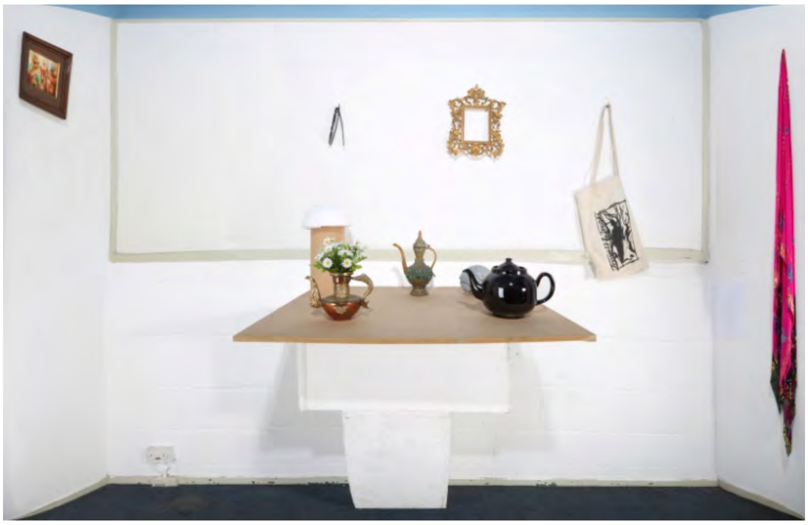


Figure 1.7. The scope of human visual information is compressed towards peripheral limits, making added objects appear larger within the fixation area.

Other perceptual image effects are also included from the visual record, such as blurring before and behind the object in focus and peripheral information being increasingly degraded towards the edge of the visual field (blurring is also used to produce this effect in digital pictures). In addition to the depth of focus limitations of the eyes which produce spatial blurring of three-dimensional scenes imaged on the retina (Mather and Smith, 2002), the increased ambiguity of objects towards the visual peripheral limit could be due to the retinal image losing sharpness towards its periphery (Pirenne, 1970). Eriksen and James (1986) describe this as the lack of resolution of detail provided by the retina in peripheral areas. Also present is a doubling of objects beyond the enlarged fixation. This simulates physiological diplopia which occurs when imaged objects found on different retina locations in each eye are outside of Panum's fusional area and cannot be fused (Agarwal and Blake, 2010). Additionally, the Fovography imaging method supports the use of an elliptical vignette border to more accurately represent the binocular boundary shape of the human visual field (Gibson, 1950), and adding self-relationship to surrounding objects through first-person perspective (Stanghellini, 2009). Pepperell hypothesises that when these features of the human binocular visual field are added to a picture, they draw emphasis to an intended focus area (object) and improve the perception of depth in a picture (Pepperell and Burleigh, 2014).

1.2 Overview of the context and aims of the research

The key aim of this research is to discover whether imaging methods based on the way artists have perceived and depicted visual space (at times adopting theories about the visual system from visual science), can be used to improve the perception of depth compared to conventional pictures generated by optical devices such as cameras.

This research investigated the way visual space is depicted in conventional geometrical perspective pictures, in comparison to Vision-Space and Fovography imaging methods, which their designers claim more closely emulate natural vision (Jupe, 2002; Pepperell and Burleigh, 2014). Many experts have argued that geometrical perspective is the only accurate way to represent the three-dimensional world on a two-dimensional plane, because it is based on the behaviour of light and the laws of geometry (Gibson, 1971; Gombrich, 1960; Pirenne, 1970; Rehkamper, 2003; Ward, 1976). They argue that the role of geometrical perspective is not to record how we perceive a scene in natural vision but to present the eye with the equivalent pattern of light that would emanate from the scene. When a geometrical perspective picture is presented correctly the observer is said to be unable to tell the difference between the picture and the reality it represents. However, a number of artists and other researchers have questioned whether a model of natural vision based purely on optical geometry is indeed the best way to create a convincing sense of depth in pictures (Herdman, 1854; Rauschenbach, 1982; Pepperell and Haertel 2014).

As with pictures created using linear perspective, Vision-Space and Fovography pictures are constructed around a fixation point in order to simulate the point of view of an observer looking at a given point in space (Kubovy, 1986). Moreover, both of these imaging methods include a number of image effects based on artist's direct observations, rather than geometrical or optical principles. In some cases theories about the visual system derived from visual science have also been adopted, with the aim of more faithfully matching the experience of natural vision.

The camera is discussed by Bruce et al. (2010) as a convenient way to model the optics of the eye. However, unlike the camera which produces a picture to be observed, the eye and brain work together to process changing optic array information (light entering the eye) which is important to understand our surroundings and perform tasks. This process involves the transfer of electrical activity (via the optic nerve) from cones and rods in the retina to the brain (Wolfe et al., 2006). Furthermore, whatever optical distortions might be produced by the lenses of the eyes, these are not apparent to the observer during perception as they are removed by the visual system (Palmer, 1999).

When presented with Vision-Space and Fovography image effects, observers may become more aware of the discrepancy with their natural vision or conventional photographs. However, both artistic depictions claim to be superior to their geometrical perspective counterparts in terms of being able to more accurately convey the visual space they depict (Jupe, 2002; Pepperell and Burleigh, 2014). As a result a number of viewing advantages have been hypothesised in comparison to pictures based on geometrical perspective. These include improved directional focus to a given fixation point (within a picture), which in turn is claimed to improve the perception of depth, object proximity, observer relation and matching closer to natural vision.

These hypothesised viewing advantages have been developed from observations based on artist's intuition, through their painting practice of how to best represent the experience of vision in pictures (Jupe, 2002; Pepperell and Haertel 2014). It is the translation of artistic vocabulary (which contains some metrics) into experiential descriptions that are used to compare the observations of pictures, to see if the claims made for both imaging methods demonstrate an impact on the observer, when compared against geometrical perspective pictures. The experiments involved participants making stimuli predilections or giving a level of agreement to experiential descriptions, to reflect their experience of the pictures. During the course of the research more scientifically rigorous metrics were defined for observers to assess their experiences, and experiments moved away from the vocabulary of art used to describe the experience of looking at a paintings. Additionally, an eye tracking element was incorporated to extend empirically the analysis of the directional focus claim.

All five of the viewing advantages mentioned above were hypothesised by the Vision-Space theory (Jupe, 2002), and the validity of these were examined in experiments 1 and 2. However, the Fovography theory predominantly hypothesised improved perception of depth and directional focus (Pepperell and Burleigh, 2014), and so it was decided to examine the validity of only these viewing advantages, which took place in experiments 3, 4 and 5. Furthermore, because the Vision-Space and Fovography pictures contain a number of interacting image effects it was also decided to explore a critical subset in order to limit the number of experimental variables. For the Vision-Space imaging method this involved using pictures with spatial radial disorder in isolation, and for the Fovography imaging method this involved the compression image effect on its own and with blur. This research aimed to test the claims of both artistic theories about visual perception, and demonstrate whether artistic output that at times adopts theories from visual science can heighten pictorial experience.

1.2.1 Objectives

In order to meet the key aim of the research and explore the validity of other hypothesised viewing advantages, four objectives were identified in relation to the study of Vision-Space and Fovography imaging theories.

Vision-Space:

i. To compare a Vision-Space picture against a geometrical perspective picture to see whether a number of viewing advantages such as improved perception of depth are experienced from a picture using a combination of Vision-Space image effects, as Jupe (2002) hypothesises.

ii. To explore the spatial radial disorder image effect, critical to a Vision-Space picture, which Jupe (2002) hypothesises to provide a number of viewing advantages, such as an improved perception of depth compared to the experience of blur in a picture.

Fovography:

iii. To explore the compression image effect, critical to a Fovography picture, which Pepperell hypothesises to provide an improved directional focus and perception of depth compared to a picture based on geometrical perspective (Pepperell and Burleigh, 2014).

iv. To compare Fovography pictures against geometrical perspective pictures to see whether improved directional focus and perception of depth are experienced in a picture using a combination of Fovography image effects, as Pepperell hypothesises (Pepperell and Burleigh, 2014).

1.2.2 Overview of research methods

A number of experiments were designed to compare pictures based on geometrical perspective against pictures with Vision-Space and Fovography image effects. The approach taken to explore the validity of hypothesised viewing advantages such as improved perception of depth over pictures based on geometrical perspective was:

i. <u>Development of experiments</u>

Plan and conduct experiments through knowledge gained from first-hand communication with the inventors of the Vision-Space and Fovography imaging methods and people familiar with designing and implementing psychophysical experiments. The methodologies applied captured both qualitative and quantitative data during the presentation of geometrical perspective pictures with and without blur, in comparison with Vision-Space and Fovography pictures containing both complete and key perceptual image effects.

ii. <u>Evaluation of experiments</u>

Each experiment was run under controlled conditions and provided a mixture of qualitative and quantitative insights through participants indicating a level of agreement towards experiential descriptions (Likert scale), stimuli predilection, giving experiential descriptions from viewing stimuli, and the recording of eye tracking data. These various sources of data were analysed and conclusions were drawn from them to determine the validity of hypothesised viewing advantages of Vision-Space and Fovography image effects in comparison to conventional pictures.

1.2.3 Chapter contents summary

<u>Chapter 2.</u> Literature review: This chapter reviews key ideas in visual perception concerning the imaging theories of Vision-Space and Fovography. This covers an

overview of main visual perception theories, perception of depth in natural vision, linear structured pictures and the Vision-Space and Fovography imaging methods of representing depth in pictures.

Chapter 3. Vision-Space Studies: This chapter sets out the research undertaken into the Vision-Space imaging method. The purpose of experiments presented within the third chapter was to explore the validity of viewing advantages hypothesised when observing a Vision-Space picture in comparison to a geometrical structured picture of the same scene. These viewing advantages were improved directional focus, object proximity, observer relation, perception of depth, and matching closer to natural vision. Additionally, to limit the number of experimental variables this research also involved the isolated examination of spatial radial disorder, a critical image effect used within Vision-Space pictures, suggested to more closely represent the spatial structure of vision within a picture compared to depth of field blur.

Chapter 4. Fovography Studies: This chapter sets out the research undertaken into the Fovography imaging method. Within the fourth chapter, the idea of geometrical perspective is challenged by the Fovography imaging theory as improving the directional focus and perception of depth in pictures. A number of experiments were conducted to compare the experience of depth and directional focus properties of photographs compared to Fovography pictures of the same scenes. Fovography image effects were also explored in isolation, namely the compression image effect suggested to be comparable to the spatial arrangement perceived within the scope of human vision.

Chapter 5. Discussion and Conclusion: This final chapter discusses the extent to which viewing advantages hypothesised by the Vision-Space and Fovography imaging theories (which use theories from visual science) have demonstrated an impact on the observer in comparison to geometrical perspective pictures of equivalent scenes. Moreover, through the confluence of art and science the widely accepted claim that conventional pictures based on geometrical perspective are the best way to accurately represent the three-dimensional world on a two-dimensional plane has been undermined, thus contributing to the advancement of the visual sciences.

2 Literature review

In order to conduct this research into imaging methods based on modeling human visual perception, it was necessary to obtain an overview of main perceptual theories and specific features of visual perception that were relevant to both Vision-Space and Fovography imaging theories. This initially involved exploring main visual perception theories, physiology of the human eye, human visual field and peripheral and central vision. Further literature concerning depth perception in human vision was also reviewed along with pictorial depth cues, first-person perspective and egocentric distance perception. The review then concludes with an explanation of both Vision-Space and Fovography imaging theories.

2.1 Overview of main visual perception theories

Palmer (1999) points out that little is understood about how the visual brain generates the conscious act of perception. The idea of what it ‘feels like’ to have a conscious visual experience is, he argues, the only adequate way to describe the phenomenon of visual awareness for a ‘sighted organism’. This is largely due to the inaccessibility of perception in consciousness, and unawareness of most of the underlying processes involved. Moreover, Palmer (1999) makes reference to Nobel Laureate Francis Crick, who further expresses the gap in understanding the nature of visual awareness, how it arises into consciousness and its importance. As Crick notes:

> There are two rather surprising aspects of our present knowledge of the visual system. The first is how much we already know – by any standards the amount is enormous…….. The other surprising thing is that, in spite of all this work, we have no clear idea how we are seeing anything.
> (Crick, 1994, p.23-24)

There are several theories that attempt to explain human visual awareness. Two that are commonly opposed are the Constructivist and Ecological theories. In the latter half of the 1800s, Hermann von Helmholtz theorised that the visual system draws on unconscious inferences when modelling our surroundings (Helmholtz, 1867/1962). The Constructivist theory argues that visual perceptions are formed by combining a person’s knowledge and expectations about the world based on previous experience, with information presented from light reaching the eyes. This approach to perception has been supported by significant vision psychologists, such as Richard Gregory (1997) and Julian Hochberg (1962) who argue that perception is largely the result of the influence of ‘top-down’ cognitive processes in which previous knowledge is used to generate perceptual experiences. In contrast, the ecological approach to vision, developed by psychologist James Gibson (1961, 1966), argues that visual perception is based on our responses to the information encoded in the array of light hitting the retina of the eye. In this ‘bottom-up’ approach, behaviour is prompted by available sensory information directly received from the light array rather than being the result of inference or interpretation. According to Gibson, it is the relationship between the patterns of light we see and our bodily motion with respect to those patterns that gives us the three-dimensional structure of the world and the objects within it (Gibson et al., 1959).

Palmer (1999) discusses an extension of Helmholtz’s approach, named the Heuristic Interpretation Process. In this theory it is proposed that the visual system constructs the most likely version of our visual environment, suggesting that our perception can be described as a high level approximate truth. In ‘The Nature of Explanation’ (Craik, 1943), Craik proposes a dynamic and predictive model to plan future actions, whereby the visual processing speed of the mind allows extrapolation of the perceptual future of moving objects whilst we manoeuvre within an environment. This theory suggests that visual perception is based on rational models of reality, providing us with a three-dimensional interpretation of how we expect to discover objects in our surroundings. In a similar way, Palmer (1999) argues perception is not reliant on optical information alone, emphasizing that our memory influences what is perceived in our environment and is dependent on our intentions. An example of this phenomenon is known as ‘visual completion’. Here the visual system automatically ‘completes’ surfaces and objects that are partly occluded by ‘filling in’ information based on knowledge about what is the most likely arrangement of the presented parts (Figure 2.1). In this sense, much of perception is made up of imagined content as well as information taken directly from the world.

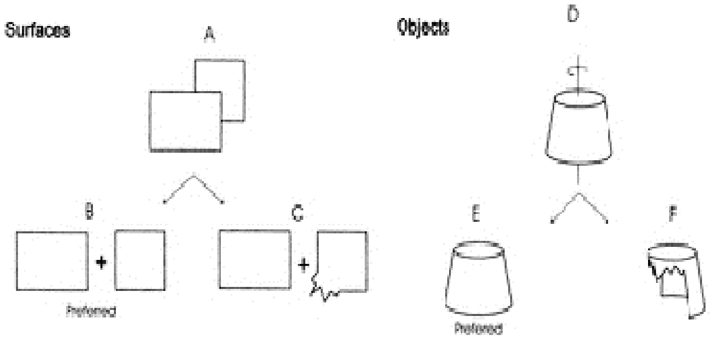


Figure 2.1. Visual completion suggests perception involves the construction of environment models by including portions of surfaces that we cannot see (Lier and Wagemans, 1999).

Attempts have been made to combine the constructivist and ecological approaches, such as in the work on the differences between perception and mental imagery (imagined objects) by Neisser (1975). Neisser describes perception as a process by which visual input is converted into a conscious precept (mental image). He suggests new mental images are processed alongside past knowledge during this information-processing to form perceptual experience. Neisser argues in favour of constructive perception over passive processing, although it is still not known how perceptual building blocks are selected. With this, further attention is given to Gibson's Ecological theory (Gibson, 1961) which suggests only optical information is needed to understand perception, with the sum of optical information said to permit only a singular outlook. However, he decides that it does not seem accurate enough to disregard the perceiver's psychological acceptance, along with the use of optical information to produce a percept (Neisser, 1975). This is referred to as Neisser's 'perceptual cycle' theory, in which the brain has the ability to combine expectation schema with environmental information in a constructivist process to produce the visual percept (what is seen). Neisser (1975, p.93) makes clear that expectation schema does not produce a percept in the act of seeing. For example, the image of my Toshiba laptop in front of me is not reconstructed by my brain to form its percept. As Neisser notes: "We perceive, attend to, and are conscious of objects and events, not ghostly mental representations". Neisser (1975, p.97) suggests perception to be an act based on developing anticipations which are subject to an ongoing exploration. As he notes: we cannot perceive unless we anticipate, but we must not only see what we anticipate. With reference to the perceptual cycle (Figure 2.2), environmental information is made understandable by allowing it to be readily updated during observation, through schema directing new explorations in line with new visual information within the optic array.

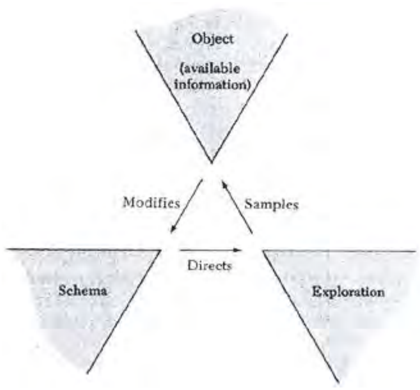


Figure 2.2. Perceptual cycle theory – Neisser combines expectation schemata with environmental information, in a constructivist visual procedure (Neisser, 1975).

Neisser suggests that this processed overview of the environment also allows past and present explorations to be compared against each other, providing a relative locality of objects (what he calls the 'exploratory image'), before optical information becomes available. It is when this exploratory image match's object information in the light array, that perceptions are said to be guided more smoothly towards the next exploratory prediction of environment information.

In the paper 'Vision and Information', Koenderink (2007) compares and contrasts a Marrean account of perception (named after the computational vision scientist David Marr) and a Goethean account (named after the early vision theorist Johann Wolfgang von Goethe). David Marr's development of computer vision programs which examined the arrangement of luminance within two-dimensional pictures, are seen as leading the way in revealing the three-dimensional spatial structure of a visual scene (Palmer, 1999). He was very much true to Gibson's ecological theories of vision and the Marrian account is widely accepted in science. Like Marr, Jan Koenderink and Andrea van Doorn have pioneered ecological computational approaches to optics, and continue to develop sophisticated mathematical techniques to recover surface depth from two-dimensional picture space. However, Koenderink (2007) argues in support of the Goethe account, that perception is closer to a controlled hallucination rather than a result of standard computations of optical data (what he calls the 'photographic record'). The function of the eye and brain working together is discussed by Koenderink as being loosely related to the optical sensors and memory chip found in modern cameras, proposing that the projected light array creates a factual version known as an ordered record in (i) optical pictures, (ii) video-signals and (iii) activity patterns in neural pathways. However, as supporters of constructivist approaches to visual physiology, Koenderink and van Doorn believe that the projected light array creates more than an ordered factual record found in optical pictures and video-signals, and that information about our surroundings is included from prior knowledge.

2.2 The physiology of the human eye

A recurring concept found in visual text books such as Palmer (1999), and Snowden et al. (2006), is that the function of the eye and the camera lens are analogous. In relation to this, it has already been discussed that photographs are not seen as representing vision in relation to perceptual phenomena. It is therefore important to construct a general understanding of the eye's physiology and some consequential effects on human vision.

The eye shown in cross section (Figure 2.3), allows light to enter it through the curved transparent surface called the cornea. This provides the eye with three quarters of its focusing power, with the adjustable lens behind providing the final portion that focuses (bends) the light onto the photoreceptors on the retina (Snowden et al., 2006).

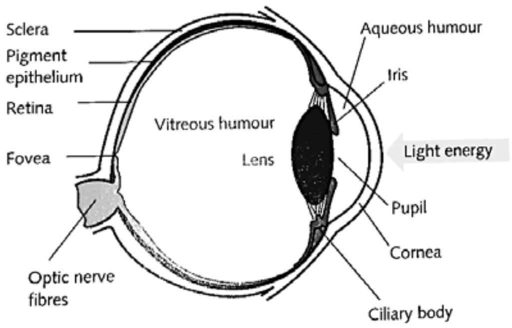


Figure 2.3. Horizontal cross-section of the human eye (Snowden et al., 2006).

The iris, which is the coloured part of the eye, regulates the amount of light that reaches the retina by controlling the pupil size of the eye which lets the light through. The lens adjustment, better known as accommodation, is performed by the ciliary muscles which stretch the lens thin (reducing refraction), when an attention object is needed to be brought into focus from a distance. As Snowden et al. notes: "...the light rays from distant objects that reach the eyes are near parallel and need little bending to bring them into focus on the retina". In contrast, by relaxing the ciliary muscles the lens is allowed to get thicker, which brings close attention objects into focus. As Snowden et al. notes: "close objects send diverging rays to the eye, which need to be bent more to bring them into focus" (Snowden et al., 2006, p.25).

It is only when the light rays finally reach the retina at the back of the eye and photoreceptors (rods and cones) absorb the light that visual processing starts (Snowden et al., 2006). Without rods and cones in the eye, which convert light from the projected environment into electrical signals for the brain to process, we would be blind. The retina is the start of the visual pathway commonly suggested in visual perception (Palmer, 1999; Snowden et al., 2006; Wolfe et al., 2006 and Bruce et al., 2010). Vision then takes place beyond the eye in the brain (the cortex), through a combination of conscious and unconscious visual processing, with more than 50% of the cortex established as being occupied with visual processing (Snowden et al., 2006). Visual processing is further described by Wolfe et al. (2006) as starting in the retina. As Wolfe et al. notes:

> Vision begins in the retina, when light is absorbed by rods and cones. The retina is like a microcomputer that transducers light energy into neural energy. – The retina informs the brain via the ganglion cells; neurons whose axons make use of the optic nerves.
> (Wolfe et al., 2006, p.45)

Rods contain the same photo pigment as cones but because rods are so sensitive to light they are not useful in daylight, whereas cones are less sensitive to light and bring us daytime vision (Snowden et al., 2006). Furthermore, rods and cones are not distributed evenly across the retina, with cones mainly found in the fovea region which provides central vision with increased detail (Figure 2.4).

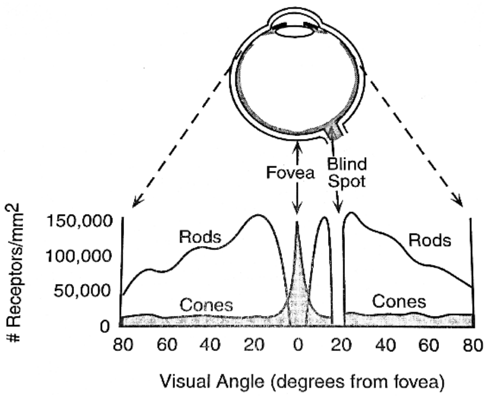


Figure 2.4. Distribution of rods and cones across the retina (Snowden et al., 2006).

The cones are made up of three types: red, green, and blue which effectively enable colour vision. As Wolfe et al. notes: "…cones signal information about wavelength, and thus provide the basis for colour vision" (Wolfe et al., 2006, p.36). Each eye has an area which has no photoreceptors, commonly referred to as the blind spot, where two varieties of ganglion cell axons (M and P cells) leave the eye, carrying colour and moving information about our environment to the cortex. Appropriately, our two eyes overlap in such a way that the blind spots are removed from our visual field (Snowden et al., 2006). The transformation of cone signals into colour vision, prior to its optic nerve transfer from the eye, to the cortex is covered in great detail by Livingstone (2002). Firstly, human visual perception uses the three types of cone in the retina to produce independent spectral information (signals), then colour opponent theory codes colour (hue) and luminance. This is achieved by the retinal ganglion cells, which either add or subtract the inputs from different cones, transforming visual information into red-green and yellow-blue colour opponent signals (chromatic channels), with the summation of cone activity producing a black-white signal (luminance channel). Livingstone (2002) advocates that the “what” system which enables colour perception and objects and faces to be recognised, uses information from ganglion cells that sum and subtract the cone inputs, and the “where” system which determines form, depth, spatial awareness, and motion uses information from ganglion cells that sum cone inputs. Due to this information processing difference, the “where” visual system uses the luminance channel above chromatic channels and provides the colour blind population with equal three-dimensional pictorial depth. When new computer generated scenes were designed to explore the Vision-Space imaging method in a second experiment (Section 3.3.2), knowledge of the visual colour system from Livingstone (2002) was used to improve the clarity of image effects added to these pictures through luminance differences.

2.2.1 The human visual field

The scope of the human visual field (Figure 2.5) extends some 75 degrees below the central line of sight, and 60 degrees above, the view in the upper region being constrained by the bony ridge above the eye (Hershenson, 1999). Laterally, the visual field extends approximately 200 degrees. The monocular visual field – the field of view of each eye – extends approximately 100 degrees laterally and is further constrained by the nose.

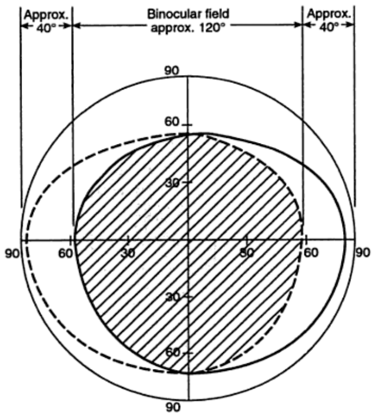


Figure 2.5. The binocular field of vision projected onto a frontal plane. The binocular field is surrounded by two uniocular fields, the monocular temporal crescents (Hershenson, 1999).

The region covered by both eyes simultaneously when looking directly ahead is approximately 120 degrees, Here visual information from the world stimulates the retinas of both eyes and contributes to binocular depth perception, known as stereopsis. Furthermore, beyond the binocular visual field lie two uniocular fields which extend a further 40 degrees in each temporal direction.

2.2.2 Peripheral and central vision

The Vision-Space and Fovography imaging methods both use knowledge surrounding the differences between central and peripheral vision. The human visual field is recognised as not being uniform, with fine visual detail decreasing away from a central fixation (acuity decreases with eccentricity) towards peripheral vision (Pirenne, 1970; Palmer, 1999; Snowden et al., 2006; Wolfe, 2000; Bruce et al., 2010). This means that there are differences in the way visual information is received by the different parts of the eye. Human vision is often described in text books as detecting high and low spatial frequencies, with high spatial frequency explained as a thin, closely packed pattern of bars, and low spatial frequency described as a wide, spaced out pattern of bars (Palmer, 1999; Snowden et al., 2006; Wolfe et al., 2006; Bruce et al., 2010). These frequencies are sensitive to contrast, and as contrast reduces so does the visual system's ability to see frequencies. The visual function of spatial contrast sensitivity creates a 'window of visibility' and, depending on an individual's sensitivity to spatial frequencies, will affect their 'visual acuity' which effectively allows different sized objects to be seen, and not to be seen (Snowden et al., 2006). Therefore, what is registered by the visual system is also directly affected by the size of objects projected onto the retina, and it becomes necessary for them to fall into the resolution limits of the eye. For example, we are less able to pick up fine-grained information in the visual periphery. As Sere et al. notes: “if one maintains fixation on a single word in a text words adjacent to the fixed word are still readable, but those further away are not” (Sere et al., 2000, p.1). It has also been shown that in order to perceive objects in the periphery it is necessary to scale them up so that they are detected by the same number of cortical cells as they would be if detected by the fovea, as illustrated in Figure 2.6 (Snowden et al., 2006).

Figure 2.6. An eye chart in which letters in different parts of our visual field have been scaled (using a cortical magnification factor) to make them equally legible (Snowden et al., 2006).

This decreasing visual acuity of objects in peripheral vision goes unnoticed in natural vision due to our unawareness of compensating eye movements, which in turn allow an extended clear detailed scene to be experienced (Pirenne, 1970; Sere et al., 2000). Consequently, this means that we are also unaware that we perceive only a small area of our visual field distinctly during a fixation (Rayner and Pollatsek, 1992). Additionally, Eriksen and James (1986) discuss the visual field as having a focus within it, theoretically suggesting that it would have a boundary from which less visual resources might be allocated, thus reducing the resolution of attention. As Eriksen and James notes: “the focus area could be sharply demarcated with a step-wise transition from high resource concentration to the remaining visual field with low residual processing capacity” (Eriksen and James, 1986, p.4). Further literature by He et al. (1996) discusses the differences between acuity driven by retinal processes and acuity of attention which is processed beyond the V1 area of the brain. The temporal resolution of attention is discussed as being course and unable to individuate finely spaced similar objects, with visual resolution used to resolve smallest perceptual detail. Correspondingly to both, is that resolution gets worse away from central vision. The phenomenal description of vision by William James 1890/1950 (cited in Eriksen and James, 1986), conveys visual attention as a focus with a margin and a fringe, where resources of visual attention decrease as a gradient from the focus outwards towards the residual field. Eriksen and James (1986), confirming work done by Jonides (1980) and La Berge (1983), found that the attention field varied in size depending on the task. A spotlight analogy was used instead of a zoom lens model to describe the visual angle alteration of focus size within the visual field. In addition, the precision of a new focus location was found to improve over time, and with it, the incompatible noise surrounding the focus boundary was found to have a less disruptive effect. However, Eriksen and James (1986) argue that highly focused attention processing would be wasted outside of the fovea because of the lack of resolution of detail provided by the retina in peripheral areas.

While objects seen in peripheral vision tend to appear indistinct they can also appear smaller than would be the case in central vision. Newsome (1972) showed that the perceived size of objects viewed peripherally, decrease with eccentricity. At the same time the visual system is able to effectively enlarge those objects attended to in central vision. Suzuki and Cavanagh (1997) have demonstrated that the perception of perceived space expands around a focus of attention which is associated with central vision recruiting more perceptual resources.

2.3 Depth perception in human vision

In our three-dimensional world we perceive objects in space using a number of depth cues which the visual system uses to determine the position of objects and our relationship to them. These typically include: binocular disparity, motion parallax, convergence, accommodation, blurring, relative size, relative height, occlusion, shadows, texture gradients, shading, blur and familiar size (Palmer, 1999). These depth cues are often categorised as ‘pictorial’ and ‘non-pictorial’, the former being those used to convey a sense of depth in pictures and the latter used to interpret depth in actual vision. Here I will discuss non-pictorial depth cues first. In general, these are not captured by two-dimensional pictures and include binocular disparity, motion parallax, convergence and accommodation. The remaining depth cues are discussed in Section 2.3.1 and produce depth information in pictures and natural vision (Ware, 2008; Bruce et al., 2010).

The principal understanding of human three-dimensional shape and depth perception is historically based on binocular disparity (two eye view) and motion parallax (body movement), also known as differential motion (Gibson et al., 1959). These optical sources of depth and shape information were first investigated by perceptual researchers Wheatstone in the late 18th century, then Helmholtz in the 19th century, and continue to be important areas of research (Norman et al., 2000). Binocular disparity is caused when viewing solid objects at close range and the retinal images from both eyes slightly differ to give disparities. This allows the extraction of distance information (stereoscopic depth perception) up to 100 feet, provides three-dimensional shape to nearby objects and is used to accurately guide hands when reaching for objects (Palmer, 1999). Ware (2008) talks about 20 percent of the population having little or no stereo depth perception. However, this population is not affected during distance tasks, such as navigational judgments when cycling, because the brain is not able to engage stereo information to judge distant objects. Nevertheless, as expected with deficient depth perception, close range tasks, such as grasping nearby objects, become problematic.

In the early 1960s, Bela Julesz developed stimuli deficient of any monocular three-dimensional shape and depth, in the form of random-dot stereograms (Julesz, 1960). These stimuli were used to demonstrate that stereopsis provides the visual system with accurate depth and shape information in the absence of monocular information. Norman et al*.* (2000) successfully used these random-dot stereograms to show that younger participants, when compared to older participants, have a better recount of depth intervals as binocular disparity increases.

Motion parallax is another non-pictorial depth cue and instead of combining a static image from each eye (stereopsis), the movement of the observer in relation to the environment provides a continuous stream of visual depth information (Gibson et al., 1959). Depth from motion parallax is based on close objects moving more across the retina than objects further away which reveals the different depths of objects as they move relative to a viewpoint.

In order that we can see objects at different distances, the eyes either rotate inwards in a process called convergence to point towards close objects or rotate outwards known as divergence to point towards far objects. Accommodation then takes place whereby the lens of each eye adjusts to bring the objects (area) being looked at into focus. As previously mentioned, accommodation is performed by the ciliary muscles which stretch the lens thin when an object is needed to be brought into focus from a distance. In contrast, by relaxing the ciliary muscles the lens becomes thicker, which brings close objects into focus. The visual system has been shown to use the processes of convergence and accommodation, allowing precise depth cue information for attention objects (Fisher and Ciuffreda, 1988). However, distance information is not available through convergence and accommodation when both eyes are diverged straight ahead (zero degrees) onto a point which is beyond 8 feet (Palmer, 1999).

2.3.1 Pictorial depth cues

Pictorial depth cues refer to the depth information used in pictures to convey a sense of space, but are also used in natural vision. Linear perspective is one of many pictorial depth cues along with occlusion, relative size, texture gradients, shadows, ground plane, shading, blurring, contrast, and familiar size.

The visual impact of perspective was embraced by leading artists of the 14th century in Florence and Italy. Filippo Brunelleschi (1377-1446) is credited for pioneering the idea of linear perspective at the beginning of the Renaissance, which he demonstrated using a peepshow device (Arnheim, 1974, 1978). However, it was not until Leon Battista Alberti's (1404 - 1472) writings about the principles of painting in 1435, titled Della Pittura (On painting), that painters in Europe had access to a linear perspective system of representing space (Alberti, 1991, originally published 1435). He described the way orthogonal parallel lines converge to a single point in the distance, known as a vanishing point in a picture, and that objects should appear closer together and smaller the nearer they are drawn to this point. On this basis the scaling of objects could be mathematically calculated to make the depth of the painting look convincing.

Linear perspective became a ground-breaking method of composing a painting into a unified scene (representing the three-dimensional world in a believable arrangement) which also allowed a greater amount of pictorial depth to be portrayed. Pietro

Perugino's fresco of the Sistine Chapel (Figure 2.7) shows the organization of the picture employs a consistent linear perspective structure, by the fact that the whole scene converges to a single point. Pirenne (1970, p.11) gives reason for using linear perspective to represent human visual space, stating that; "…while we can hear round corners, we cannot see round corners, because light propagates itself in straight lines".

Figure 2.7. Pietro Perugino's fresco of the Sistine Chapel (1481–82) shows his usage of perspective to structure the world around him into picture space (Tyler and Kubovy, 2004).

As previously mentioned, the geometry of pictures that are recorded with lens-based technologies, such as cameras, largely conform to linear perspective (Pirenne, 1970). Hochberg (1962) discusses the connectedness between optical pictures and Leonardo da Vinci's glass tracing teaching aids of linear perspective: how light from the environment passes through a sheet of glass to be recorded as an unaffected scene, similar to a photographic representation. In recent years, the painter David Hockney has collaborated on publicised scientific studies into past and present artists' use of optical projections within their work (Hockney and Falco, 2000). These findings make the scientific case that Renaissance art was largely underpinned by the use of optics and mirrors to project scenes onto canvas for the tracing of optical perspective. Using computerised image analysis techniques, it was shown that paintings dating back to 1430 contain features that are a mixture of direct optical replication and portions altered equivalent to being viewed by the eye (Hockney and Falco, 2006). Even in modern times, artists continue to conform to using combinations of pictorial laws based on these first-hand optical observations to proportionally help replicate real life scenes. However, observations of linear perspective which painters use to make their paintings realistically represent three-dimensional space and appear less flat, are based on viewing a fixed point with a single eye, whereas we use two eyes to view the world.

A second pictorial depth cue is relative size, where the knowledge that objects get smaller with distance is used when comparing the size between objects, which is then used to infer depth differences (Ware, 2008). Perspective cues give the relative size of objects in pictures, with absolute size mediated through the size knowledge of a reference object. Consequently the same geometrical relations used within our physical environment for familiar size cannot be based on the viewing distance (range) of objects for a picture, because the observers eye is not included as part of pictorial space. The premise for familiar size is that objects within our physical environment are used as an effective depth cue. This is because the distance from the eye to an object is suggested to equal the ratio of its physical size to its angular extent in the visual field (Koenderink et al., 2011).

Occlusions are another important pictorial depth cue, as the visual system can give a ranked order of depth to objects by obscuring them into the background (Ware, 2008). In contrast, because there is no occlusion information to process the relative depth of the sun and moon, these two objects appear the same distance away (Finkel and Sajda, 1992).

Shadows cast from objects provide ground plane reference and distance information between objects. Furthermore, because of the ground plane dominance in everyday life, objects higher in the picture plane present an increased effect of distance (Ware, 2008). Also, object shape is enhanced by shading and/or reflection of light through a point of reference to a light source. Livingstone (2002) remarks on the shading cue making use of the graduating dark-light contrast of the luminance channel to convey the shape of curved surfaces and fine textures in greatest detail.

Contrast has been shown to promote cues for visual distance perception (O'Shea et al., 1997). Contrast is the difference in illumination between two parts of the same object or an object and its background. Lewis and Maller (2002) performed experiments into the mutual use of contrast and blur cues within pictures. They found that when a greyscale background had two shapes of different greyscales superimposed, the lower contrast shape to the background (when coupled with increased blur) extended the apparent distance from the viewer. Such techniques are used by artists to create three-dimensional representations. As Lewis and Maller note:

“indeed, painters commonly use these effects to create a three-dimensional world on a two-dimensional canvas” (Lewis and Maller, 2002, p.1).

Lastly, blur is not a depth cue readily shown in artists’ work, but the use of depth of field blur as a depth cue in human vision is widely accepted (Atchinson and Smith, 2000; Mather and Smith 2002; Ciuffreda et al., 2007), whereby objects either side of a focus plane become increasingly blurred with distance. The occurrence of blur in human vision has been shown to provide environmental objects with relative and absolute depths (Fisher and Ciuffreda, 1988; Marshall et al., 1996; and Mather 1996, 1997).

The Fovography imaging theory suggests the use of blur before and behind the object in focus and that the indistinctness of peripheral information becomes increasingly degraded towards the edge of the visual field (using blurring to produce this visual effect in digital pictures). However, the Vision-Space imaging theory claims that spatial radial disorder more closely represents human visual depth within a picture, compared to depth of field blur.

The blur formed in a retinal image is described by Mather and Smith (2002) as showing the optical limitations of the eyes which produces the same effect as depth of field blur found in optical pictures; that being “...objects nearer or farther than the plane of fixation are blurred by an amount that depends on their relative distance from the fixation plane” (Mather and Smith, 2002, p.1). Demers (2004) discusses depth of field as the area that appears sharp and in focus within a picture, with surrounding areas appearing out of focus and blurry. Blur transpires because the lens is unable to converge the light passing through it to a single point, which is determined by lens focal length, subject distance and aperture size. Mauderer et al. (2014) discuss that blur can produce a sensation of depth in pictures through representing the depth of field limitations of the eye. That is, whatever is chosen to focus on will be detailed and clear on the retina with everything else becoming progressively blurred with increasing distance from a focus plane. The depth of field effect produced in vision and real optical systems is also talked about by Lin and Gu (2007) as an important visual cue used in photographs and computer graphics pictures (based on real lens calculations) to illustrate focus of attention and depth perception. It is also a common design technique to use blur to direct the viewer's attention to a more detailed and clearer area within a picture (Ware, 2008). This is something that photographers do by using a small amount of depth of field to put emphasis on a certain object (Wang et al., 2001). A study into the aesthetic appeal of depth of field in photographs by Zhang et al. (2014) found a significant interaction between depth of field and content of photographs, that specific amounts of depth of field blur were found to be more appealing for certain content. In addition they found that depth of field in artificial pictures significantly improved aesthetic appeal, with a smaller depth of field being preferred which was opposite to what they had expected.

The blur depth cue in natural vision and photographs is characterised further by Nguyen et al. (2005), with 'defocus blur' used to describe the eye's optic blur from a physical scene and 'object blur' recounting the physical blur produced in a photograph. When an object is converged on and then accommodated, the amount of blur found on an object in a physical scene will increase equally in front of and behind its planar position, whereas the latter produces a blur which cannot be removed by accommodation after convergence on its planar surface. In the paper 'Depth of Field Affects Perceived Depth in Photographs of Semi-Natural Scenes' (Nefs, 2012) it was demonstrated that the effect of depth of field blur was an important perceptual depth cue. Nefs' (2012) results showed an interaction between depth of field blur values and viewing distance, with increased depth of field blur being best understood when viewing the picture from the same distance from which it was taken. However, the depth of field values in the study did not relate to predicted viewing distances, which is as expected because binocular disparity reminds the participants that the photograph is flat, and pictorial depth cues are unable to give absolute measures. As Nefs notes:

> ...there are inherent cue conflicts in viewing photographs: Namely the depth cues within the image are in conflict with the cues that say the photograph is flat (e.g. motion parallax and binocular parallax). Hence it is not immediately evident how Depth of Field affects depth perception, nor how it affects depth perception when viewing conditions are changed.
> (Nefs, 2012, p.4).

When computer generated pictures do not use depth of field blur they can look artificial (Hillaire et al., 2008). Blur effects in real-time virtual reality through point of focus eye tracking systems, are discussed by Rokita (1996) as being important when generating realistic visual experience. In addition, the attention directing ability of image blur was confirmed by Kenny et al. (2005) who found that in first-person shooter games it held participants' attention in the centre of the screen (where there was no blurring) for 82% of the game play. The simulation of depth of field blur was pioneered by Potmesil and Chakravarty (1981), whereby a certain depth of field remains detailed; this is known as the circle of confusion (Barsky, 2004). Using algorithms based on optics, the circle of confusion can be calculated for a projected scene passing through a virtual lens, effectively rendering blur outside of the circle of confusion to simulate depth of field blur. (Potmesil and Chakravarty, 1981). Other vision realistic rendering processes similar to depth of field have been developed to match that of the human eye (Barsky, 2004), with the inclusion of optical distortions (aberrations) of peripheral vision proposed as important contributions in visual appearance needed to be addressed.

In addition to depth of field blur, pictures have also been made to mimic human peripheral blur by showing coarser acuity of the eye, from the fovea to visual margins (Anstis, 1998). Hillaire et al. (2008) proposed that when peripheral blur is applied to pictures it simulates the decreased sharpness of objects viewed towards the margins of human vision and is supplemental to and independent of depth of field blur. The use of real-time blurring in video game experiments by Hillaire et al. (2008) simulated the defocus of objects in front of, and behind focus points within a three-dimensional scene using depth of field blur. Peripheral blur was also applied, simulating increased blurring levels on objects towards the extremities of the human visual field. The introduction of blur effects within video games provided nearly half of the participants with increased performance such as presence, realism and enjoyment of the gaming experience without negative effects being conveyed.

2.3.2 First-person perspective and egocentric distance perception

One of the critical features of the Fovography imaging method is attempting to represent the visual perception of our own bodies in order to produce an additional experience of depth. Even though experiments within the Fovography study did not examine a first-person point of view, it is recognised as a way in which we judge our sense of depth in the world. The phenomenological philosopher Merleau-Ponty (1945) proposed that the world around us includes the body and the self-experience of being engaged in the moment. In the paper 'Embodiment and Schizophrenia', Stanghellini (2009) discusses the first and third-person experience of an environment and the difference between lived body (Leib) and physical body (Koerper) phenomenology (body-subject and body-object) which became widely accepted in the 20th century. As Stanghellini notes:

> The first is the body experienced from within, my own direct experience of my body in the first-person perspective, myself as a spatiotemporal embodied agent in the world. The second is the body thematically investigated from without, as for example by natural sciences as anatomy and physiology, a third person perspective...
> (Stanghellini, 2009, p.1)

As well as three-dimensional effects becoming common in video games, attempts to improve their immersive depth has included the representation of the person playing the game from a first-person perspective, where the player can see their arm and leg movements (Figure 2.8) or where they can see their entire body from a third-person perspective (Figure 2.9).

Figure 2.8. Mirror's Edge, a first-person perspective action adventure game developed by DICE and published by Electronic Arts in 2008 for the Xbox 360 and PlayStation 3 (Gamespot, 2014).

Figure 2.9. Harry Potter, a third-person perspective interactive computer simulation produced by Electronic Arts (EA games) and based upon the eponymous movies (Gamespot, 2014).

The mental and bodily states which make up human self-consciousness (such as perception, attitudes, opinions and interactions) are thought to be dependent on the ability to adopt a first-person perspective (Vogeley and Fink, 2003). This first-person outlook is described by Vogeley and Fink (2003, p.1) as a 'minimal self' outlook, allowing the multimodal components of observed space that are ever present on our centred body to be subjectively understood. As Vogeley and Fink note: "to assign a first-person-perspective is to centre one's own multimodal observed space upon one's own body, thus operating in an egocentric reference frame". Third-person perspective, on the other hand, is somewhat disjointed and removed from the observed real moment.

Advances made in immersive virtual environments have enabled industries such as architecture to let clients inhabit renders, allowing excellent spatial impression from a first-person perspective (Bruder et al., 2010). It has become common practice for an immersive virtual environment to use a head mounted display, blocking real environmental information from the viewer (including their body) and allowing only virtual information to be perceived. Moreover, head mounted displays with optical capabilities (described as being see-through) are able to combine real world objects and the wearer's body with virtual information in a mixed reality method (Figure 2.10).

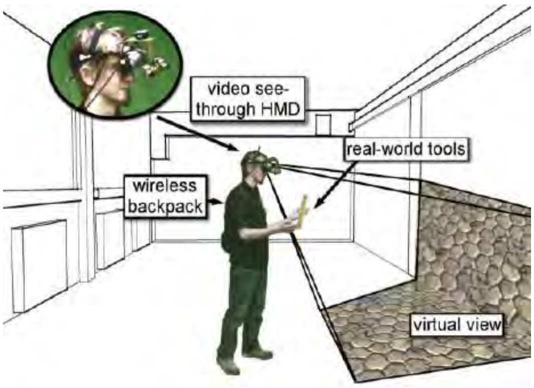


Figure 2.10. Illustration of a see-through head mounted virtual environment: The pavers on the right illustrate the user's virtual view, while the head mounted display captures and displays real-world tools and objects in a mixed-reality view. (Bruder et al., 2010).

The field of computer graphics has become a main contributor in uncovering the dynamics that influence egocentric distance perception within immersive virtual environments (Renner et al., 2013). In experiments by Ries et al. (2008, 2009), it was found that first-person perspective significantly improved distance estimations in immersive virtual environments, in comparison to viewing the same environment without any egocentric reference. This shows how the experience of our own bodies acts as a reference for the perception of depth. As Ries et al note:

> This result provides one of the rare examples of a manipulation that can enable improved spatial task performance in a virtual environment without potentially compromising the ability for accurate information transfer to the real world.
> (Ries et al., 2009, p.1)

Additionally, from their review of current knowledge on distance perception in immersive virtual environments, Renner et al. (2013) showed that distance perception is improved by: (i) pictorial depth cues, (ii) replicas of previously experienced environments, and (iii) embodiment experienced through the use of an avatar.

2.5 Theory of Vision-Space imaging method

Over the past 20 years, through insight of his and other artists' work, John Jupe has been concerned with understanding the perceptual structure of the visual field and how to best represent the experience of vision in pictures. Through intuitively recording 'how' as well as 'what' is being seen during his painting practice, Jupe has identified key components that he believes are involved in the reconstruction of natural vision.

During Jupe's early observations of the phenomena of vision, his attention turned to blur being rarely seen in a painter's rendition of peripheral vision and that there seemed to be more visual information available in peripheral vision than if blur was present. After further investigations into the perceptual structure of the visual field, it was proposed that peripheral vision could be more realistically represented in pictures through disordering (scrambling) visual information (Jupe, 2002).

The use of disorder to structure a picture is claimed by Jupe (2005) to create a visual effect that replicates the spatial awareness of intuitive visual artists, experimenting with their presentation of vision. These spatial arrangements (visual effects) used by capable artists in two-dimensional artworks are said to suggest the same observed depth cues that are projected from within the physical environment in which it was conceived. Furthermore, these artistic insights into perceptual processes are said to reveal important compositional features of human visual experiences which are not contained in photographic representations.

Disorder can take many forms; for example, the self-portrait by Vincent Van Gogh (Figure 2.11) is suggested to show him painting stylistically, using a spatial texture. The hierarchy of disorder is shown as a spatial texture increasing from the right eye towards the background. When the eye (reduced area of disorder) is used as a fixation point, the head is brought to the foreground, thereby producing an increased feeling of depth.

Figure 2.11. Self-portrait by Vincent Van Gogh: Jupe (2002) proposes that he was painting within his visual perception, producing a disorder hierarchy which helps to place the head in space.

The Paul Cézanne landscape (Figure 2.12), shows a red roofed building with a reduced level of disorder, which we can appreciate as the artist's established fixation through the branches of the tree. The hierarchy of spatial texture on the foreground tree has greater disorder, giving less detail, which decreases outwards over the foliage and signifies that he has maintained concentration on the selected fixation point. Jupe advocates that Cézanne is giving a texture value to the position in space that these objects occupy, allowing an understanding of the real space more clearly when looking at the selected fixation point (Jupe, 2002).

Figure 2.12 Painting by Paul Cézanne (1895) 'Large Pine and Red Earth' - Displayed at the Hermitage Museum, St. Petersberg.

From discussions with Jupe, it is evident that he advocates that peripheral vision has its own form of attention, consisting of a simultaneously understood visual field which is capable of factoring the perceiver into the scene through the explicit consideration of objective form under fixation. As a result, he describes peripheral vision as prior, directing our gaze through a disordered understanding of our surroundings. Ware (2008) describes peripheral vision as “terrible” in comparison to the information experienced in central vision where colour and spatial vision are more acute due to a higher concentration of cones. He states that visual perception is a non-uniformity process; that our knowledge of peripheral objects is attained from past saccadic eye movement and not from resolving everything from one view. This view is supported by the high proportion of visual brain power that is used to direct central vision, which only forms 5 per cent of visual perception (Ware, 2008). In context, the knowledge of where to look in surroundings which results from prior attention, links with Vision-Space theory. Jupe (2005) suggests that an individual does not merely move their gaze to a new location, acknowledge what is there and then fixate on a new object - the brain is continually processing environment updates, modelling new reference points and supporting an understanding of where in space the individual is.

Jupe’s painting “Candelabra number 3/3” (Figure 2.13) records his view of still life from a selected fixation point using a hierarchy of spatial texture that he refers to as peripheral vision (Jupe, 2005).

Figure 2.13. Candelabra Number 3/3 by John Jupe. As we view still life, we select fixation points. The conditions over the painting are controlled by the image type referred to as peripheral vision, and allow a realistic sense of spatial volume to be achieved (Jupe, 2005).

Whilst fixating on the area where the candelabra arms meet, he depicts an increase in spatial texture at the point where his central vision converges with his peripheral. This is similar to how Cézanne illustrates progressively less detail in objects found further away from the fixation point, as discussed previously. In addition to the hierarchy of spatial texture that Jupe uses in his candelabra paintings, he illustrates a discontinuity of each arm at the demarcation line around central vision and the area under fixation becomes enlarged. However, when viewing this painting from the fixation point that it was drawn, the candelabra arms become complete and a sense of spatial depth is achieved.

2.4.1 Overview of the spatial radial disorder depth cue

Human vision is often described in text books as detecting high and low spatial frequencies (Palmer, 1999; Snowden et al., 2006; Wolfe et al., 2006; Bruce et al., 2010). These frequencies are sensitive to contrast, and as contrast reduces, so does the visual system's ability to see frequencies. During the mid-seventies, research undertaken by Koenderink and van Doorn (1978) led to the proposal of a two-dimensional self-similar sunflower model (Figure 2.14), deemed ubiquitous throughout the visual processing system, as a basis for the distribution of contrast across the human visual field from a fixation.

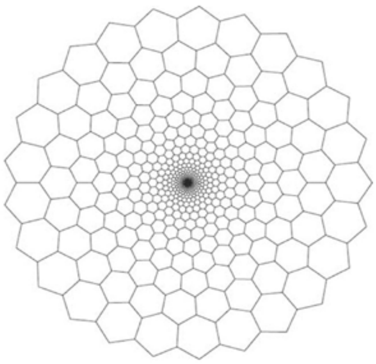


Figure 2.14. Two-dimensional self-similar sunflower model showing the distribution of contrast in the x & y axis from a fixation (Koenderink and van Doorn, 1978).

Later work on peripheral theory by Koenderink and van Doorn (1999, 2000) suggested that visual information could be disordered across the visual field. Whilst conventional imaging methods are often reliant on blur to mimic human visual depth, when disorder is used to remove the spatial detail it is argued that the structure of the picture is more appropriately maintained. This is because data is lost when pixels are merged during the blurring process, whereas disordering of pixels preserves more picture information. This theory was extended by Koenderink (2001) into a bespoke algorithm for John Jupe; detailing an X and Y axis spatial disorder that originated from a focus point based on Koenderink and van Doorn's (1978) two-dimensional self-similar sunflower model for the distribution of contrast across the human visual field. The distribution of disorder across the picture is applied from a fixation point using a log-polar transform, where the amount of disorder used is a function of distance.

It is this computational formula that underpins the unique Vision-Space arrangement of spatial radial disorder, also set out from a central fixation, incorporating the additional ‘Z’ axis to suggest three-dimensional spatial depths. Effectively the two-dimensional log-polar transform of disorder within a picture was replaced with a three-dimensional (radial) transform of disorder using camera position and linear depth map image data of the scene. Jupe suggests that the depth cues produced from the application of spatial radial disorder (in an X, Y and Z axis) progresses the original two-dimensional concept outlined by Koenderink (2001), to more closely represent the spatial structure of natural vision within a picture, compared to depth of field blur.

This radial field surrounding a fixated object is hypothesised by Jupe et al. (2007) to provide depth cues capable of factoring the perceiver into the scene, as if a picture were a real environment. In addition, it is anticipated that an observer will be able to make more precise and quicker proximity judgments from two-dimensional media that contain a focused spatial radial disorder (Figure 2.15).

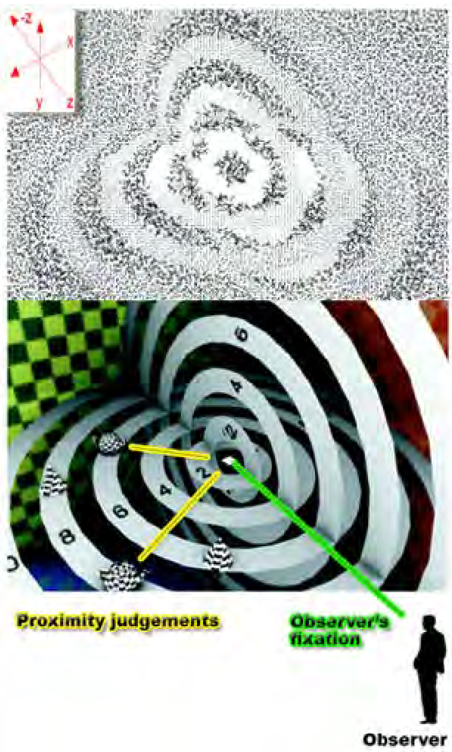


Figure 2.15. Vision-Space pictures use a spatial radial disorder, which is set out in all directions from a selected fixation point. This arrangement of spatial cues is suggested to emulate our phenomenological visual structure (Jupe et al., 2007).

The hopeful upshot of spatial radial disorder is that peripheral vision becomes a directing influence of central vision attention, producing an immediately understood field, which should provide proximity of objects from the viewer to a fixated object in relation to all surrounding objects. The fixation area found at the origin of the spatial radial disorder is expected to help extrapolate depth cues within static and moving pictures, making it more salient than current optical methods which use depth of field blur. Jupe et al. (2007) describes the expressed spatial perception throughout a picture's visual field as being true when a prearranged point (object) in the picture is fixated on. This promotion of information from peripheral to central vision is suggested to separate the exchange between the 'where' and 'what' forms of attention.

Jupe often refers to McGilchrist (2009) who discusses the perceptual merit of dividing the brain into a left and right hemisphere, with both being relied upon to produce a mutually relating implicit and explicate understanding of the world. The implicit right hemisphere is considered at ease with ambiguity, showing aptitude towards describing new experience within a holistically connected view of the world; the explicit left hemisphere affords an ability to rationalise precise features and predictable information made directly available. When these two hemispheres are combined, McGilchrist suggests that they give specific meaning to perception, with implicit visual information denoting an overall experience ('where') whilst being inclusive of visual information from focused detail ('what'). However, the explicit nature of the left hemisphere does not allow mutual information transfer. This suggests that tasks carrying out intentions are based on habit and are attained without digression from implicate environment information. This connects with the perceptual structure of Vision-Space pictures which are based on the brain continually processing environmental updates and modelling new reference points to support an understanding of where, in space, individuals are.

By applying spatial radial disorder to a picture, the observer is expected to make a full range of depth judgements similar to how they experience space first-hand in an environment. Furthermore, the spatial order is expected to allow the observer to ascertain whether a fixated object is moving away or towards them within moving media. To do this, the intensity value of spatial radial disorder increases proportionally in all directions, giving the observer spatial depth cues from a fixation point outwards. This is formulated through Jupe's interpretation of how a scene occurring in real life is seen; with the value of spatial radial disorder differing considerably in relation to an object under fixation, both at close range and at distance. In simulations the spatial radial disorder is also claimed to show how secondary objects are moving in relation to the fixation point and, it is hoped, in relation to the observer. The outcome is said to reduce the observers need to make multiple fixations, to understand the space presented as in pictures produced using conventional imaging methods.

2.4.2 The use of linear depth map images to produce accurate spatial radial disorder within Vision-Space pictures

In order to produce a Vision-Space picture with accurate spatial radial disorder using the Vision-Space post production tool, it is necessary for a linear depth map image to be processed alongside the geometrical perspective picture (normal picture) of the same computer generated scene. The linear depth map image contains important measurement values within scene programming, with ‘Z’ buffer values making clear which objects are hidden behind others. These values prevent 'flimmering' (where objects show through each other) and establish the ‘Z’ depth of objects close-up and at distance within a computer generated scene. Most noticeable of a rendered linear depth map image is that the outputted scene uses a white, grey and black scale (Figure 2.16). Foreground objects are highlighted in white, and objects behind become progressively black as they move further backwards in the virtual imaged scene.

Figure 2.16. The Z buffer produced by a linear depth map image is used to establish the Z depth of close objects and those at distance within an image. Image outputted from Blender stimulus.

There are a number of commercial depth map (ranging) cameras such as Flash Lidar, Time-of-Flight (ToF), and RGB-D which are capable of outputting linear depth information along with pictures of real-life environments, but these can be costly pieces of equipment to acquire (Figure 2.17).

Figure 2.17. Two high-end commercial depth map cameras are the Swiss Ranger SR4000 by Mesa Imaging and the CamCube 2.0 by PMD Tech products (Hizook 2014).

Conversely, the increasing demands on gaming companies to improve user experience have seen the Microsoft Kinect, a motion sensing input device, enter the market allowing the gamer to interact without game controllers. This device contains a camera and a depth sensor which tracks the three-dimensional movement of the user. However, the ‘Z’ buffer in nearly all computer software (and the Kinect controller) is non-linear, which means they follow a logarithmic scaling. This affords increased ‘Z’ depth precision for close objects rather than those further away and gives objects closer to the viewer’s eye (clipping plane) greater detail when rendered. A linear depth map image, on the other hand, produces ‘Z’ buffer measurements that are evenly spaced throughout the scene from the clipping plane. This allows consistent ‘Z’ axis location measurements to be understood for all imaged objects within a corresponding normal picture of the same scene. When applying spatial radial disorder, the white, grey and black scale produced by a linear depth map image would be used as a guide to position a fixation point on either a close range or distant object. This fixation point becomes the origin for converting the linear depth map image into a radial depth map for assigning spatial radial disorder to the Vision-Space picture. If a non-linear depth map image was to be used instead of a consistent linear unit of measurement, the radial depth map produced would not be truly radial. This would effectively mean that the spatial radial disorder would not be radial either. With a true radial depth map used within the normal picture, the computational formula that underpins the unique Vision-Space arrangement of spatial radial disorder can be applied with its required intensity value (falloff value).

Because of the cost restrictions on outputting a linear depth map image and its necessity within the post production tool to produce a true radial depth of field, it was decided to develop a software extension (Plug-in) for an open source (developer unlocked) computer aided design system. This would allow a linear depth map image to be outputted with its corresponding normal picture from the same virtual camera.

The computer aided design system ‘Blender’ was chosen as it was free, readily available software and would accommodate the needed changes for spatial radial disorder stimuli to be accurately created within the post production tool. The Blender modelling tools and rendering features would first need to be learnt in order to make new scenes and export them as normal pictures with corresponding linear depth map images. It was not anticipated that this process would be problematical. At the same time, the post production tool program and its property values would need to be learnt so that new Vision-Space stimuli could be appropriately produced for participant studies. Furthermore, throughout the process of generating new stimuli, feedback regarding the requirements of Vision-Space pictures was relayed to the software engineer, to push the user development of the post production tool and future Blender plug-ins.

It is anticipated that the spatial radial disorder previously illustrated in Figure 2.15 would provide imaged objects with an orientation cue likened to our real-world spatial organisation and a virtual crossover of real life tasked awareness. However, assigning this depth cue would demand post production tool operator judgement as disorder intensity is expected to require regular modifications to match the visual differences of awareness that the Vision-Space method proposes when fixating on an object at close range or at a distance, as illustrated in Figure 2.18.

In addition, to further enhance attention towards a planned focus location (object), the adjustments made to the spatial radial disorder falloff value of a normal picture in the post production tool can be quickly evaluated and updated as special effects. The external viewing location of individuals could vary considerably (not calibrated externally) in relation to the scene, which is outside the post production tool operator’s control. Considering this, it is important that the spatial radial disorder falloff values proposed for fixating on an object at close range, or at a distance, contain a suggested viewing location; by accounting for an individual’s position, this method can be made more effective.

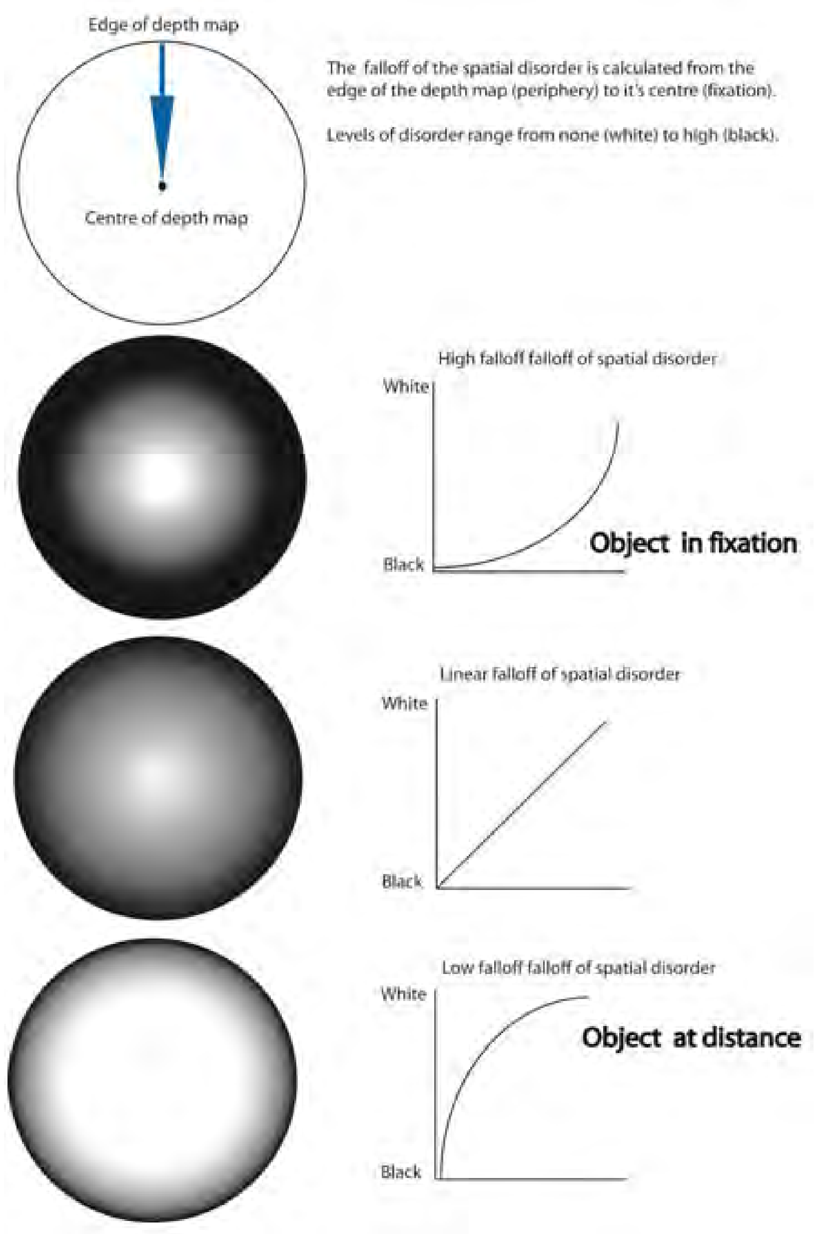


Figure 2.18. Self-produced illustration: detailing the spatial radial disorder falloff values for an object under fixation at close range, and at distance within a Vision-Space picture.

2.4.3 Arrangement of central and peripheral visual information in Vision-Space pictures

Another painterly insight that Jupe shares is that visual information is offset by a number of degrees across the entire visual field, with this rotation from the vertical to the right suggested to make visual information easier to understand in a picture. This visual rotation is also said to be reduced as a fixated object increases in distance and can be applied in the opposite direction with visual dominance. These insights are associated with the majority of people having visual dominance in the right eye during binocular sources of depth information, such as convergence (depth information up to 8 feet) and binocular disparity from stereoscopic information (depth information up to 100 feet), and that convergence beyond 8 feet directs both eyes straight ahead (zero degrees) onto a point (Palmer, 1999). Jupe suggests that visual information within the central fixation area remains vertical, so that the world can be understood accurately as being level and true. He suggests this as being inconsequential in the peripheral view, as spatial radial disorder proximity cues and their spatial awareness should contain greater importance than attending to the orientation of objects. In addition to the peripheral rotation and central fixation remaining vertical, a stretch in the Y axis is used to elongate the peripheral data set and a stretch in the X axis widens the central fixation data set. This allows additional discordance between the 'where' in space and the 'what' being accurately fixated on, which Jupe suggests encourages a further sensation of natural depth. The stretching of the peripheral data set and widening of the central fixation data set shows a connectedness with how Suzuki and Cavanagh (1997) describe the enlargement of perceived visual space around a focus of attention and Newsome's (1972) experiments which showed that the perceived size of objects, when viewed peripherally, decrease with eccentricity.

These descriptions are an explanation of how Jupe suggests peripheral and central visual information should be arranged during object observation at distance, object tracking, and at the onset of object fixation. In addition, Jupe suggests a variation on this first system based on an object held in fixation within central vision, with the belief that the central fixation area (fovea region) becomes partially suppressed during the contemplation of a fixated object. This is replaced in part by peripheral information, which produces deformations due to its rotated nature. Jupe uses 'The Blue Vase, by Paul Cézanne' (Figure 2.19) as an illustration of this unique system of representation taking place, within the assessment of object form over time. Taking the vase as Cézanne's central fixation, the left side of its representation has been given a different shape from the right side. The two do not align and a broken outline is noticeable. Jupe suggests that this illustrates Cézanne replicating his contemplation of central and peripheral visual information entering into his fixation area (fovea region). Each eye looking either side of the fixated vase creates an asymmetry with deformations, which he suggests allows a better understanding of the objective form.

Figure 2.19. Le vase bleu (The Blue Vase) 1885-87, By Paul Cézanne. The asymmetry of central vision regularly recorded by artists (Jupe et al., 2007).

Jupe's take on visual awareness is fundamentally different in relation to a photograph, because the optical detail is not sampling these suggested observed differences. Jupe claims that when these deformations nearly reflect reality they can be easily fused, creating a sense of 'pop out' of the object under fixation. This focused understanding of objective form works in conjunction with the spatial awareness generated in the peripheral view. Whilst attending to an object at the origin of the spatial radial disorder, peripheral visual information enters one side of central vision. As Jupe notes:

> This is the configuration of the visual field used by many other visual artists as they carefully investigate and assess a still life set up. It's a specialist projection that the brain is able to set up for us when we consider carefully the proximity of objects in space.
> (Jupe, 2005, p.6)

Jupe advocates that an optical illusion effect plays a role within our capabilities to combine these deformations in our fixation area (fovea region). If this visual information was unable to be aggregated, it would syncopate (things never come to a conclusion), and the image starts to spin. As a result, he suggests that both central and peripheral visual information is endlessly trying to unite during the contemplation of objective form. This brings about the more complicated task of replicating real-time visual information in the fovea region in a single eye (monocular), and our anatomical two-eyed (binocular) view of the world. Jupe's collaboration with Jan Koenderink established meaning behind the deformations recorded by artists such as Cézanne. As Jupe notes:

> The so called 'deformations' in art are showing us flashes of perceptual structure.
> (Jupe, 2002, p.16).

2.4.4 Overview of Vision-Space pictures

The Vision-Space theory suggests that vision can be described as being stereo prior to the introduction of our second eye (binocular stereo). Jupe identifies that a monocular visual field consists of two independent data sets which can be said to be composite; that is, containing a central fixation (explicit) within peripheral (implicit) information. Jupe suggests that these two independent data sets are broadly related to the separate neural pathways of rods and cones located within each eye, and their broad associations with fixated objects (explicit) in space (implicit). This is the most straightforward Vision-Space picture arrangement for post production tool processing, as computer aided design systems render a picture from a single virtual camera.

As discussed earlier, Vision-Space pictures are based on the formation of a radial field of awareness, suggested as being similar to the peripheral visual field which sub-consciously directs attention to a predetermined fixation point. This central vision attention is suggested to allow contemplation of objective form and tracking of objects that surround a fixation point. Furthermore, without the spatial framework of peripheral vision surrounding a fixated object, the available data in central vision is thought to be meaningless. This understanding that Jupe has of viewing an environment is formed from examining a photograph of a scene and then the same scene in real life. He documents the differences perceived between the two representations of the scene in his peripheral and central vision (data sets), depicting his observed scenarios as a skilled painter and developing an aesthetic style to add real-life cues to his visual descriptions. As Jupe notes:

> We are testing intuitive values of a computational visual structure, to recreate observed scenarios of vision within current two-dimensional media. We are discovering things about people's experiential reality, where people's insights will consist of different values of visual awareness.
> (Jupe, personal communication, 2012)

For a Monocular Vision-Space picture to be appreciated correctly, central and peripheral visual information are attuned independently allowing both types of visual awareness to be formed appropriately. Jupe, suggests that this composite layout is closer to the appearance of natural vision by way of peripheral information (data set 1) given a rotation towards the right from vertical, with this rotation decreased as the fixation point becomes more distant. However, central fixation information (data set 2) in this Vision-Space picture remains vertical. The method used to reprocess a normal picture with a linear depth map image to produce a Monocular Vision-Space picture is illustrated in Figure 2.20.

Once a fixation point has been chosen on either a close range or distant object using the linear depth map image, it is processed into a radial arrangement using this fixation point as its centre for the appropriate falloff (intensity) of disorder to be applied. This spatial radial disorder effect is then set to the normal picture which is elongated in the Y axis and then rotated. The rotation decreases as the distance to the fixation point becomes more distant in the picture and this completes the visual layout for peripheral data set 1. A copy of the original normal picture is then stretched in the X axis to form the needed central fixation discordance for data set 2. The original fixation point is used to select the visual information from this area, which is then positioned without any rotation over the peripheral data set 1. In Vision-Space simulations, the central fixation information is described as cascading into place, but due to technology limitations it is currently overlaid into position.

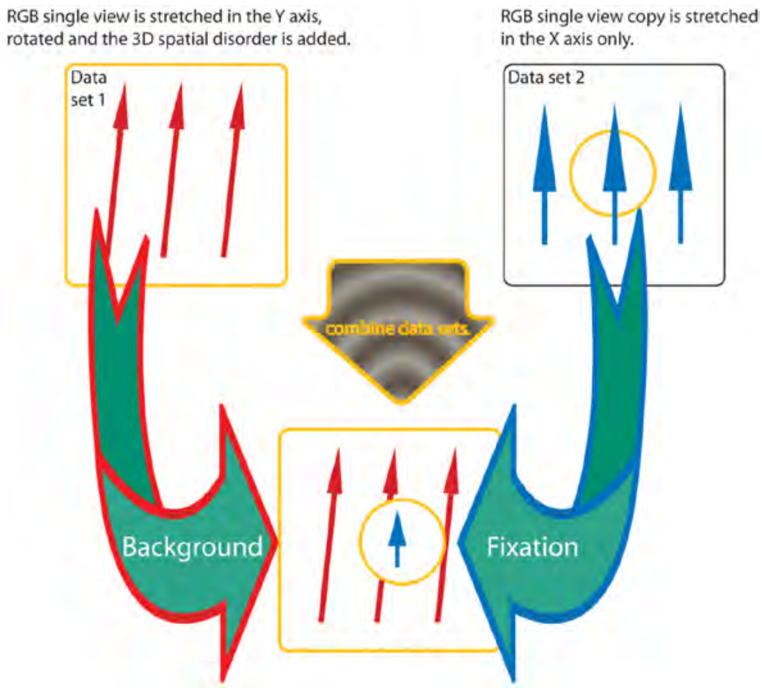


Figure 2.20 Self-produced illustration showing the monocular Vision-Space picture layout. The peripheral visual information (Data set 1) is rotated towards the right and stretched, with central fixation information (Data set 2) overlaid into position from a normal picture copy which has been widened but remains vertical.

The future development of Vision-Space media is expected to involve the spatial radial disorder feature being updated on screen concurrently with the viewer's central fixation in real-time, like in a computer simulation (Figure 2.21).

Figure 2.21. A Vision-Space picture taken from a simulation using monocular composite principles which convert a normal picture using an early post production tool. The fixation for this picture is on the grill of the car and the spatial radial disorder is updated on the changing distance between camera and fixated area.

In summary, the artistic insights by Jupe, using supporting work by Koenderink and van Doorn (1999, 2000) with respect to the computational nature of peripheral vision, have led to the Vision-Space imaging method. From personal discussions with Jupe, the perceptual structure of Vision-Space pictures aims to represent the perceiver's phenomenal field and intent in the world, with central vision suggested to be an entirely different data set to peripheral vision. These central and peripheral data sets are therefore seen as being independent systems, combined (cascaded) to provide a full comprehension of the world from the light array entering the eye. Peripheral vision is not considered as being lower quality than central vision, rather more a highly specialised system of spatial awareness which provides human vision with essential proximity cues. From this standpoint, peripheral vision is described as providing most of the information relating to 'where' things are in the world and is suggested to factor the perceiver into his or her environment. In contrast, central vision is regarded to contemplate objective form over time, producing awareness directly to 'what' is being attended to. In addition, the attention in central vision is considered to be compiled through multiple fixations, whereas peripheral vision is viewed as being ever-present and prepared for visual change at all times (Jupe, 2002, 2005). The following example of a physical room further explains the claimed spatial qualities of a Vision-Space picture: when it is entered and an object is fixated on, instead of being dependant on central vision to establish its depth through binocular cues, occlusions and other depth cues, the room's spatial structure is said to be instantly understood within the perceiver's visual field.

2.5 Theory of Fovography imaging method

The aim of a Fovography picture is to model human visual perception through proportionally representing the full scope of the embodied human visual field. This first-hand visual perspective is increasingly being pieced together through Robert Pepperell's ongoing research into the experience of human vision.

Around five years ago, Pepperell's interest in human visual perception and consciousness started to evolve within his art practice. His interest surrounding vision was on a technical and biological level which involved exploring many visual perception theories for answers to his visual questions. Pepperell's main interest was how to paint or draw what is seen, which Ogle (1964) describes as the unified visual image from two laterally displaced eyes. This seems straightforward: an individual looks and draws what is seen. However, there are many simultaneous occurrences in the surrounding environment (in the visual field) of which the individual is not always aware. Even artists who have trained themselves to paint how they see find it difficult to accomplish a true first-person representation. This led Pepperell to attempt to understand how he sees through an analysis of how his visual field is comprised. He based the extents of his own visual field as 200 degrees laterally and 135 degrees vertically, suggested by Hershenson (1999) as the estimated normal when looking straight ahead. As he formulated this self-visual analysis, he started to see many different visual effects happening in his vision of which he had not previously taken much notice. When he explored the science and the art history of these visual effects (depth cues/image effects), he found that some of them had been noticed but only dealt with in a very minimal way, or they had generally not been observed before.

During the first two years of Pepperell's increasing interest in visual perception, he mainly painted, drew, read, and tried to understand the nature of vision. By doing this, he realised that the optical structure of the camera is different from the optical structure of the human visual system and that there were ways of editing an optical picture to emulate human visual perception. This was an important milestone as no camera or technique currently exits that will produce the human visual field in the way that it is actually seen. The best demonstration of this difference is to look through a 35mm camera on its standard setting with a 50mm lens; commit to memory how the scene appears through the lens, and then compare it to what is actually seen when the camera is removed. At first glance, one might suggest that the only difference is less space and that this can be rectified. Clearly, through a 40mm lens, one would see more field of view but never see the same scope as the human visual field (the visible space the eyes can bring into being without any head movement (Pirenne, 1970). Although a closer representation can be achieved by using a fisheye lens, unwanted edge distortions (barrelling) are generated and wide-angle panoramas produce very long formats. Through regarding what is seen through the lens, then removing the camera and reviewing what is actually being seen, the comparison shows that, in addition to less space, there are other important visual effects which the camera does not record.

Pepperell suggests that by comparing the structure of the human visual system with a geometrical perspective picture and making those differences appear in media, it could allow the revision of the camera to record what the eye sees in a human format. The result would give pictures more depth and breadth without the need to use specialist eyewear or a screen (Pepperell and Haertel, 2014). It is also important to present media in an appropriate way so that the visual brain can process it correctly for an immersive experience. As far as it is known from researching available media and the History of Art, this is something that has not been done before: no one has combined human visual effects in a software package or developed a way of making media that closely represents human visual perception.

When Pepperell was investigating the nature of vision, the content of his paintings were disproportionately shaped by an attention bulge and peripheral compression. He would paint his entire visual field based on empirical observation, rather than geometrical principles (linear perspective) and find the peripheral content getting increasingly squashed, while the main area of interest (intended focus area) became enlarged. His bulged paintings in comparison to photographs of the same scene (Figure 2.22) were effectively trying to replicate the native picture format that the visual brain is used to; not the geometrical perspective format that people normally supply it with. This provides one example of a visual effect that is not normally noticed in visual perception.

Figure 2.22. Comparison between a geometrical perspective picture, and the redistribution of the same space by Pepperell, using his method of painting the visual field on a bulged canvas.

Pepperell's experience of the bulge was initially explained through the Helmholtz (1867/1962) checkerboard experiments. When closely viewing the checkerboard below (Figure 2.23) with one eye, a bulge appears in the middle, similar to a fisheye lens. Helmholtz (1867/1962) reported that if the checkerboard covered the whole visual field it would appear to have a barrel distortion (similarly produced by the fisheye lens), and for the checkerboard to appear undistorted up close, an amount of pincushion distortion would be needed.

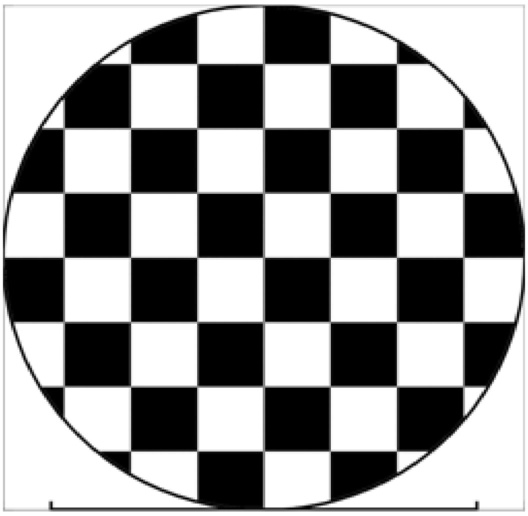


Figure 2.23. The checkerboard should be viewed from a distance the length of the horizontal bar.

Pepperell's experience of the bulge can also be linked with how Suzuki and Cavanagh (1997) describe the enlargement of perceived visual space around a focus of attention. Additionally, the picture being increasingly compressed towards its periphery is supported by Newsome (1972), whose experiments showed that the perceived size of objects viewed peripherally decrease with eccentricity. However, the attention bulge and peripheral compression is not captured on the 35mm camera sensor using a standard 50mm lens, with all the light being evenly distributed across the sensor using a central projection (Pirenne, 1970).

The introduction of the attention bulge and peripheral compression effect to a picture is in order to determine their proportions as experienced from natural vision and then return them to the media. These perceptual differences were eventually developed into an artistic method of representing the visual field in two-dimensional pictures (Pepperell and Haertel, 2014). Pepperell later found that other artists such as John Constable, Vincent van Gogh, and Paul Cézanne had been depicting visual space similarly. From further analysis of Cezanne's paintings, Pepperell discovered that the way in which he interpreted space was not dissimilar from Cezanne's paintings (Pepperell and Haertel, 2014). It had not previously been noticed that Cezanne was recording what he could see without using a system (geometrical principle) to assist.
Pictures produced using Pepperell's method of representing the human visual field allow far more visual information to be contained within the normal photographic format (captured on a 35mm sensor using a 50mm lens) which subtends to 43 lateral degrees (Pepperell and Haertel, 2014) and without the distortions associated with a fisheye lens or panoramas. The use of this picture format in comparison to geometrical perspective depictions of the same scene have also been shown to significantly depict space in a more natural looking way (Baldwin et al., 2014). This study and a second unpublished study (Baldwin et al., In Press 2015) which explores the apparent size of objects in the peripheral visual field further support of the Fovography imaging theory (Appendices 12).

A number of different visual effects were also brought into Pepperell's paintings, such as peripheral indistinctness and double vision (psychological diplopia). These depth cues go unnoticed when focusing on an object: that is every object in front of and behind loses focus and is doubled (Pepperell and Ruschkowsk, 2013). Pepperell uses blurring to demonstrate peripheral information becoming increasingly degraded towards the edge of the visual field, which he suggests produces a natural visual effect of depth in his digital pictures. This simulates the visual science theory that retinal images lose sharpness towards its periphery, due to the receptors having a different sensitivity to the ones in central vision (Pirenne, 1970; Palmer, 1999; Snowden et al., 2006; Wolfe, 2000; Bruce et al., 2010). Eriksen and James (1986) describe this as the lack of resolution of detail provided by the retina in peripheral areas. As well as reduced visual resolution driven by retinal processes, further visual science theory about the visual system (Jonides, 1980; La Berge, 1983; Eriksen and James, 1986; He et al., 1996) discusses that as a completely separate process attentional resolution diminishes away from central vision, as a result the ability to selectively attend to a specific location gets worse in peripheral vision.

Also present in Pepperell's digital pictures is the blurring before and behind the object in focus which simulates the depth of focus limitations of the eyes producing spatial blurring of three-dimensional scenes imaged on the retina (Mather and Smith, 2002). As Mather and Smith note "...objects nearer or farther than the plane of fixation are blurred by an amount that depends on their relative distance from the fixation plane" (Mather and Smith, 2002, p.1). Additionally, because the eyes are separated, the unified visual image created from binocular vision produces stereopsis within Panum's fusional area which enhances the sensation of depth. This fused area of disparity is roughly the size of the focus of attention; however, outside this area, the images projected onto the retina of each eye are unable to be seamlessly fused together. This creates a doubling effect to peripheral viewed objects (Agarwal and Blake, 2010). Additionally, double images have also been shown to produce stereopsis without complete fusion (non-fused stereopsis) and an increased sense of depth (Wilcox and Allison, 2009).

The effect of blur in natural vision mostly goes unnoticed until the individual is reminded of its presence. For instance, if two fingers are held slightly apart in front of a viewer and attention is maintained on the left one, it will appear sharp and very clear; the surrounding becomes progressively more blurry towards the periphery limits. The viewer probably will not see much of their right finger but will be aware of it. If the gaze is changed to the right finger, the effect will be the other way around; with progressively increased fading of surrounding information. However, even though the other finger is now out of focus, the viewer can remember a great deal about its orientation and how it looks from memory. To continue, if one finger is held in front of the other and the gaze is drawn directly at the closest finger; the far finger will appear as if it has split in two. If attention is then turned to the far finger, the front finger will now have this doubling effect. Whilst blur is an important image effect, the fact that there is two of everything out of focus, is also an important perceptual aspect. Moreover, rather than just blurring the background of a picture, the effect of viewing the world with two eyes is added. Pepperell and Ruschkowski (2013) detailed the visual effect of ‘double vision as a pictorial depth cue’ and an import image effect which enhances the representation of depth in natural vision. Both of these image effects produce depth cues, which are used to judge where things are in relation to space, but again they are not something cameras use. In fact, stereoscopic technology used for cinema and television completely ignores these effects, by forcing focus onto two different planes at the same time. By working out all these visual clues and using them in the right way, it is hoped that the brain can be ‘tricked’ into thinking a picture is more real than it actually is and, ultimately, replicating vision so recorded media can be viewed in the way the real world is, improving depth perception and making it more immersive.

2.5.1 Overview of Fovography picture

As previously mentioned, for this research a normal photograph is seen as being created by a 35mm film or sensor using a standard 50mm camera lens which is understood to subtend to 43 lateral degrees (Pepperell and Haertel, 2014). This familiar format is commonly used in everyday media types which are largely viewed as two-dimensional print and digital media. A digital Fovography picture firstly uses multiple photographs of the same type taken from different points of view and covering the whole visual field which is approximately 135 degrees vertically and 200 degrees laterally (Hershenson, 1999). These are then joined to produce the full scope of the human visual field which allows foreground objects (along with the viewer’s body, otherwise excluded in everyday two-dimensional media) to be included. However, some picture processing milestones had to be met in order to produce a digital Fovography picture and one that could be allied with a normal photograph of the same scene for comparative tests:

i. A semi-professional studio had to be set up to control lighting conditions during the camera work of assemblage photographs used to capture the full field of view of advertising scenarios in the environment.

ii. In addition, a technical process had to be developed using image-editing software (Photoshop), so that a full visual field picture could be generated from the assemblage photographs and Fovography image effects applied

When the research direction changed to Fovography pictures, the digital imaging process was still in its infancy; photographs were adjusted through basic computer generated manipulations. The Fovography paintings, which were the first developmental stage, were also still being advanced at this time and continued to be where the visual process was being researched. Nevertheless, the digital Fovography pictures were able to replicate the visual effects that Pepperell was portraying in his paintings, and became a key step in leading to the design of various Fovography experiments.

The image effects used to produce a complete digital Fovography picture (Figure 2.24) from a picture containing the scope of the human visual field include progressively compressing the proportions of the picture towards the periphery of the scene, and enlarging of the focus area which is mainly the intended object of interest. Blurring and object doubling are then added behind and in front of the focus object, and the intensity of blur and object doubling is progressively increased towards the periphery of the scene, where the compression of visual information is also at its greatest. This rectangular Fovography picture could then be given an added elliptical vignette to more accurately represent the binocular boundary shape of the human visual field (Gibson, 1950).

Figure 2.24. A complete Fovography picture.

Even without an elliptical vignette, the overall combination of Fovography image effects are still hypothesised to direct the viewer to an intended focus area faster, and provide a more natural sensation of depth and spatial awareness in comparison to the appearance of a normal photograph of the same scene (Figure 2.25).

Figure 2.25. The Fovography picture (right) contains a range of image effects, suggested to better emulate human visual perception than a normal photograph of the same scene (left).

A photograph is the simplest format to present Fovography media and could become an appealing advertising platform for magazines trying to find new ways of making the content of their adverts more engaging. In a very simple presentation, a Fovography picture can also be shown on a normal flat screen television with an added vignette on it. This makes such displays commercially transferrable to venues such as shops, airports, etc. In addition, now that ultra-high definition televisions and projectors (with their increased resolution) are easily available and much more affordable, it is possible to achieve a much higher resolution in the fixation area. This extra cue could produce a more convincing result, whereby on-screen representations more closely mimic reality. The enrichment of cue has been taken further still, with media developed using a virtual reality headset for Gaming (Oculus Rift - www.oculusrift.com). The use of this head mounted display has allowed the head movement of the viewer to be tracked and mirrored into the media in real time, which seems to add a percentage of extra depth through motion parallax. A tablet version works similarly but this is controlled by tilting the hand-held device. Ultimately, the goal of the Fovography imaging method is synthetic vision, whereby looking at a Fovography picture creates the same experience as if viewing first-hand.

3 Vision-Space research

This research was initially aimed at exploring the validity of the Vision-Space imaging method as a way of improving directional focus, spatial awareness and the perception of depth in geometrical perspective pictures. Through the use of a post-production tool, the spatial radial disorder image effect is added to a geometrical perspective picture (normal picture), along with other perceptual image effects, to produce a Vision-Space picture. Whilst conventional imaging methods use depth of field blur to mimic human visual depth (Lin and Gu, 2007; Nefs, 2012; Mauderer et al., 2014) and direct attention (Ware, 2008), Jupe (2002) suggests that spatial radial disorder provides a visual quality that matches closer to natural vision. As a result, Jupe hypothesises that improved directional focus, spatial awareness and perception of depth are experienced in a picture. Additional image effects, such as central information being widened and peripheral information being elongated and rotated, are also suggested to further encourage the sensation of depth in a Vision-Space picture. It is the combination of these Vision-Space image effects that, according to Jupe (2002), creates a greater sense of immersion or perceptual realism in a picture.

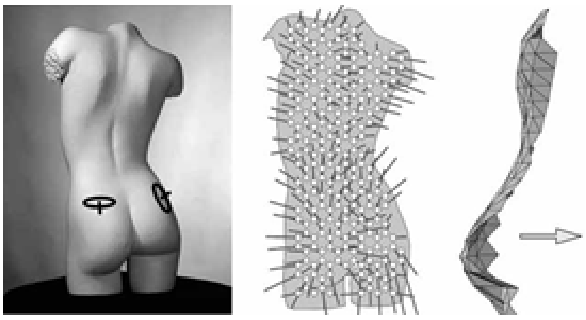
After initial research into the Vision-Space theory, its imaging method, and exploration of vision science literature, an opportunity arose to receive training in experimental methods for probing pictorial depth, founded on methodologies developed by Jan Koenderink and Andrea van Doorn. This involved visiting Dr Maarten Wijntjes at Perceptual Labs, Technology University Delft, where quantitative methodologies were developed for exploring the relief and relative sizing of objects in Vision-Space pictures. This collaboration facilitated the design of two psychophysical experiments, and was an important progression in self-development of combining science knowledge with vison knowledge as my background was in product design and education.

Even though both experiments seemed promising for the research at the time, they proved problematic during piloting because they concentrated on comparing pictures with exact scene proportions; whereas the combination of Vision-Space image effects transformed the shape and size of picture content. These preliminary experiments were put aside, with the technicalities surrounding both methodologies and why they were negated explained in detail in Sections 3.1 and 3.1.1. However, this led to the design of experiments 1 and 2 using alternative approaches, which involved qualitative comparisons between Vision-Space and normal pictures.

Experiment 1 (Section 3.2) used current Vision-Space pictures which employ a number of interacting image effects, and experiment 2 (Section 3.3) examined a critical Vision-Space variable, namely the spatial radial disorder image effect. Experiment 2 compared disorder against blur in the same spatial radial application and, without the complete image effects found in Vision-Space pictures, they would continue to proportionally match the normal picture. This also made it permissible to compare the normal picture (devoid of image effects) against the spatial radial blur and spatial radial disorder pictures. In both of these experiments, questions were developed in relation to five viewing advantages that a Vision-Space picture was hypothesised to have over a geometrical perspective picture (Jupe, 2002). These being improved directional focus, object proximity, observer relation, perception of depth, and matching closer to natural vision. According to Jupe, Vision-Space image effects create these viewing advantages which ultimately result in a greater sense of being ‘factored into’ (present in) a picture.

3.1 Negated preliminary experiments

The first negated preliminary experiment used a ‘gauge figure’ to quantify the curvature of an object in space, giving it a pictorial relief as perceived by an observer. The gauge figure experiment was first used to quantify the perceived three-dimensional structure of a pictorial surface (Koenderink et al., 1992). With clear instructions, the observer interacts with a pointer (probe) called a ‘gauge figure’ adjusting its ‘attitude’. The observer then makes a circular wireframe disk lie flat on the object’s surface, to follow its curvature with a rod, sticking out perpendicularly from its centre. Each new rod pointing outwards in a different direction is used to record new orientation data for the probe which is then used collectively to construct a three-dimensional surface as shown in Figure 3.1.



Two gauges are shown in the left picture. The right gauge shows the needle sticking out at a right angle to the surface and is a visual fit. This is what the task was aiming for, and is shown in totality in the middle picture. The picture on the right shows the results converted into a profile. (Todd, 2004)

Figure 3.1. The 'gauge figure' pictures are taken from a study conducted at the University of Utrecht in the Netherlands, and was published in the journal 'Perception' (Koenderink et al., 2004).

Using the background article, 'Probing Pictorial Relief' (Wijntjes, 2011) and through discussions with the author, background information about how the gauge figure quantifies pictorial relief was available, and experiments were designed. The calculations needed for the gauge figure test to work keep the community of scientists limited to those that not only understand the mathematics, but can experimentally put it into practice. Using the Matlab software to run PsychToolbox (Brainard, 1997; Pelli, 1997) and gauge figure experiment software written for PsychToolbox (Wijntjes, 2011), would allow the experimenter (in this case, the author) to select pictures and prepare gauge figure particulars in the UK for experimentation. The recorded three-dimensional attitudes of probes from observers would firstly be reconstructed into three-dimensional surfaces for visual analysis and then exported into 'Mathematica', a program that uses bespoke algorithms programmed with linear depth map image data, to produce 'best match' surface analysis.

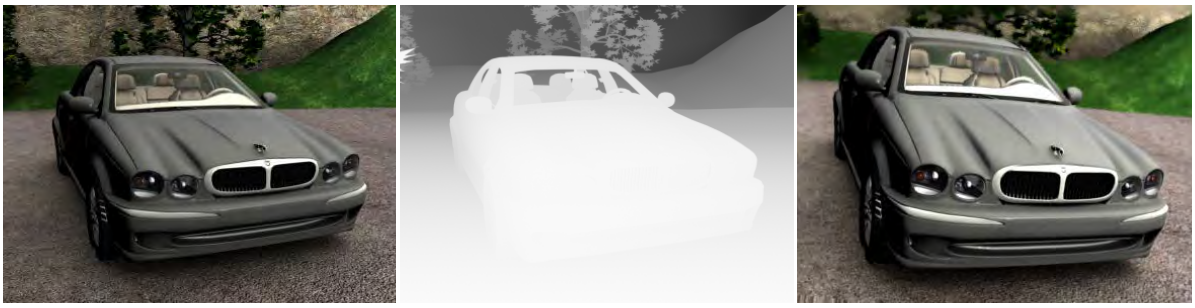
The Vision-Space simulations made during early post-production tool developments were designed to promote the monocular imaging effect (Figure 3.2), and the binocular stereo imaging effect (Figure 3.3) to possible investors.

Figure 3.2. Jaguar car: Monocular scene with an overlaid central fixation area.

Figure 3.3. Coke can: Binocular stereo with left and right views of the same scene, joined vertically through the modulating fixation area.

When adding spatial radial disorder to both sets of pictures during the creation of these simulations, it was decided that those viewing this new media type might be unconvinced by the suggested spatial radial disorder falloff value that an object under close range fixation ought to be given. Because of this, the likely enhanced immersive and spatial depth experience from appropriate levels of spatial radial disorder was reduced, making these pictures look similar to depth of field blur found in optical pictures. This meant setting minimal spatial radial disorder in the periphery of pictures and using falloff values that would be used for viewing an object at distance, rather than for a close-up viewing scenario. However, the spatial framework remains evident and the complete Vision-Space image effects are still contained, allowing insight into whether the directing of central vision attention and the perception of depth is improved within these pictures.

The Vision-Space simulation of a Jaguar car, titled ‘SIGGRAPH 1,’ was used for the gauge figure experiment, primarily as it was produced using the most up-to-date post-production tool. The camera path (panning in and out around the car) for the simulation was permanently set in the original output of the computer generated scene, with this also being the case for Vision-Space features such as spatial radial disorder falloff and peripheral tilt added using the post-production tool. A Vision-Space picture was then chosen from the simulation along with the normal picture and a linear depth map image used to produce it (Figure 3.4).



jag_spin_RGB_00109 jag_spin_depth_00109 outfile00109

Figure 3.4. At this stage we have three pictures, corresponding to the same point in a simulation. The first is a geometrical perspective picture (normal picture), the second is a linear depth map image, and the third is a post-production Vision-Space picture.

The selected Jaguar picture was at the end of a camera movement, which reduced the distance between the lens of the virtual camera and front of the car. This gave the largest possible view of the bonnet, and workable selection zone for the experimentation. This was important as gauge figure experiments are suggested to be more accurate when performed on shapes with a gradual contoured surface, in comparison to those which have sudden changes in contour. For this reason, the well-versed experimenter brings into being stimuli that should fit the prerequisite (Wijntjes, 2011). Equally important was that the central fixation area is located on the front of the car, giving the bonnet contours the increased clarity found in comparison to peripheral information.

The selection zone placed over the bonnet of the car comprises identical triangles that share face edges, forming a continuous surface called a triangulation grid (Figure 3.5a). In the experiment, it was important to ensure that the bonnet contours in the picture were broad, reducing unstable results through few shared edges. The size and position of the linked triangles were also altered so that an appropriate triangulation grid could be mapped within these contours. A ‘barycentre’ is rendered and saved for the central point of each triangle. It is these locations within the experiment which are used in random order as gauge figure markers (Figure 3.5b). In total, 129 barycentre’s are assigned over the bonnet contours, which present the observer randomly with 129 locations for gauge figures to be given intuitive attitudes in the Vision-Space and the normal picture stimuli.

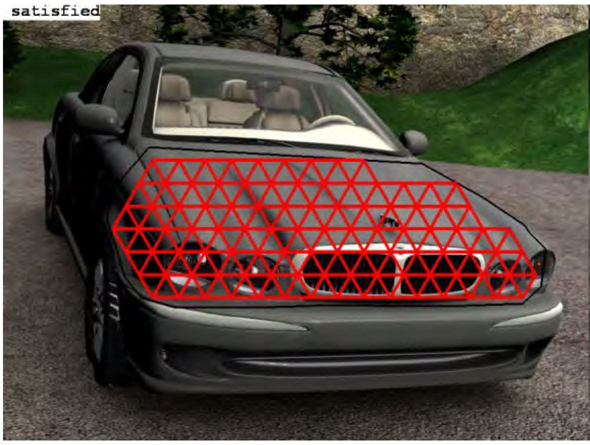


Figure 3.5a. Jaguar car: Triangulation picture - Triangulation grid.

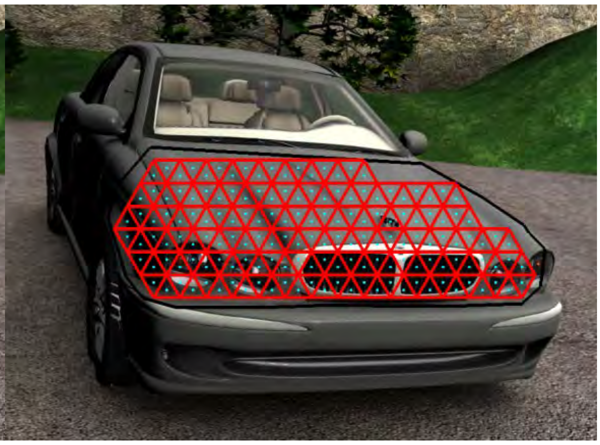


Figure 3.5b. Jaguar car: Triangulation picture0 - Barycentre points.

The observer's interactions with both pictures are measured against the Z-buffer values contained by the linear depth map image. These Z-buffer values are used alongside an analysis algorithm within 'Mathematica', to produce true references of the bonnet's surface profile. This allows a 'best fit' comparison to be made between observer's positioning of gauge figure points in both pictures and the true shape of the three-dimensional object.

During piloting of the gauge figure test, it was noted that the rotation across the entire field in the Vision-Space picture, and its stretched proportions in the X and Y axis, changed the shape and location of objects in comparison to the normal picture and the linear depth map image. This meant that the data recorded from the 129 barycentre in normal and Vision-Space pictures could not be compared against each other using the linear depth map Z-buffer value. Due to the visual characteristics of a Vision-Space picture, it was decided to rotate the linear depth map image and normal picture clockwise so that all scenes aligned. If the Vision-Space picture had been rotated anticlockwise to match, the sought rotation and vertical image effects in the peripheral and fixation areas of the picture would have swapped. Finally, the stretched proportions of the Vision-Space layer needed to be transformed to align with the linear depth map image and normal picture. As all these adjustments were required to be undertaken manually, the end similarities between the three pictures were only precise to the eye (Figure 3.6).

jag109ps jag109dm jag109vs

Figure 3.6. Three pictures corresponding to the same point in a simulation. The first is a normal picture, the second is a linear depth map image and the third is a post-production Vision-Space picture.

The second negated preliminary experiment was a variation of the relative sizing experiment described in the article ‘Space Perception in Pictures’ (van Doorn et al., 2011), which uses identical markers that are superimposed in pictorial space. In this new experiment, an existing object (e.g. butterfly) is duplicated from a normal picture then copies of this probe (Figure 3.7) are repeatedly positioned randomly throughout the Vision-Space and normal pictures.

Figure 3.7. Butterfly probe - fly3cut.

The participant’s interaction with both pictures sees them intuitively adjusting the relative size of each probe, one at a time. This was done so that it corresponded to its new pictorial location and used the original butterfly in the same scene as a relative sizing reference (Figure 3.8).

newerfly3ps newerfly3vs

Figure 3.8. The original butterfly is used in both pictures as a relative sizing reference.

Because the relative sizing method uses the whole scene, it is important to ensure that the probe is not positioned ambiguously. When determining the locality of probes, it was important for their positioning to be exact and this was managed using the white, grey, and black scale of the linear depth map image (Figure 3.9). Placing the probe onto the rim of the cup (light foreground colour) in a linear depth map image provides considerable safeguard from overstepping into a background location on the table (dark background colour), because of the sudden colour falloff (white to black).

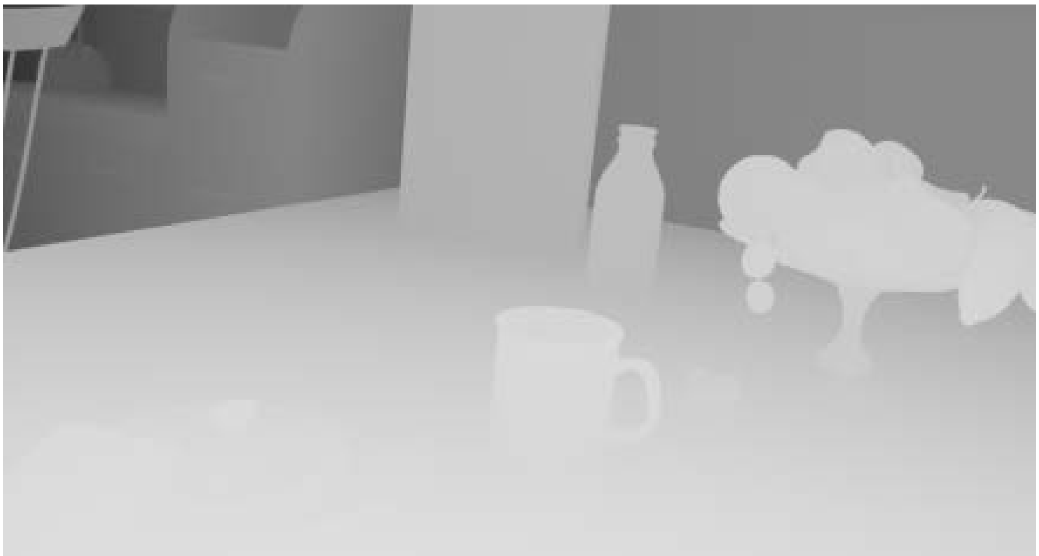


Figure 3.9. newerfly3dm - Managing the position of probe location using the white, grey and black scale of the linear depth map image instead of the normal picture.

In addition to increasing the accuracy of probe placement, a pixel pointer was developed to select a preferred expansion centre for the probe, which was chosen to be the longest leg of the butterfly. By default the graphical expansion points are set to the centre of a probe, which due to this resizing gave them an unwanted floating appearance. This new expansion centre would keep the grounded appearance of the probe during participant resizing.

3.1.1 Concerns with using original Vision-Space pictures as stimuli

The computer generated Jaguar car and butterfly simulations used to select stimuli for experiments, had their image effects intuitively assigned during the development and testing stages of the first Vision-Space post-production tool. The designer of these two simulations was an integral part of the team developing the post-production tool, and received continual feedback from Jupe so that Vision-Space picture effects could be applied fittingly. This collaboration helped advance the desired image effects and usability of the Vision-Space post-production tool for imaging applications. It also provided monocular pictures and simulations to promote the Vision-Space method to possible investors, commercial and academic.

> This butterfly simulation was prepared as a demo for the film industry, and we did not feel that they could tolerate the spatial disorder falloff values being close to a real encounter, when the fixated object was up close.
> (J. Jupe, personal communication, 2012)

In both experiments Vision-Space image effects significantly changed the shape of the normal picture from its original geometrical representation, which was problematic as recognised picture probing methods concentrate on comparing pictures with exact scene replications. However, if the Vision-Space picture were to be given no transformation other than the spatial radial disorder component, it would continue to match its paired original normal picture. Unfortunately, because the Vision-Space pictures used in both simulations were produced in 2010, their original computer aided design data and post-production tool image effect records could not be located to make the required changes to pictures. This meant that, in order to produce appropriate Vision-Space pictures, new computer generated scenes were required. Moreover, this presented the advantage of using an object with a more reliable contoured surface for the triangulation grid in the gauge figure test. Additional benefits of producing new computer generated scenes for both experiments would allow an improved understanding of features within their build, such as the virtual camera location and rendering values. It would also be possible to gain an accurate understanding of the visual influence of different spatial radial disorder falloff values being applied to an object fixated on at both close range and at distance. Furthermore, with only the spatial radial disorder component of a Vision-Space picture added to the original normal picture, the Z-buffer values confirming the depth location of objects within the linear depth map image would relate to the same objects located within the spatial radial disorder and normal picture. The gauge figure and the relative size experiments would use this Z-buffer value to allow analysis of the data recorded from participant’s interface with the spatial radial disorder and normal picture stimuli. However, because a spatial radial disorder picture does not include image stretch in the X and Y axis, scene tilts, or discordance from an overlaid fixation, the suggested benefits of a complete Vision-Space picture in comparison to a normal picture is not possible. Nevertheless, spatial radial disorder is the main spatial framework deployed within a Vision-Space picture which is suggested to be similar in structure to the eye's peripheral visual field, sub-consciously directing visual attention whilst allowing the meditation of depth to surrounding objects.

The gauge figure and the relative size experiments both conform to quantitative favoured vision science research methods as each produces numerical data, contrasting with qualitative approaches which tend to record participant data as descriptions. However, as it was not possible to output a reliable linear depth map image at this juncture, spatial radial disorder and normal pictures could not be produced with the same object Z-buffer values required for comparative analysis. With uncertainty over the timeframe for essential changes to take effect within the computer aided design system (Blender) and Vision-Space post-production tool, it was decided to first examine the subjective visual experience provoked from the Jaguar car and butterfly Vision-Space pictures in comparison to their original normal pictures. This brought about the need to design new qualitative experiments, which involved the collection of measured responses by way of Likert scales (Trochim, 2006). Participants' responses would then be coded and statistically analysed using the Statistical Package for the Social Sciences (SPSS), giving a quantitative insight from qualitative comparisons of pictures.

3.2 Experiment 1

As with pictures created using linear perspective, Vision-Space pictures are constructed around a specific fixation point in order to simulate the point of view of an observer looking at a given point in space. A Vision-Space picture is designed to direct the attention of the observer to this fixation point by the inclusion of several image effects, among them being the use of spatial radial disorder around the periphery. Jupe (2002) hypothesises that viewing a Vision-Space picture more faithfully matches the actual experience of natural vision and provides an improved directional focus, spatial awareness and perception of depth, in comparison to a geometrical perspective picture (normal picture). This opening Vision-Space experiment tests Jupe's claims through participants answering questions (using artistic vocabulary) in relation to hypothesised viewing advantages that a Vision-Space picture has over a normal picture.

3.2.1 Design

It is important to note that the reproduction of Vision-space image effects are not possible due to the limitation that the Vision-Space post-production tool is proprietary software, and therefore unavailable outside of this research. However, in the description of the Vision-Space theory I have explained the background nature of the image effects, their property values and outlined the software approaches taken to produce stimuli.

Experiment 1 was designed to compare the visual experience between two picture conditions, a normal picture and a Vision-Space picture reprocessed through a post-production tool using a copy of the normal picture. The experiment was a repeated measures design, with participants viewing both types of pictures and answering a series of questions using attitudes (strongly disagree to strongly agree) relating to a Likert scale (1-5) for statistical analysis. The questions were based on the hypothesised viewing advantages that a Vision-Space picture has over a normal picture. These being improved directional focus, object proximity, observer relation, perception of depth and matching closer to natural vision. Then in a final question participants were asked to describe their reasons for a preferred picture matching closer to natural vision.

3.2.2 Stimuli selection from original Vision-Space pictures

From dialogue with Jupe, whose insight was used to establish the property values for the Vision-Space pictures found in the jaguar car and butterfly simulations, both sets of Vision-Space pictures had the same monocular principles applied to them using the post-production tool. This saw normal pictures being given a Y axis stretch, spatial radial disorder, a rotation throughout the Vision-Space picture and a central fixation overlay (X axis stretch without rotation). Custom updates to the falloff values of spatial radial disorder in each Vision-Space picture also took place throughout both simulations, as the distance between the virtual camera and fixated object changed with the camera path panning in and out. Furthermore, it was made clear that the falloff value of spatial radial disorder was set to a minimum to allow for a more familiar picture presentation to possible commercial clients. This low falloff value of spatial radial disorder produced an oversized clear area for viewing a close range focus object and assigned low levels of disorder, which increased moderately towards the periphery of the picture. Conversely, the Vision-Space theory suggests that this arrangement of spatial radial disorder is best suited to replicating the first-hand visual experience of observing an object at distance, or tracking in motion. Because these simulations were created using monocular Vision-Space pictures, the overlaid focus area was not modulated through each frame (e.g. butterfly's flight) and looked similar to the normal pictures.

The Jaguar car was decided to be best suited as the experiment stimuli and once a matching Vision-Space and normal picture had been paired, a red dot was placed in the same object location corresponding to the Vision-Space central fixation area within both pictures. The positioning of these dots would be used to direct the fixation of participants to matching locations within stimuli while answering questions. This was intended to ensure the Vision-Space pictures were viewed appropriately from the planned focus location and that the picture space viewed by participants when responding to questions would be the same (Figure 3.10). However, after consideration, there was a concern that the red dot being used as a viewing instruction could add an erroneous effect to both conditions, and the rigorousness of gathered data.

Figure 3.10. Related normal picture and Vision-Space picture with fixation dots in place.

Because of the unknown visual effect that a red dot might have in stimuli, it was decided that the butterfly pictures would better suit both conditions in this experiment. A verbal reference to the butterfly located inside the fixation area was made, with surrounding objects depicting the change in spatial radial disorder falloff in the radial field (Figure 3.11).

Figure 3.11. Vision-Space picture (Picture 1) and normal picture (Picture 2).

3.2.3 Questions based on the hypothesised viewing advantages that a Vision-Space picture has over a normal picture

The Vision-Space imaging theory proposes five viewing advantages that a Vision-Space picture has over a normal geometrical perspective picture. These are improved directional focus, object proximity, observer relation, perception of depth, and matching closer to natural vision (Jupe, 2002). It is the combination of these viewing advantages that, according to Jupe, creates a greater sense of immersion in a Vision-Space picture. In order to test the validity of these hypothesised viewing advantages they were investigated using a qualitative method: The first four viewing advantages were designed as closed-ended questions, with participants answering through a scaled response indicator (Likert scale) after viewing both conditions. The coupling of visual questions allowed the bias between conditions to be swapped so that a balanced analysis of pictures could be achieved. The greater sense of perceptual realism between conditions included participants choosing which matched closest to their natural vision and then reporting their reasons why.

Directional focus

Improved directional focus was the first hypothesised viewing advantage of a Vision-Space picture, in comparison to a normal picture (Appendices 1.1, questions 1 & 2). Participants were asked to choose a level of agreement towards the butterfly, maintaining visual interest when this object is fixated on. This question was based on the claim that Vision-Space image effects improve the saliency of a planned focus location, directing visual attention more rapidly and maintaining focused attention at this location for longer.

Object proximity

Improved object proximity was the second hypothesised viewing advantage of a Vision-Space picture, in comparison to a normal picture (Appendices 1.2, questions 3 & 4). Participants were asked to indicate a level of agreement as to understanding the spatial location differences between objects that surround the fixated butterfly. This question was asked because Vision-Space image effects are claimed to provide more distance information regarding the differences between the locations of objects that surround a planned focus location.

Observer relation

Improved observer relation was the third hypothesised viewing advantage of a Vision-Space picture, in comparison to a normal picture (Appendices 1.3, questions 5 & 6). Participants were asked to indicate a level of agreement as to their sensation of being 'factored into' (present in) the scene when focusing on the butterfly. This question was asked because Vision-Space image effects are claimed to provide more distance information regarding the proximity of the observer to a planned focus location which increases the feeling of being 'factored into' (present in) the scene.

Perception of Depth

Improved perception of depth was the fourth hypothesised viewing advantage of a Vision-Space picture, in comparison to a normal picture (Appendices 1.4, questions 7 & 8). Participants were asked to indicate a level of agreement towards an increased feeling of depth awareness within the scene. This question was asked because Vision-Space image effects are claimed to increase the apparent presence of distance between the planned focus location and surrounding objects (rest of the image space).

Matching closer to natural vision

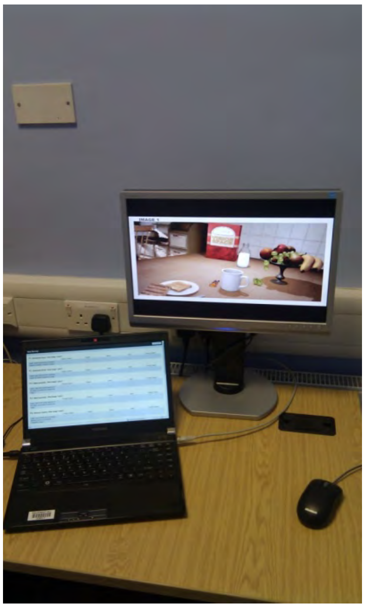
Matching closer to natural vision was the fifth hypothesised viewing advantage of a Vision-Space picture (Appendices 1.5, questions 9). Participants first had to decide which condition would best match the scene's reproduction in natural vision. Additionally, in an open-ended question, participants were asked to express their observations that led to the selected picture by giving an extended descriptive answer (Appendices 1.6, questions 10).

3.2.4 Participants

The experiment recruited 21 participants by way of a sign-up email (Appendices 2.1) to first and second year Psychology students, of which 5 were male and 16 were female. Although there was no monetary payment for taking part in the experiment, the Psychology Department awarded course participation credits. All participants were naive to the research prior to joining the experiment; before consent was asked for, participants were given an information sheet with a clear title of the experiment and an outline of their participation in the research project.

3.2.5 Apparatus

The stimuli were presented on a 19 inch screen of a Dell desktop computer using the program 'Windows Live Photo Gallery'. Using a mouse and a Toshiba Portégé laptop (Figure 3.12), participants were able to navigate between both pictures at their own pace whilst completing an online questionnaire (Surveymonkey.com).



Picture 1 – Vision-Space picture

Picture 2 – normal picture

Figure 3.12. Experiment environment - Participants control stimuli slideshow whilst answering 10 online survey questions using a Toshiba Portégé laptop.

3.2.6 Procedure

Participants were brought into the testing room one at a time and seated at a desk with the computer equipment in front of them. In addition to applying for ethical approval to run the experiment (Appendices 2.2), an information sheet detailing the purpose of the experiment, and the tasks involved, also had to be approved (Appendices 2.3). This was discussed with participants so that they were able to give informed consent to take part (Appendices 2.4). After this, participants were shown how to navigate between displayed pictures using a mouse and how to complete the survey questions on a separate laptop, using attitude dimensions (Table 1).

Strongly Disagree (1)	Disagree (2)	Neither (3)	Agree (4)	Strongly Agree (5)

Table 1. Likert attitudes with the related numeric scale (1-5) that participants used to reflect their answers whilst navigating between pictures.

Participants were asked to read questions consecutively and respond as quickly and as accurately as possible whilst observing the stimuli labelled picture one (Vision-Space picture) and picture two (normal picture). Because participants were able to navigate back and forth between the Vision-Space picture and the normal picture at their own will, the presentation of stimuli was not randomised. This meant that participants could either be viewing a Vision-Space picture or a normal picture at the start of every new question. In total there were ten questions, of which the first eight questions used Likert attitudes as comparative measures between both conditions. Question nine asked participants to decide which of the two pictures was most realistic. The final question asked participants to explain their preferred picture choice from the previous question. It generally took participants a session time of around 10 minutes to complete these ten questions, whilst navigating between both stimuli.

3.2.7 Findings

The self-reported measures for questions one to eight were used to examine the popular preference (subjective performance) between the Vision-Space picture and the normal picture in the areas of directional focus, object proximity, observer relation, and perception of depth (Appendices 3.1). The participant results gave a higher mean rating of preference towards the Vision-Space picture, over the normal picture in all four areas (Figure 3.13).

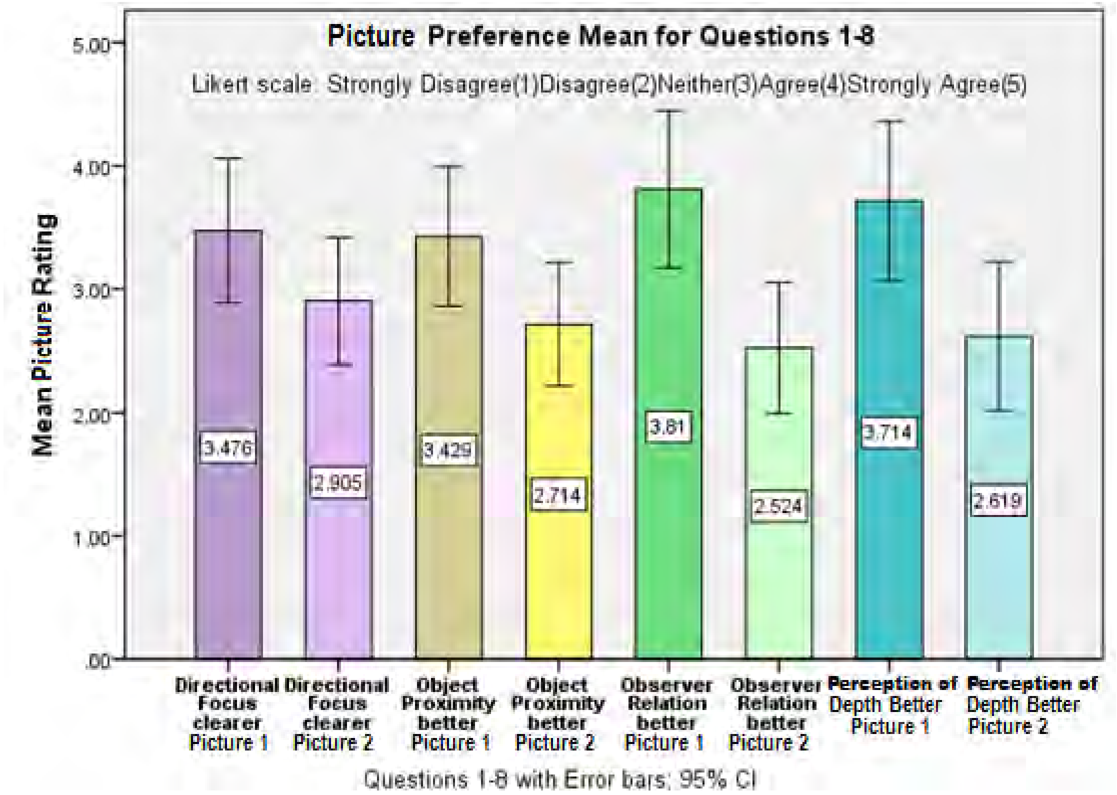


Figure 3.13. A Bar chart showing participants' Mean preference between Vision-Space picture (Picture 1), and normal picture (Picture 2), for directional focus, object proximity, observer relation and perception of depth.

'Paired t-tests' (Parametric) were decided to show more meaningful results when compared to a Wilcoxon's matched pairs tests (Nonparametric). The paired t-tests (Appendices 3.2) showed that there was no significant difference (p>.05) between the Vision-Space picture and the normal picture when interpreting directional focus t = 1.176, df = 20, p = .253, d = .26, and object proximity t = 1.462, df = 20, p = .159, d = .32. However, according to Cohen (1988) both results produced a small effective size (Appendices 3.3).

Furthermore, paired t-tests did give significant (p<.05) differences between both pictures for observer relation t = 2.402, df = 20, p = .026, d = .52, and perception of depth t = 2.104, df = 20, p = .048, d =.46. According to Cohen (1988), a medium effective size was produced in each case.

The Bar chart below (Figure 3.14) shows the participant's choice between the Vision-Space picture and the normal picture appearing most realistic. Picture two, the normal picture, was chosen by 12 out of the 21 participants (57 percent) (Appendices 1.5).

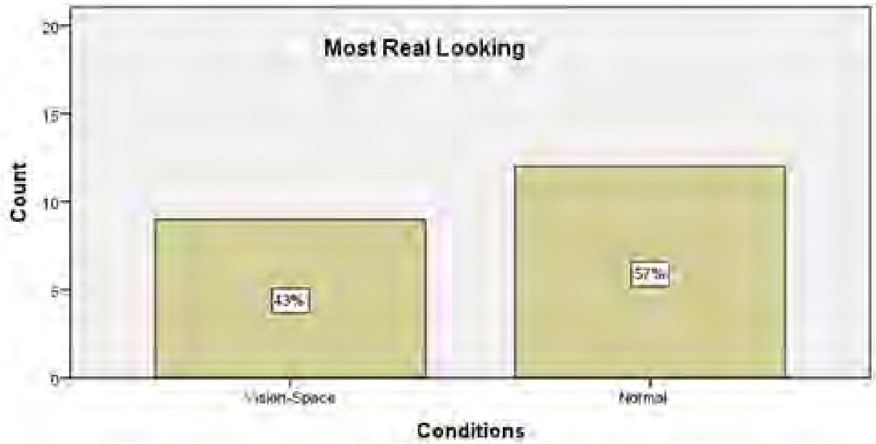


Figure 3.14. A Bar chart showing participants preference towards the normal picture over the Vision-Space picture, looking more realistic.

As there are only two conditions: participant preferences were towards either a Vision-Space picture or a normal picture. The recorded data was therefore best calculated by way of favouritism, using a 'Chi-square test of association' to show the relationship between the two variables (Appendices 3.4). The Chi-square test showed that there was no significant difference (p>.05) between the normal picture being more experientially realistic than the Vision-Space picture: X^2 (1, N = 21) = .429, p = .513.

The final question asked participants to explain their observations that led to the preferred picture choice in the previous question (Appendices 1.6). The explanations of their selection of the normal picture over the Vision-Space picture involved both positive and negative accounts of viewing spatial radial disorder. Below are three examples of such participant responses:

> "Although image one does have a depth type effect, it lacks similarity to reality. It seems as though the effect is created by blurring objects more as they get further away. However this attracts the eye to the blur as this seems so out of place. Image two does not have such a striking depth effect, although the shading from the light source provides some depth awareness, with the clarity of the whole picture allowing the eye to focus on areas with little distraction" (Participant 1).

> "I don't believe the scene in real life is as blurry as Image one, because it is much clearer than Image one. Image two is a lot more bolder [sic] in colour, as I think it is in a scene in real life, which lead to my answer being number two" (Participant 7).

> "The Image two is more real life compared to Image one. As image one shows fuzziness outside of the main focus point of the table [sic]. Normally you would see all things clear" (Participant 8).

However, participants who favoured Image one only gave positive accounts of their experience of spatial radial disorder and other Vision-Space image effects:

> "Because, as I am focusing on the direct object (butterfly) rather than the whole picture it is more similar to my visual perception as if I was observing the objects in real life. My vision is blurred around the other objects I'm not directly looking at" (Participant 6).

> "Image one seems more lifelike due to the depth effect, objects seem more realistic because of this" (Participant 9).

> "Image two is all in focus, even objects which are in our peripheral vision. In Image one, background objects are blurred and therefore more realistic" (Participant 20).

Directional focus:

The mean results from question one and two showed a higher rating given to the Vision-Space picture over the normal picture in maintaining the participants' attention on a planned focus location in a picture. Yet, these mean results were not significant, suggesting that the low falloff value of spatial radial disorder surrounding the butterfly focus area was not enough to produce the spatial cue intensity needed to assist in directing and maintaining participant fixation on the butterfly. A comparison made between the most commonly chosen scaled responses of these two closed-ended directional focus questions showed a reasonable difference between participants' levels of agreement towards the butterfly maintaining visual interest in both pictures.

The results of the first two questions show 10 participants agreeing that the Vision-Space picture improved their directed focus, with 4 disagreeing. Additionally, in response to whether the normal picture improved their directed focus, 12 participants disagreed with this statement, whilst 6 agreed. These two questions demonstrated a consistent participant margin of 6 in favour of the Vision-Space picture, with its various image effects giving a clearer directional focus towards the butterfly.

The spatial radial disorder is not suggested as a main image effect in Vision-Space pictures but one of many image effects collaborating to create a more realistic representation of physical space. Yet, without spatial radial disorder, spatial cues would not be formed around a planned focus location. In addition, the extent to which the combined image effects applied alongside spatial radial disorder (such as stretch and tilt) have on the enhancement of an object held in attention is difficult to ascertain. Even though the falloff value of spatial radial disorder within the Vision-Space picture is suggested to be best suited for replicating the visual experience of observing an object at distance, it has been shown to have enhanced the mean directional focus of a close-up fixated object. It is speculated that if this scene were recreated with an increased, more fitting falloff value of spatial radial disorder for close-up fixated viewing of the butterfly, a significant difference could be established.

Object proximity:
The mean results from the third and fourth questions showed the Vision-Space picture as improving the spatial understanding of objects surrounding the butterfly fixation (at the forefront of the picture) in comparison with the normal picture. Yet these mean results once again did not prove significant, suggesting that the low falloff value of spatial radial disorder surrounding the butterfly focus area, was again not elevated enough to produce the spatial cue needed to relate the locality of objects within the scene to the object under fixation. However, when a comparison was made between the commonly chosen scaled responses of these two questions, a difference was evident between participants' levels of agreement towards each picture.

The results from the third question indicate that 11 participants agreed that the Vision-Space picture improved their spatial awareness of surrounding objects, whilst 4 disagreed. In response to the normal picture improving their spatial awareness, 12 participants disagreed with this statement, whilst 6 agreed. These two questions saw the participant margin increasing to 7 in favour of the Vision-Space picture, with its various image effects improving their understanding of the location of objects surrounding the fixated butterfly.

Without the application of spatial radial disorder, there would be no introduction of a spatial cue outwards from the fixated object, which would leave periphery objects unambiguous and without a cue to provide spatial relation to surrounding objects. Moreover, by disregarding the unknown amount by which the combined image effects of stretch and tilt are influencing the spatial understanding of objects surrounding the fixated butterfly, it can be suggested that the falloff value of spatial radial disorder in the Vision-Space picture has shown some ability to increase spatial understanding of surrounding objects. However, with only a nominal amount of disorder made noticeable from the fixated butterfly for commercial clients, this made the spatial radial disorder more aligned with the Vision-Space theory on replicating the visual experience of observing an object at distance, rather than close range. It is therefore anticipated that if a higher falloff value of spatial radial disorder for close-up viewing of the butterfly were to be assigned, a significant difference would be created in favour of the Vision-Space stimuli.

Observer relation:
The third set of mean results showed that, in comparison to the normal picture, the inclusion of Vision-Space image effects produced a significant (p>.05) improvement to the participants' sense of proximity with the fixated object (butterfly). This result is very positive in relation to the falloff value of spatial radial disorder being suggested as not elevated enough to produce a spatial cue, which significantly improves participants' directional focus or their spatial awareness of objects within the scene in relation to the object under fixation. A comparison made between the commonly chosen scaled responses of the two observer relation questions showed that participants' levels of preference towards the Vision-Space picture increased from agree to strongly agree.

The results saw 9 participants strongly agreeing that the Vision-Space picture improved their sense of proximity with the fixated butterfly, with 3 disagreeing. In response to whether the normal picture improved their observer relation, 11 participants disagreed whilst 5 agreed. In addition, 6 participants agreed with the statement in relation to the Vision-Space picture, which further highlights the participants' preferred choice as being the Vision-Space picture.

The Vision-Space theory relating to spatial radial disorder suggests participants understand that something new is contained within a picture as they accept the scenario. Furthermore, they may possibly notice such an addition very quickly because they know it is absent within the normal picture. It is the application of spatial radial disorder, leading away from the fixated object towards the periphery of the picture that the Vision-Space theory suggests replicates the spatial cue in reality. This result shows that a low falloff value of spatial radial disorder assigned to a Vision-Space picture produces a significant effect in increasing a participant's observer relation. Yet, it is again important to note that the extent to which different image effects within the Vision-Space picture affect participants' decisions is difficult to ascertain. Disregarding these other image effects, the low falloff value of spatial radial disorder is considered to be a main visual factor involved in improving the relative proximity of the observer to an object under fixation, and promoting a sensation of being included in the scene when focussing on an object. Conversely, if a higher falloff value of spatial radial disorder were to be assigned for close fixated viewing of the butterfly, it is unsure how this significant difference in favour of the Vision-Space stimuli might be altered.

Perception of depth:

The fourth set of mean results suggests that the inclusion of Vision-Space image effects also significantly improves (p>.05) the participants' sensation of depth, in addition to their external inclusivity. A comparison made between the commonly chosen scaled responses of the two depth awareness questions showed a strongly agreed level of preference towards the Vision-Space picture.

The results indicate 8 participants strongly agreeing that the Vision-Space picture improved their depth awareness, with 6 participants agreeing and 4 disagreeing. In response to the normal picture improving their depth awareness, 7 participants disagreed with this statement, 5 agreed and a further 5 strongly disagreed. These results highlight the significant improvement in depth awareness experienced whilst viewing the Vision-Space stimuli.

This result is suggested to be linked to 'any' introduction of spatial radial disorder over the normal picture's 'deficiency' when viewing the butterfly scene. However, as previously noted, the spatial radial disorder cannot be completely attributed to this experience in Vision-Space stimuli as there are a variety of image effects established whose visual influence is also unknown. This result continues to suggest that when assigned to a picture, a low falloff value of spatial radial disorder can have a significant effect in increasing participants' depth awareness. This supports the notion that spatial radial disorder produces a significantly better spatial relation between the observer and the object in fixation. It is therefore thought that a low falloff value of spatial radial disorder is enough to improve the relative proximity of the observer to an object under fixation, and to promote a sensation of being in the scene when focussing on an object.

However, if a higher falloff value of spatial radial disorder for close-up fixated viewing of the butterfly were to be assigned, it is unsure how this significant difference in favour of the Vision-Space stimuli might alter.

Matching closer to natural vision:
The participants' descriptions strongly imply that their gaze was exploring the scene, moving away from the planned focus location containing the butterfly when deciding which stimulus would best match the reproduction of the scene in real life. With this being a most likely viewing scenario, it is understandable that more participants (12 out of the 21) chose the unambiguous normal picture as being a better representation of how they might see the scene in real life. However, nine participants preferred the Vision-Space picture as being a closer representation of real life, producing a non-significant difference (p>.05) between both stimuli. This result suggests that the increasing levels of disorder towards the periphery of this picture were not markedly off-putting when viewed directly, rather than viewed indirectly. A main reason for the Vision-Space picture being so well received is that the falloff value of spatial radial disorder was set to a minimum, and a more familiar presentation of a normal picture was produced.

3.2.8 Summary

Participants showed continuous favour towards viewing the Vision-Space picture over the normal picture, with significant improvements in their sense of proximity to the fixated object and their perception of depth. However, the directional focus helping participants maintain their fixation on the planned focus location was not significantly improved, nor was the spatial awareness of objects surrounding the object under fixation. From these results, it is proposed that the first two hypothesised viewing advantages investigated in this experiment (i. Directional focus, ii. Object proximity) require an increased falloff value of spatial radial disorder to come into force; whereas a low falloff value was adequate to produce a significant difference in the following two viewing advantages (i. Observer relation, ii. Perception of depth).

In addition, the overall positive findings relating to the spatial properties of a Vision-Space picture did not match with the participants' matching closer to natural vision opinion, which saw the normal picture marginally favoured as representing the scene closer to real life. It was established that directly viewing increasing values of disorder set out from the focus area in the Vision-Space picture, was the main reason for the normal picture being more widely chosen as a realistic representation of the scene. However, the Vision-Space theory proposes that when the clear focus area is updated with each new fixation in real-time, visual ambiguity would be removed. In addition, the real-time fixation update which allows the spatial radial disorder to be viewed indirectly (as a peripherally intended depth cue), is suggested to further enhance the spatial properties of a Vision-Space picture, similar to increasing the falloff value of spatial radial disorder.

3.3 Experiment 2

In experiment 2 it was decided to focus on spatial radial disorder as a critical image effect used within Vision-Space pictures. Whilst conventional imaging methods use depth of field blur to mimic human visual depth (Lin and Gu, 2007; Nefs, 2012; Mauderer et al., 2014) and direct attention (Ware, 2008), Jupe hypothesises that a picture with spatial radial disorder more closely mimics the appearance of peripheral vision; leading to improved directional focus towards a planned focus location, spatial awareness, perception of depth, and matching closer to natural vision (Jupe, 2002). This experiment was initially designed to compare depth of field blur against spatial radial disorder, both viewed as a geometrical perspective picture (normal picture). However, instead of depth of field blur, spatial radial blur was used in its place. The change from depth of field blur took place due to the imprecise value of blur being generated by eye, using computer design software, to match up with the falloff value of spatial radial disorder. Instead, a three-dimensional computer generated scene was processed with matched ‘Spatial Radial’ values of disorder and blur. In addition to comparing spatial radial disorder against spatial radial blur both viewed as normal pictures, a further comparative condition of a normal picture devoid of additional image effects was included. This second experiment tests Jupe’s claims through participants, comparing the three conditions, whilst answering questions based on viewing advantages that a Vision-Space picture has over a normal picture.

3.3.1 Discarding original Vision-Space pictures

Whilst researching the Vision-Space imaging method it was recognised that the application of spatial radial disorder, (which increases in intensity from a central fixation point in all directions) has no transformational impact on the picture layout; this is the same as depth of field blur in a normal picture. Depth of field blur can be easily applied to a computer generated scene so that it is rendered similar to pictures produced through photography. This is accomplished by selecting a fixation point located on an object and applying an increased level of blur (out of focus effect) to objects, as their planar location (in front of and behind the focused object) increases (Figure 3.15).

Figure 3.15. A depth of field picture, rendered directly from the scene built in Blender.

The blue circle positioned in Figure 3.16 illustrates how depth of field blur makes the balloon knot an unambiguous fixation area, which is also an essential requirement for the fixation area of spatial radial disorder.

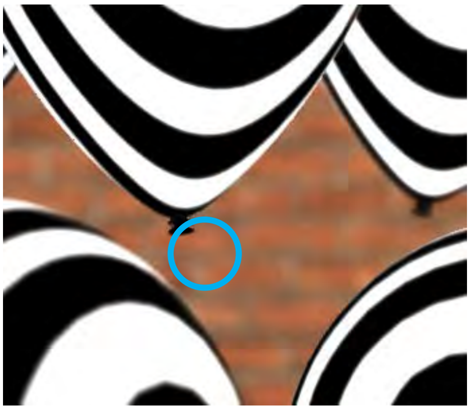


Figure 3.16. Shows the clear fixation area on the front left balloon knot, produced using the depth of field features in Blender.

The pictures used in experiment 1 are early examples of the post-production tool's potential to produce monocular pictures (transformed from a normal picture) with complete Vision-Space image effects. As previously discussed, the arrangement of

Vision-Space image effects transforms the shape, size, and positioning of objects in relation to the original normal picture. These transformational Vision-Space image effects in the butterfly picture include: peripheral Y axis stretch with a rotation, and central X axis stretch within the positioned fixation area. This meant that Vision-Space pictures would not align when overlaid with their normal pictures, a property required by existing vision science experimental methods to compare pictures. In addition, the normal pictures were unable to be rendered with linear depth map images, which are essential when assigning spatial radial disorder accurately within the post-production tool. This brought about a 'quick fix' at the time of the Vision-Space butterfly simulation and saw normal pictures duplicated using image editing software (Photoshop). These normal pictures were manually given a black and white gradient appearance similar to that of a linear depth map image. However, these pictures could not offer an exact representation of the scene's Z depth, so a true radial field of disorder was not actually accomplished for original Vision-Space pictures. This brought about the need to produce new computer generated scenes which a linear depth map image could be rendered at the same time as a normal picture.

3.3.2 New stimuli produced using computer generated scenes

Experiment 2 was initially designed to use depth of field blur instead of spatial radial blur. This change took place due to the imprecise value of depth of field blur being generated by eye within Blender (Figure 3.17), to match up with the falloff value of spatial radial disorder produced using the post-production tool.

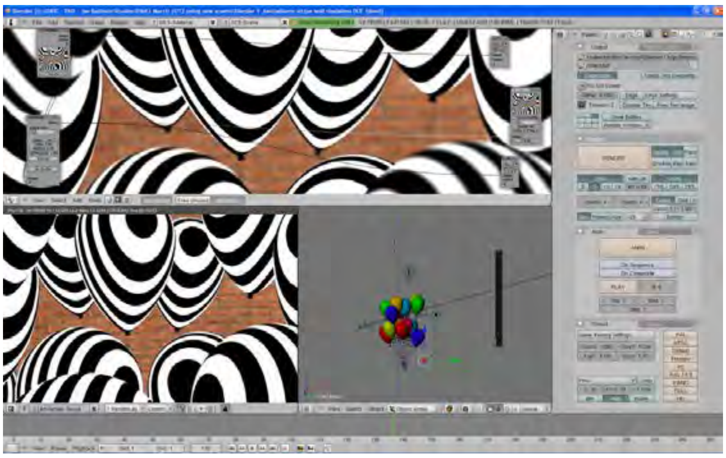


Figure 3.17. Setting depth of field within Blender to appropriately match post-production tool falloff value of spatial radial disorder.

The change in stimulus from depth of field blur to spatial radial blur, allowed blur to be compared against disorder in the same spatial radial application, whereas depth of field blur is applied planar. Furthermore, without the complete range of image effects found in Vision-Space pictures, the spatial radial disorder and blur pictures would continue to proportionally match the normal picture which has no added image effects. Software upgrades were made to Blender to allow a corresponding linear depth map image of a scene to be rendered at the same time as its normal picture (Figure 3.18).

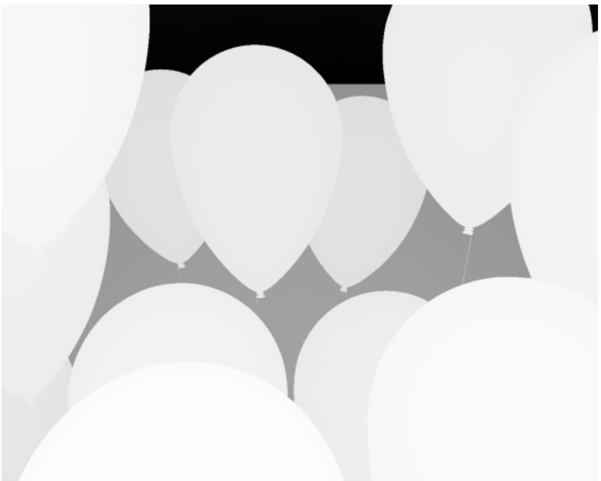


Figure 3.18. A linear depth map image of the scene rendered using Blender.

The ability to render a linear depth map image, containing the exact spatial location of objects in the normal picture, made it possible within the post-production tool to produce a true radial field around a fixation point (shown with a blue dot in Figure 3.19). For the first time, this allowed both the accurate and appropriate falloff value of spatial radial disorder to be applied to a normal picture as outlined in the Vision-Space imaging method.

Figure 3.19. The intensity of disorder is increased outwards in an X, Y and Z direction from a fixation point (blue dot) to form a spatial radial disorder.

An occlusion software issue was found in the post-production tool during the assigning of spatial radial disorder to the origin of a fixation, which prevented a clear fixation area from being placed at the edge of a foreground object. The blue circle positioned in Figure 3.20 highlights this poor visual clarity when setting the balloon knot as the fixation area. It was established that this was linked to the disordered environment directly behind, in this case the wall being transmitted through the boundary of the fixation area which extends beyond the boundary of the fixated portion of the object.

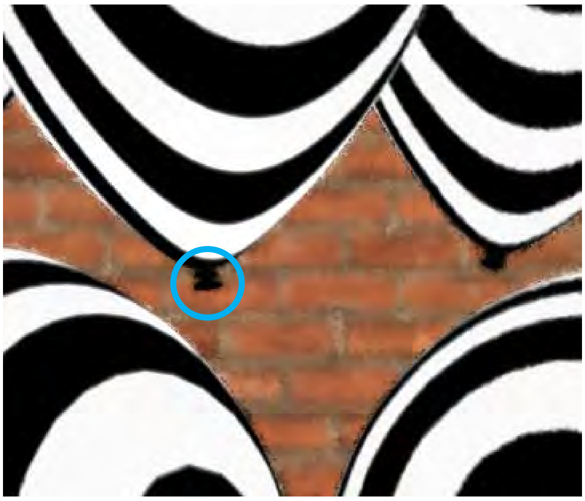


Figure 3.20. Shows the indistinct fixation area over the front left balloon knot when spatial radial disorder boundaries receive interference from the occluded scene.

In order to address this occlusion issue, it was important that the boundaries of the clear fixation area remained within the balloon's larger surface area.

When new computer generated scenes where being designed the necessary low intensity change of disorder and blur covering solid coloured objects was found hard to see. From understanding that fine detail is better expressed through luminance differences, it was decided to apply a black and white pattern to objects in an attempt to help emphasise the intensity change of blur and disorder being compared in these pictures. This was largely based on visual colour system literature by Livingstone (2002), who remarks on the dark-light contrast of the luminance channel being used to convey the shape of curved surfaces and fine textures in greatest detail. It is also suggested that additional detail is obtainable through increased luminance contrasts, black-white being the most acute contrast possible.

It was also important to make sure that a computer generated normal picture was rendered without blur so that spatial radial disorder could be established without any other image effect interference. Furthermore, the virtual camera automatically renders shading and shadow pictorial cues which were removed from the normal picture output settings in Blender (Figure 3.21).

Figure 3.21. A normal picture with shading and shadow pictorial cues, and a second normal picture without shading and shadows.

In addition, the colour and contrast render levels set for the normal picture needed to correspond to the post-production tool render settings, to ensure that only the difference in conditions was being compared. This was not the case with the normal picture and Vision-Space picture used in the first experiment, largely because these pictures were built and rendered by a third party for commercial promotion during early post-production tool development (without testing in mind).

3.3.3 Design

Experiment 2 compares the visual experience of stimuli comprising of three conditions. The first condition was a normal picture without blur (infinite depth of field), the second and third conditions were reprocessed from the normal picture using the Vision-Space post-production tool, to produce a spatial radial disorder and spatial radial blur picture. As previously discussed, instead of creating a picture with depth of field blur, a spatial radial blur picture was rendered using the same post-production tool values used to create the spatial radial disorder picture. This meant that the same fixation origin and image effect falloff was used to create the spatial radial disorder and spatial radial blur conditions. Apart from the blur and disorder effect being visually different, everything else in both conditions would remain identical.

Experiment 2 was a repeated-measures design, with each participant viewing all conditions, whilst answering a series of questions based on the hypothesised viewing advantages used in experiment 1. These questions were used to measure the experience of viewing a picture with spatial radial disorder over a picture with spatial radial blur and a normal picture devoid of additional image effects.

The experiment instructions, questions, and stimuli were composed within an interactive PowerPoint with a set duration for viewing each slide within the slideshow. Participants answered questions through interacting with stimulus, using a mouse as an input device, by marking either an identified focus location, drawing areas of expressed interest during verbal response, or choosing a preferred response word from a list of attitudes (Figure 3.22).

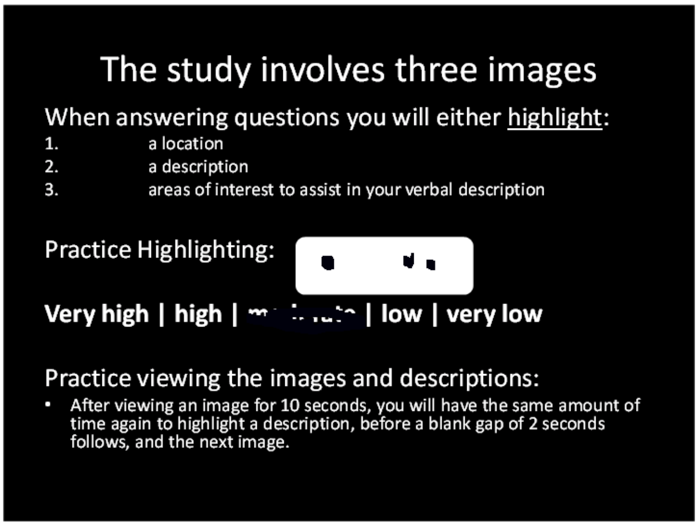
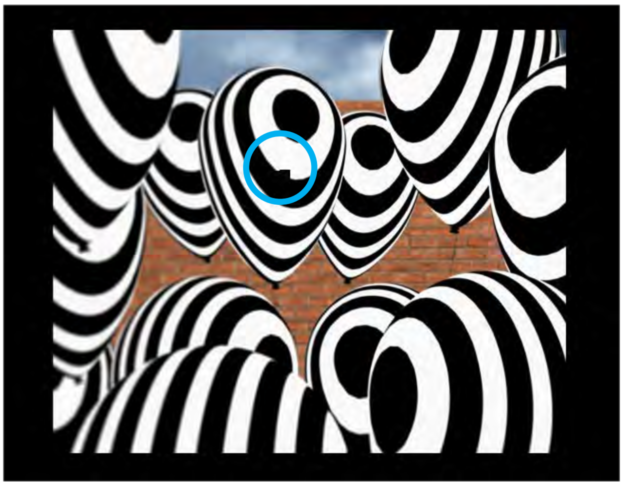


Figure 3.22. A PowerPoint slide, showing practice using the input device (mouse) to highlight an appropriate response (Participant DSV1).

The counterbalancing of stimuli within this repeated measures experiment was controlled by way of six different combinations being produced using the normal (S), spatial radial disorder (V), and spatial radial blur (D) conditions. These six combinations of stimuli were used to create six separate PowerPoint presentations, each named using a reference letters for viewable order of stimulus: VDS1, VSD1, DVS1, DSV1, SVD1, and SDV1. Three PowerPoint presentations were made from each viewable order e.g.: VDS1 PowerPoint, VDS2 PowerPoint and VDS3 PowerPoint, creating 18 participant PowerPoint sessions in total. This was thought to be robust enough in arrangement to counteract order effects of stimuli. The viewable order of stimuli is demonstrated using question one from participant DSV1 PowerPoint session (Figure 23).

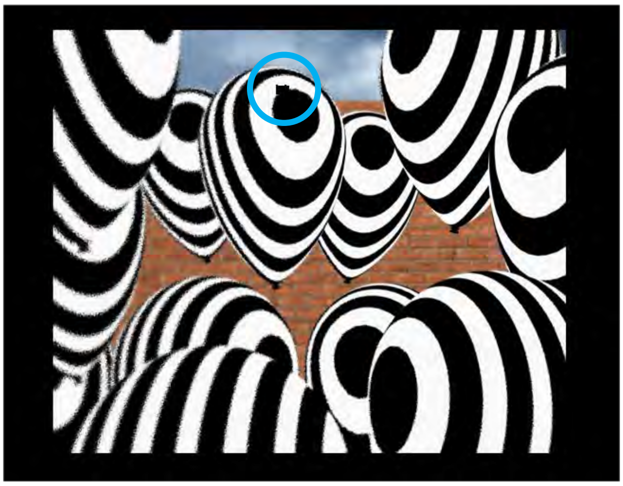


Participant DSV1 PowerPoint session: Question one.

Showing the identified focus location in the spatial radial blur condition (D).

Participant DSV1 PowerPoint session: Question one.

Showing the identified focus location in the normal condition (S).



Participant DSV1 PowerPoint session: Question one.

Showing the identified focus location in the spatial radial disorder condition (V).

Figure 3.23. Participant DSV1 PowerPoint session: Showing the viewable order of conditions spatial radial blur (D), normal (S), and spatial radial disorder (V) and the identified focus location given for each condition in the first question.

3.3.4 Questions based on the hypothesised viewing advantages that a Vision-Space picture has over normal picture

The technical language was simplified for the instructions and questioning to increase participants' engagement and reduce their need for background understanding. In total, nine questions were developed to explore the hypothesised viewing advantages of a Vision-Space picture in comparison to a normal picture used in experiment 1. These questions were repeated for each of the three conditions created using the balloon scene.

The first part of question one provided participants with practice using the mouse as an input device (Figure 3.24). This was to ensure that a small red dot representing their identified focus location could be marked onto each of the three conditions that followed. This first question gave participants 20 seconds to view each condition, decide on, and highlight an identifiable focus location. There was a brief blank period between each of the three conditions.

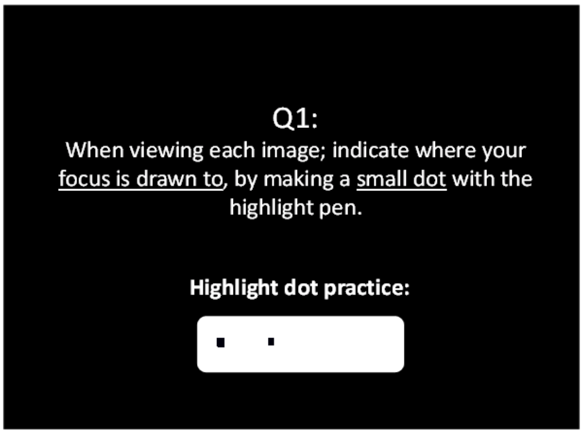


Figure 3.24. A PowerPoint slide explaining the task to be completed on the three stimuli which followed, and further highlighting practice using the input device (mouse).

Question two (Figure 3.25) asked participants to highlight an attitude which reflected the competence of each condition to direct their focus to their identified focus location. This type of question gave participants 10 seconds to view each condition, followed by a further 10 seconds to decide on, and highlight an answer. This was followed by a brief blank period between each condition to refresh viewing.

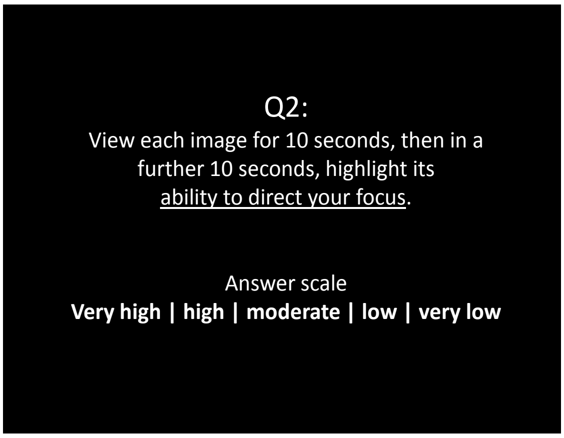


Figure 3.25. A PowerPoint slide explaining the task to be completed on the three stimuli which followed, and further highlighting practice using the input device (mouse).

Question number three (Figure 3.26), asked participants to look directly at where they had positioned their identified focus location within each condition and describe any observations linked to their focus being directed. This type of question gave participants 20 seconds to describe their visual experience, whilst using the mouse to highlight these discussed areas of interest, followed by a brief blank period before the next condition to refresh viewing.

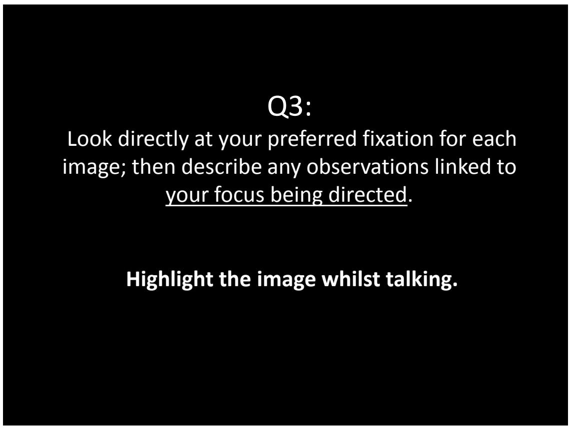


Figure 3.26. A PowerPoint slide explaining the task to be completed on the three stimuli which followed.

Question four (Figure 3.27) asked participants to highlight an attitude dimension which reflected the ability of each condition to convey the different locations of balloons within the scene, through an improved apparent presence of distance. During this question, participants were reminded to continue looking where their identified focus location within each condition had been positioned.

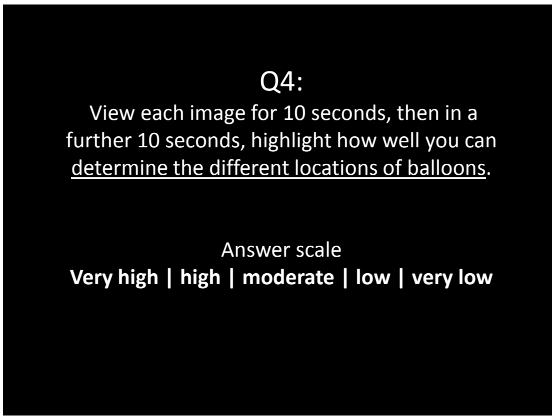


Figure 3.27. A PowerPoint slide explaining the task to be completed on the three stimuli which followed.

Question five (Figure 3.28) asked participants to look directly where they had positioned their identified focus location within each condition and describe any observations that helped determine the location of different balloons. Whilst participants described their visual experience, they were reminded to use the input device to highlight these discussed areas of interest.

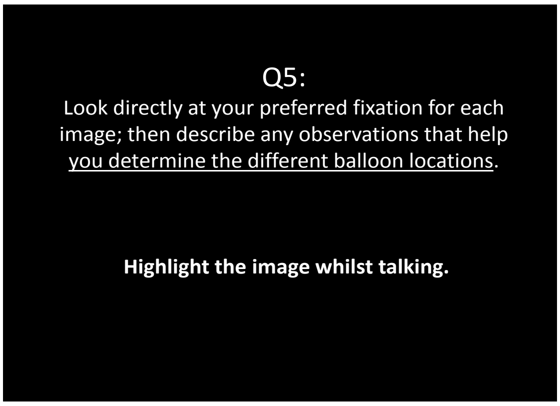


Figure 3.28. A PowerPoint slide explaining the task to be completed on the three stimuli which followed.

Question six (Figure 3.29) asked participants to highlight an attitude dimension which reflected the ability of each condition to suggest a sense of being ‘factored into’ (present in) the scene.

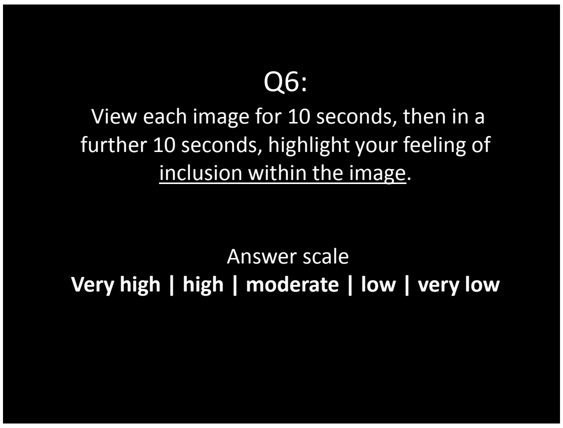


Figure 3.29. A PowerPoint slide explaining the task to be completed on the three stimuli which followed.

Question seven (Figure 3.30) asked participants to highlight an attitude dimension that reflected the ability of each condition to suggest a sensation of spatial awareness within the scene, which was used as an alternative indication to the perception of depth. During this question, participants were reminded to continue looking where they had positioned their identified focus location within each condition.

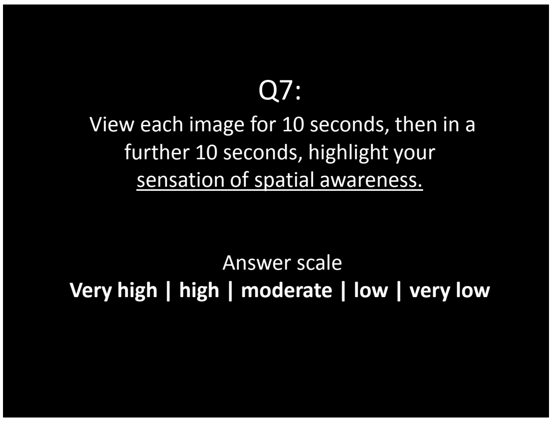


Figure 3.30. A PowerPoint slide explaining the task to be completed on the three stimuli which followed.

Question eight (Figure 3.31) asked participants to highlight an attitude dimension reflecting a level of viewing comfort when observing each condition, which was used as an alternative indication of matching closer to natural vision. During this question, participants were reminded to continue looking where they had positioned their identified focus location within each condition.

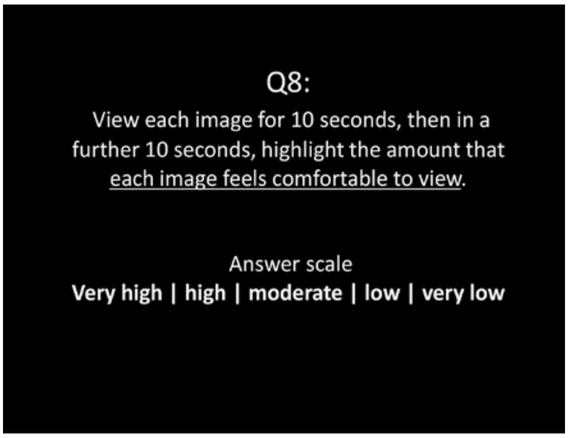


Figure 3.31. A PowerPoint slide explaining the task to be completed on the three stimuli which followed.

Question nine (Figure 3.32) asked participants to describe any observations that made each condition feel naturalistic (realistic) whilst being viewed from their identified focus location. Whilst participants described their visual experience, they were reminded to use the input device to highlight these discussed areas of interest.

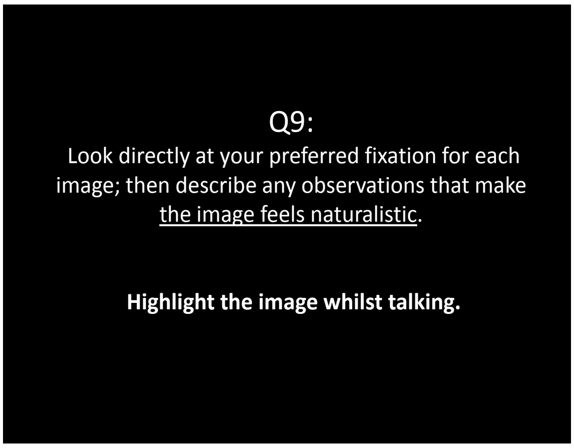


Figure 3.32. A PowerPoint slide explaining the task to be completed on the three stimuli which followed.

3.3.5 Participants

By way of a sign up email and promotion of the experiment out of term time, 18 participants signed up to take part in this second experiment. No monetary payment, nor course participation credits were awarded. There was a mixture of both staff and students who participated, of which 7 were male and 11 were female.

3.3.6 Apparatus

The experiment was presented on a 30 inch Dell U3011 display screen (VDU), using a Toshiba Portégé laptop running PowerPoint. To fulfil the experiment questions, participants were familiarised with using a mouse as an input device. Throughout each session, a mobile Tobii eye tracker head set was worn by participants, recording gaze travel and fixation information during the viewing of stimuli as well as the recording of verbal responses. A Dell Laptop was used to run the Tobii eye tracking software, and data from the head set was stored on a mobile storage unit (Figure 3.33).

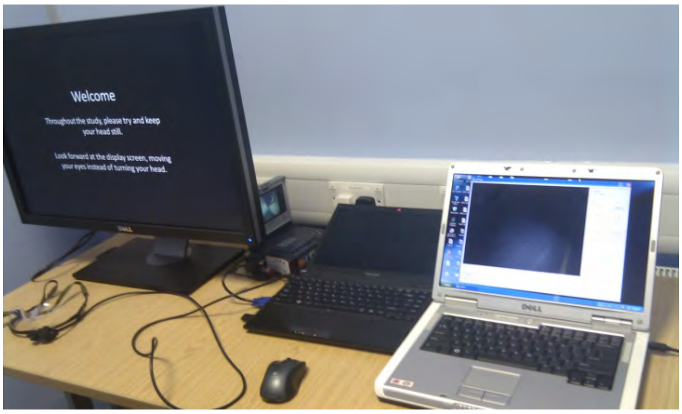


Figure 3.33. Experiment equipment - Toshiba Portégé laptop connected to a Dell U3011 30 inch flat screen display (VDU), and Tobii eye tracking glasses with its dedicated software laptop.

The mobile eye tracker is essentially a pair of lens less glasses which have a single camera attached that captures the reflected movement of pupil saccades from one eye. Eye tracking information is commonly used to see which points of a picture or physical space have been fixated on and which have not. The recorded viewing data is dependent on what the observer finds interesting and the task given. For example, the data can be used to show the sequence of eye movements during a task or the points that a person deliberately fixates on the most (Snowden et al., 2006). The recorded eye tracking data of participants' viewing new stimuli would allow gaze travel and fixation information to be compared inside and outside of areas of interest later assigned to the pictures during analysis. However, the data recorded using the eye tracking equipment was not considered during the analysis of this experiment as it lacked the consistent accuracy required.

3.3.7 Procedure

Participants were brought into the testing room one at a time and seated at the desk with the experiment equipment in front of them, ready for the experiment to take place. All participants were naive to the stimuli and questions prior to joining the experiment; however, before participants could give their informed consent they were given an information sheet with a clear title of the experiment which outlined their involvement as in the previous experiment (Appendices 2.3). To ensure that the mobile Tobii eye tracker accurately interpreted where the participants were looking on the VDU, fixation locations had to be precisely mapped out onscreen for each participant. The need for this was established with the help of an explanation at the start of the experiment PowerPoint, and a predetermined co-ordinate system was created by way of calibrating participant fixations to the visual area of the screen (Figure 3.34).

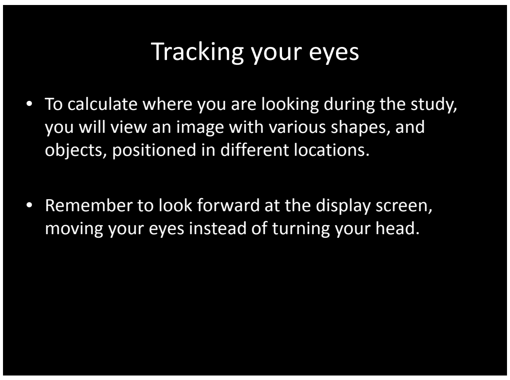


Figure 3.34. Calibration instructions for eye tracking displayed on the VDU.

After further required adjustments to the positioning of the eye tracker head set, a picture with various coloured shapes and objects was displayed on screen (Figure 3.35).

Figure 3.35. Eye tracker calibration picture displayed on the Dell U3011 VDU.

Participants were asked to maintain their fixation directly on the particular picture, whilst I, the experimenter, confirmed an accurate relationship between the fixation and the picture location. Only after all locations had been successfully matched, could an accurate recording of the participant's gaze path be triangulated throughout the session. The eye tracker was then set to record during the practice viewing and marking of stimuli (Figure 3.36) which occurred prior to question one.

A number of potential participants that were willing to take part in the experiment had to be rejected due to unsuccessful calibration of pupil fixations with the mobile eye tracker. This was largely due to the difficulties of calculating pupil fixations through surfaces with reflective properties, primarily the thick lenses of glasses over contact lenses. This meant that replacement participants had to be found for sessions at short notice and because of this, it was decided to not use individuals who wore glasses unless they could comfortably participate without.

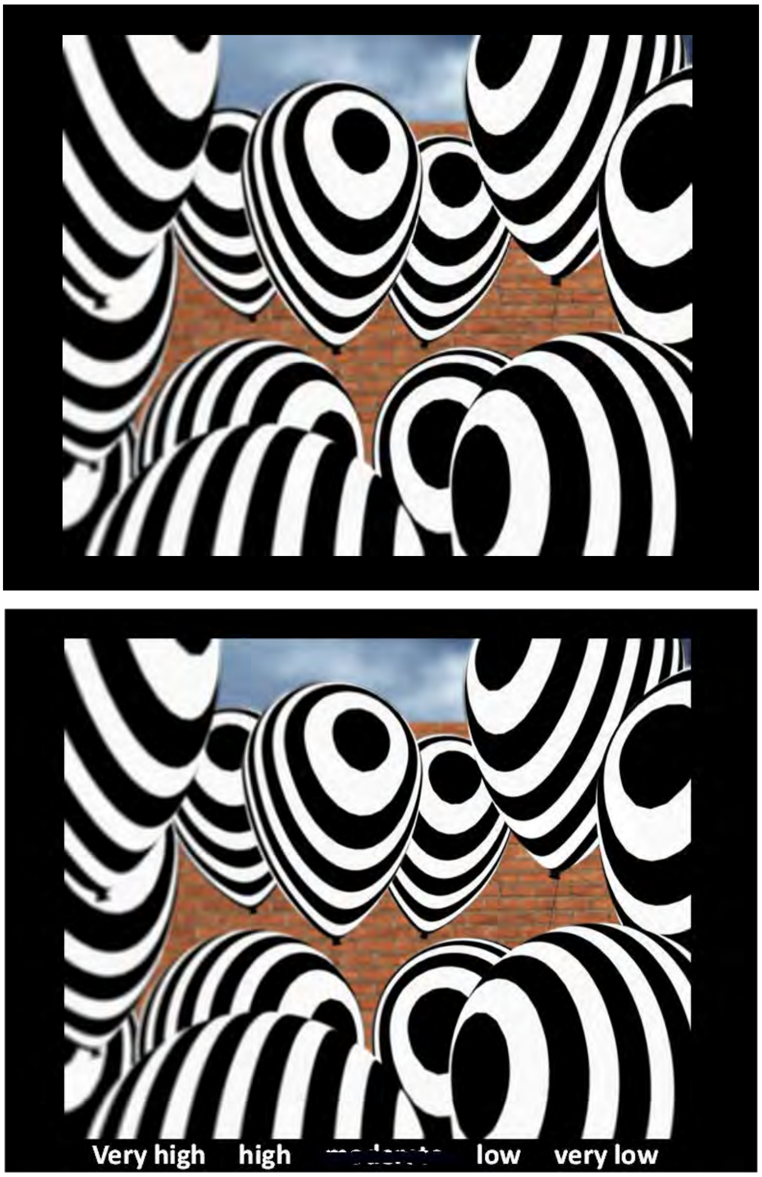


Figure 3.36. Practice viewing timed stimulus and highlighting an answer.

3.3.8 Findings and summaries of questions

Question 1 - Findings

The participant data for question one was brought into Photoshop and the identified focus locations for each of the three conditions (spatial radial blur, spatial radial disorder, and normal) were initially layered separately (Figure 3.37a, 3.37b, & 3.37c).

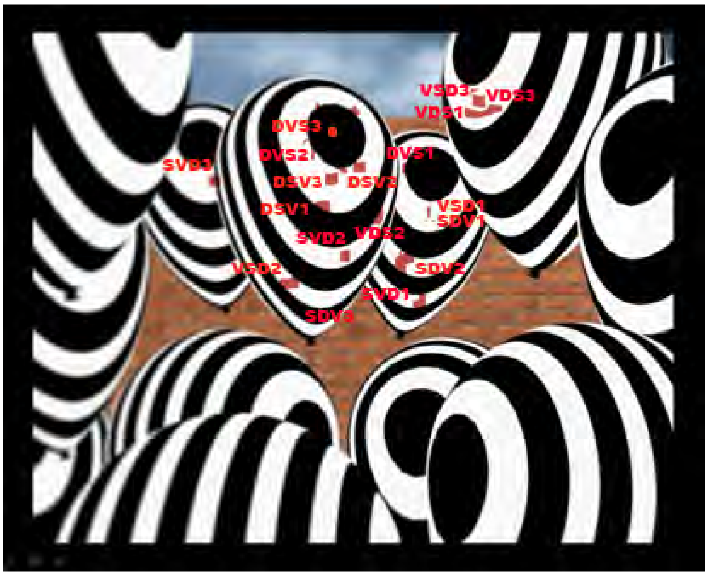


Figure 3.37a. The identified focus location of the 18 participants when viewing the spatial radial blur condition (D).

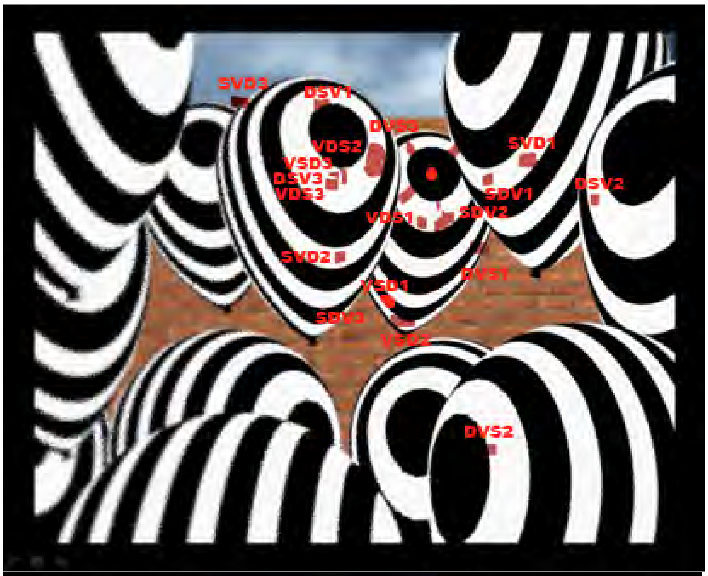


Figure 3.37b. The identified focus location of the 18 participants when viewing the spatial radial disorder condition (V).

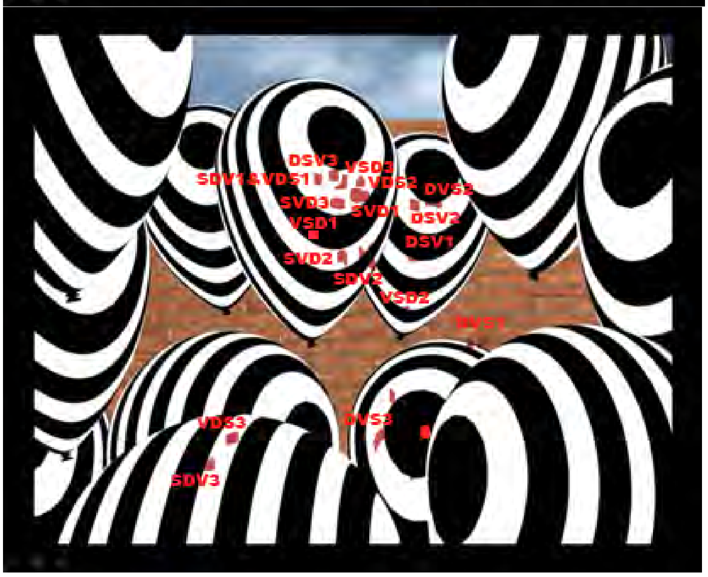


Figure 3.37c. The identified focus location of the 18 participants when viewing the normal condition (S).

Because the normal picture has no image effect, it was chosen to present the collective identified focus locations of participants when viewing all three conditions against the planned focus location (Figure 3.38). The planned focus location was shown using a pink dot located on a balloon on the right-hand side of the scene, corresponding to the origin of the radial image effect used in the spatial radial disorder and spatial radial blur conditions.

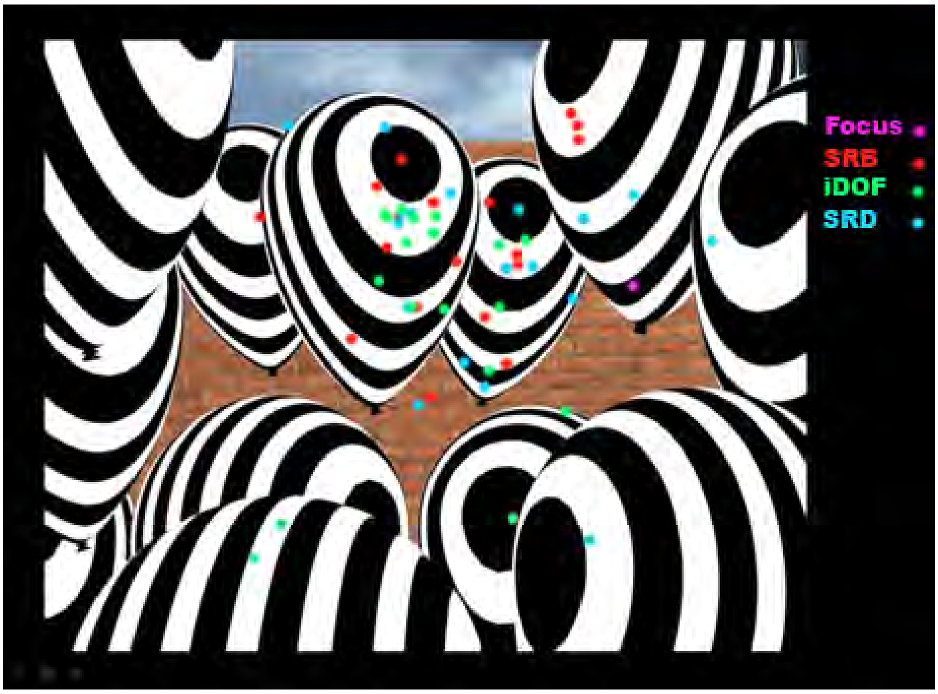


Figure 3.38. Combined conditions picture: Showing the planned focus location (Focus) used in spatial radial disorder (SRD) and spatial radial blur (SRB) conditions, and the collective identified focus locations of participants when viewing these conditions and the normal condition without a focus directing image effect (iDOF).

The combined conditions picture (Figure 3.38) shows a number of identified focus locations on the same balloon as the planned focus location when spatial radial disorder and spatial radial blur conditions are viewed. The preferred area for focus locations to be made by participants viewing the spatial radial disorder and spatial radial blur conditions appear similar: with blue and red focus markers found primarily on the complete balloon and its occluding balloon in the middle of the scene. This is a more ambiguous area in comparison to the planned focus location found in both of these conditions.

In contrast to spatial radial disorder and spatial radial blur conditions, the normal condition showed that participants identified focus locations were more centrally grouped, in this case, on the complete and occluded balloon within the scene. This closely-grouped cluster of identified focus locations could be due to the sky and wall background being clearly understood, allowing improved depth ordering and increased prominence of these balloons (Finkel and Sajda, 1992). In addition, it could be that the balloons being central objects are fixated on more often. Zelinsky (2012) reports the uncommonly robust central fixation bias of fixations clustering around the centre of scenes in videos and static images. In experiments conducted by Zelinsky (2012) he showed that a first fixation tends to be drawn to the centre of a picture. As Zelinsky notes: “...once drawn to the centre of the scene, search proceeded from that location as if gaze had initially been positioned at the centre” (Zelinsky, 2012, p.12).

The balloons on either side of the complete central balloon are similarly occluded but they have not maintained the same number of identified focus locations. It is uncertain whether the framing arrangement created by occluded balloons in the periphery could have produced this bias. However, participants have been consistent in ignoring the left balloon throughout the conditions. In experiments carried out by Nuthmann and Henderson (2010), participants were found to prefer to fixate within the centre of objects in scenes, which might be a reason for the complete and more visible occluded balloon being selected. A further study by Pajak and Nuthmann (2013) extended eye-movement understanding on fixated objects, with data supporting that the geometric centre of objects afford optimal visual processing, and that larger objects were more prone to be centrally viewed and revisited.

In addition, the normal condition received two identified focus locations on the bottom left balloon of the scene, which happens to be in a high falloff area for the blur and disorder conditions. Both of these identified focus locations came from different combinations of stimuli, with the normal condition being viewed first or last in sequence. Because the visual effects of spatial radial disorder and spatial radial blur were counterbalanced with the normal picture to produce six different viewing combinations of stimuli, the identified focus locations suggest that participants were not guided by previously viewed conditions.

Question 1 - Summary

The identified focus locations placed by participants whilst viewing the normal condition were mainly grouped on the complete and occluded balloon in the middle of the scene, with two identified focus locations found on a balloon that would look more indistinct in the other two conditions. Even though the spatial radial blur and spatial radial disorder conditions show a wider spread of identified focus locations, on the complete and occluded balloon in the middle of the scene, participants have not marked identified focus locations on balloons in very ambiguous areas. An important observation is that spatial radial disorder and spatial radial blur conditions both receive identified focus locations on the balloon with the planned focus location, whereas this area on the right-hand side of the scene does not receive any identified focus locations when viewed as a normal condition. The results suggest that the observed indistinct effect created by blur and disorder has influenced the focus of several participants towards the more detailed planned focus location within these pictures. In addition, although the spatial radial disorder and spatial radial blur conditions are both rendered with the same post-production tool values, the visual effect of disorder has produced closer identified focus locations to the planned focus location in comparison to blur.

It is necessary to highlight that the participants' identified focus locations have been discussed whilst viewing each condition in the same two-dimensional (X&Y) view. As previously explained, to reprocess a normal picture with Vision-Space image effects a linear depth map image of the same scene is essential. This is why new stimuli were built using computer aided design software (Blender). This allowed the computation of the normal picture Z depth information to produce radial (X, Y, & Z) image effects within reprocessed normal pictures. Because spatial radial disorder and spatial radial blur conditions both used radial image effects, consideration was given to using the three-dimensional computer generated scene to ascertain the differences in distance between identified focus locations and the planned focus location. To do this accurately, it would be necessary for identified focus locations to be moved along the Z axis until they reached line of sight balloons in the computer generated scene, where a measurement tool would be used to calculate spatial distance to the planned focus location.

Unfortunately, a distance plug-in was unable to be provided before the collaboration between Perceptual Technologies (Vision-Space) and Cardiff Metropolitan University ended, and the research focus changed to Fovography. Nevertheless, the identified focus locations were plotted within the computer generated scene using the combined conditions picture (Figure 3.38) as a visual X and Y axis reference for the positioning of each identified focus location. Next came the arduous task of moving each identified focus location along the Z axis and onto line of sight balloons, whilst maintaining the equivalent identified focus location pattern shown in the combined conditions picture (Figure 3.38). Once all the identified focus locations for the three conditions were positioned correctly onto line of sight balloons in the Z axis, it was important to add the capability to make a visual measurement from the planned focus location to the identified focus locations of participants. This was achieved by adding concentric circles from the planned focus location, which were horizontal to the ground plane and used the same unit scale with which the balloon scene was built (Figure 3.39).

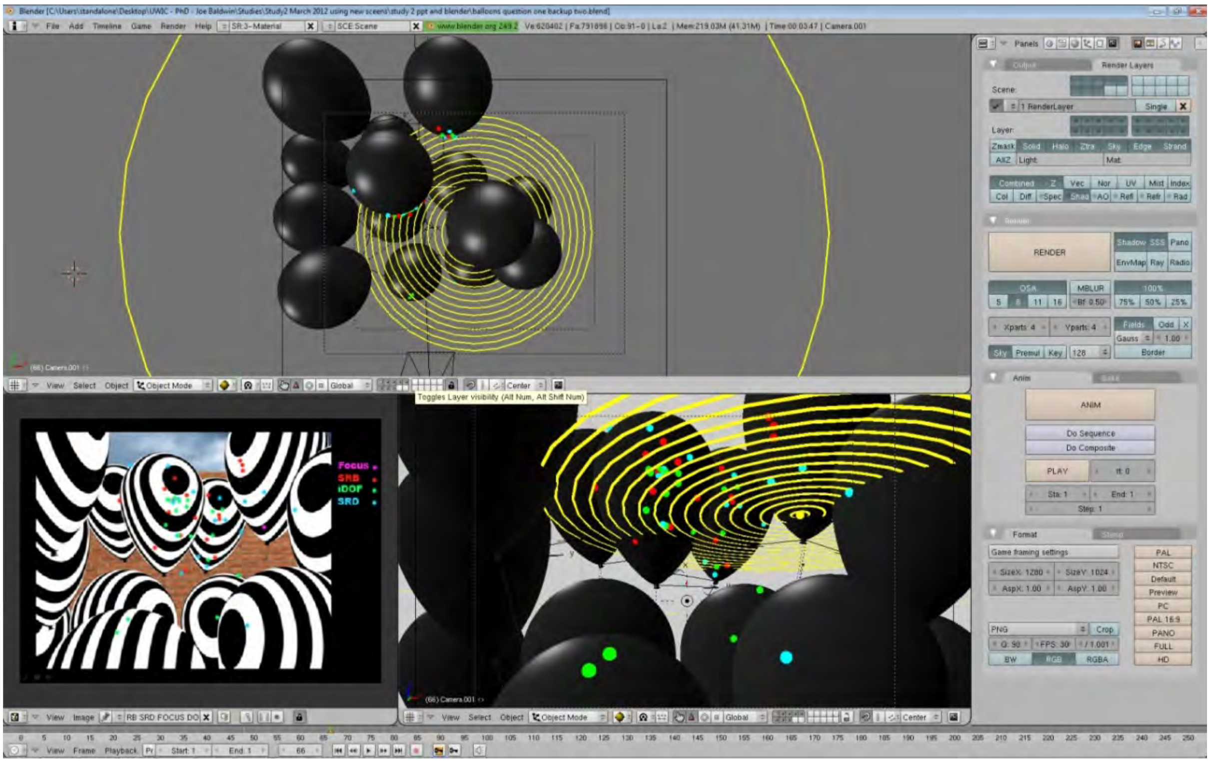


Figure 3.39. Blender print screen: the bottom left picture is the combined conditions picture, used as a visual reference for plotting the identified focus locations in the computer generated camera view, on its right. The top picture shows the variation of Z distance between identified focus locations positioned onto line of sight objects and the planned focus location (occluded by central balloons).

Then the identified focus locations were moved onto line of sight objects. They were found to be in front of and behind the planned focus location, as well as above, below, and to the right and left (Figure 3.40).

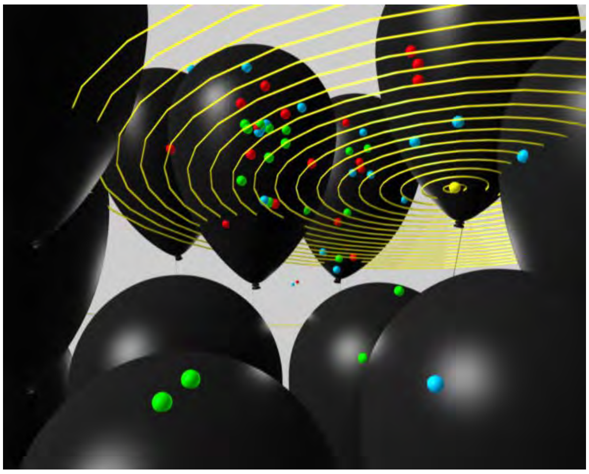


Figure 3.40. Identified focus locations placed onto line of sight objects.

Viewing the known diameter of concentric circles from above would allow identified focus location measurements to be made (Figure 3.41).

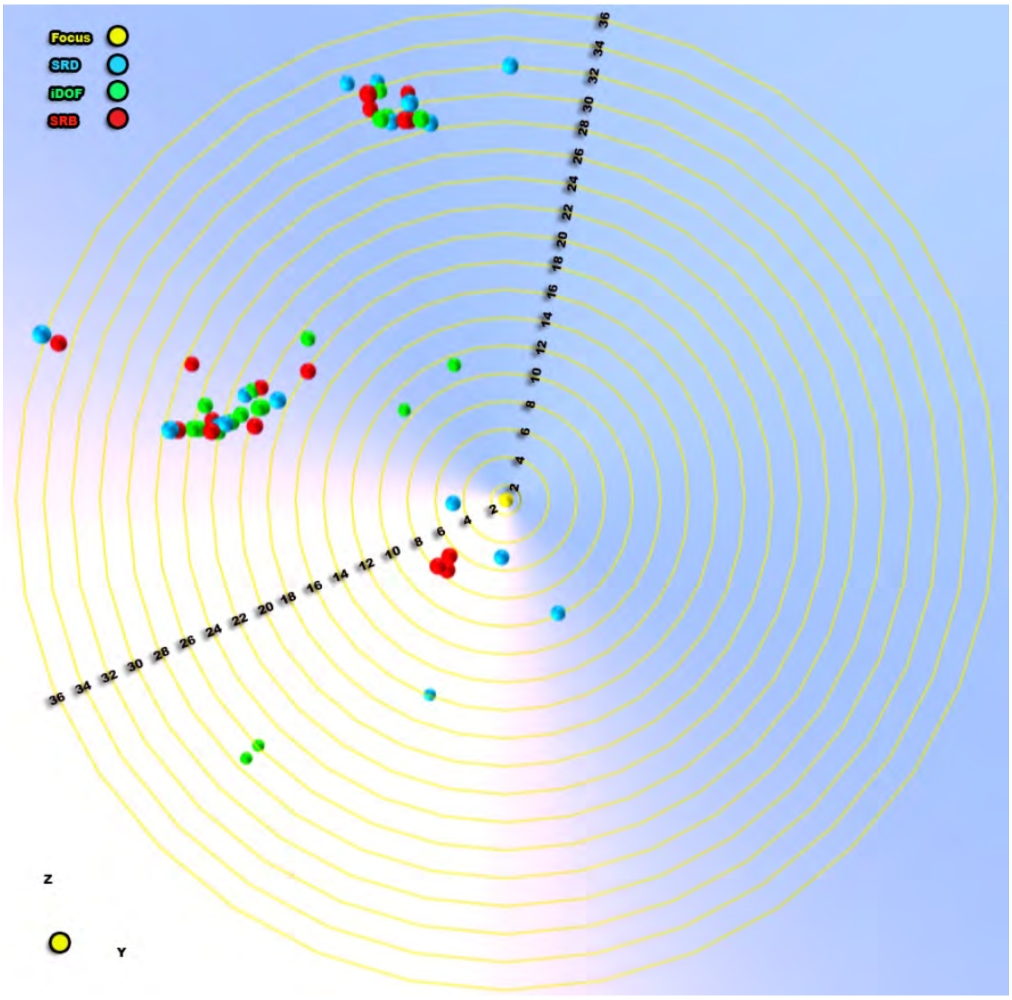


Figure 3.41. Blender print screen: Showing a top view of participants identified focus locations, with unit diameter measurements added from the planned focus location to allow a visual Z, & Y depth comparison to be made between conditions - (spatial radial disorder condition (SRD), spatial radial blur condition (SRB) and normal condition without a focus directing image effect (iDOF).

These combined Z & Y axis measurements would provide Z depth understanding which was absent in the combined conditions picture (Figure 3.38). However, without X axis data, a true radial comparison of exact distance inaccuracy (from the planned focus location to the identified focus locations of participants) is not possible. At best, only an accurate radial measurement for the identified focus locations is possible using the concentric circles, with identified focus locations below and above the planned focus location not being calculated. However, by using the planned focus location as an origin to rotate the concentric measurement circles within the computer generated scene, a combined X, Y, and Z radial measurement can be made visible for each identified focus location. This measurement would relate to the radially applied depth of disorder and blur, instead of planar akin to depth of field. The complexity of the manual procedure, however, would take some time to complete for the 54 identified focus locations to be accurate (Figure 3.42).

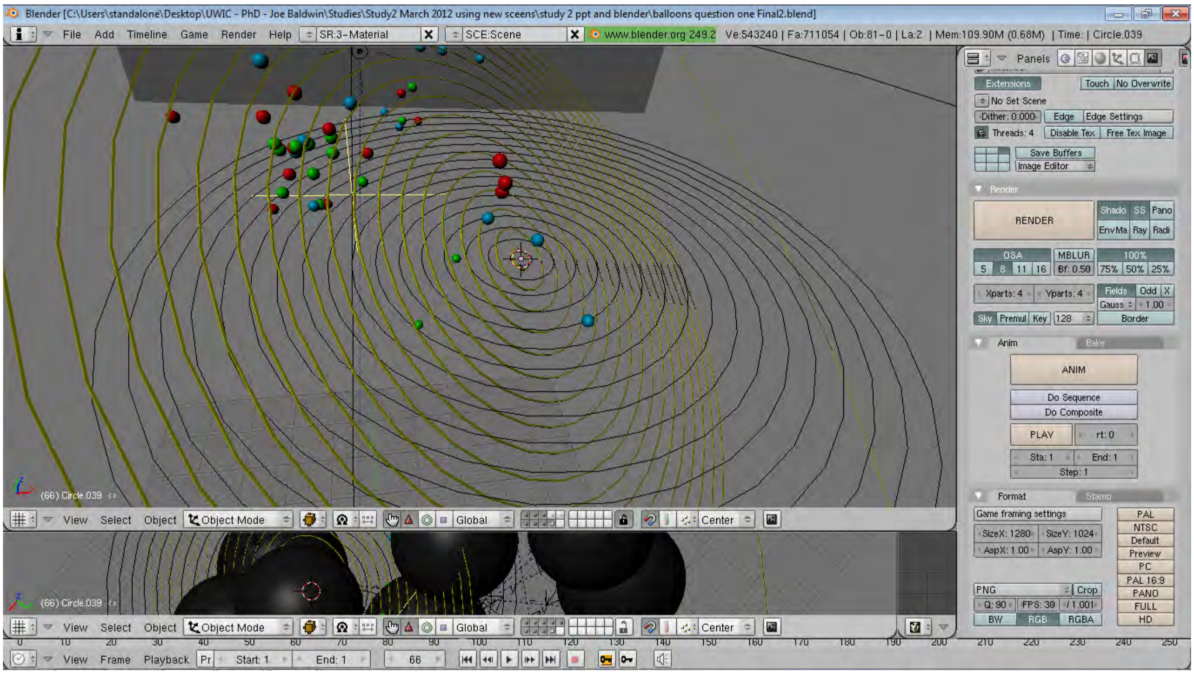


Figure 3.42. Blender print screen: the planned focus location used as an origin to rotate the concentric measurement circles within the computer generated scene, allowing a combined X, Y, and Z radial measurement for each identified focus location.

Because participants indicated where their focus was drawn to when viewing each condition as a two-dimensional picture, it was decided more appropriate to use the same X & Y axis to interpret participants' closeness to the planned focus location. This removed the need to explore the three-dimensionality of the computer generated scene.

Question 2 - Findings

The second question asked participants to highlight a competence rating which reflected the ability of each condition to direct participants' focus to the planned focus location. This involved re-viewing each condition, without the prompt of seeing their previously demarked identified focus location. The popular preference from these PowerPoint slides was then coded into a ranked number scale (Appendices 4.1) so that a 'mean' opinion within conditions could be calculated.

A Bar chart illustrating these mean competence ratings (Figure 3.43) shows the spatial radial blur and spatial radial disorder conditions as having a moderate rating; whereas, the mean competence rating for the normal condition was low. In addition, the normal condition has the greatest confidence interval (95%) with its boundaries not being as elevated as, and falling considerably lower than, the spatial radial disorder and spatial radial blur conditions.

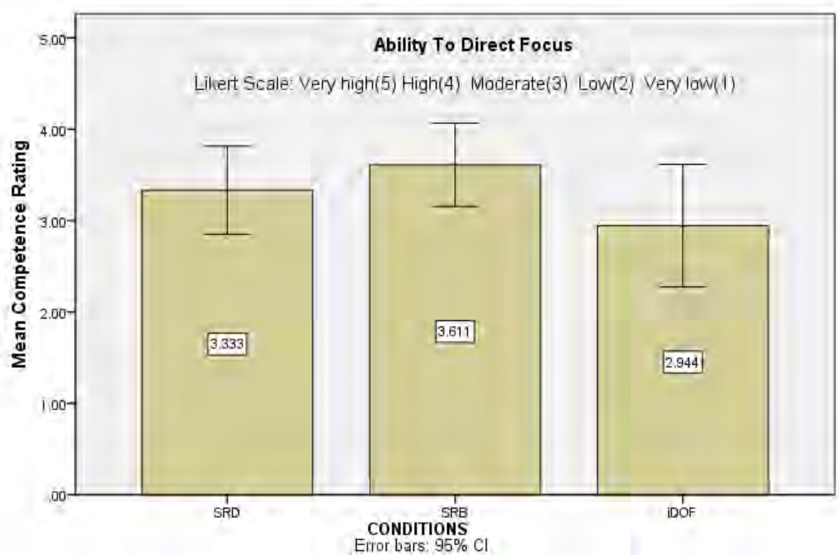


Figure 3.43. Bar chart comparing participants mean competence ratings, given to each condition in directing their focus to the planned focus location - (spatial radial disorder condition (SRD), spatial radial blur condition (SRB) and normal condition without a focus directing image effect (iDOF).

A one-way ANOVA was then applied to compare the mean differences within these three conditions, using statistics software (Appendices 5.1). The results of the one-way ANOVA showed no significant difference (Bonferroni tests, p>.05) between the participants' mean competence rating of each condition directing their focus to a planned focus location: F (2, 34) = 1.56, p = 0.23, n^2 = 0.084.

Question 2 - Summary

Even though there was no significant difference between the mean competence ratings of each condition in directing participants' focus to a planned focus location, a visual connection can be suggested when comparing these means alongside the combined conditions picture (Figure 3.38). This picture showed participants' identified focus locations when viewing the normal condition to be least connected to the planned focus location set in the spatial radial disorder and spatial radial blur conditions. As such, two identified focus locations were found in what would be an indistinct area in these two conditions. This coincides favourably with the normal condition not containing a focus directing image effect, and producing the highest participant uncertainty when assigning an accurate identified focus location.

A greater participant confidence that an accurate identified focus location had been chosen corresponds with spatial radial disorder and spatial radial blur conditions, both receiving identified focus locations close to the planned focus location. However, participants felt more certain that they had chosen an accurate identified focus location when viewing the spatial radial blur condition, rather than the spatial radial disorder condition; yet the visual effect of disorder produced closer identified focus locations surrounding the planned focus location.

The higher competence rating of blur than that of disorder could be due to the familiarity that participants have with blur over disorder in normal media. This is based on the psychological phenomenon known as the 'mere-exposure effect' (Zajonc, 1968; Bornstein, 1989), by which people tend to develop a preference for things merely because they are familiar with them. Through a variety of experiments, Zajonc (1968) showed that typically felt anxiety towards novel stimulus reduced with their repeated exposure and attitudes towards them enhanced. In a meta-analysis of 208 experiments, Bornstein (1989) showed the mere-exposure effect to be reliable and robust, producing a significant effect size $p<.05$: the effect was at its strongest when unfamiliar stimuli were presented briefly and reached its limits within 10-20 presentations.

Question 3 - Findings

The third question asked participants to re-examine the three conditions and describe the visual information which helped to direct their identified focus location in each case (Appendices 6.1). As with the previous question, this was without the prompt of seeing their previously demarked identified focus location. To aid participants in providing these descriptions, they were also able to highlight each condition simultaneously. A large proportion of participants' transcribed observations further supported the findings of question two. The visual properties of the normal condition were articulated as being unable to express an identified focus location, whilst participants felt that the pictorial cues created by spatial radial blur and spatial radial disorder conditions encouraged their directed attention towards unambiguous areas, and the planned focus location. It was interesting listening to participants discuss their reasoning behind giving directional value to the normal condition; however, these explanations were not as positive as the mean competence rating bar chart portrays (Figure 3.43).

The descriptive preference towards an identified focus location being increasingly directed by spatial radial blur and spatial radial disorder conditions are shown below, using the transcribed descriptions of participants VSD2 and VSD3 (Figure 3.44a). Additionally, the transcribed descriptions of participants SVD3 and DSV1 (Figure 3.44b) provide some explanation towards the normal condition being preferred to spatial radial disorder and spatial radial blur.

Participant VSD2:		
		
Spatial radial disorder (V): This one I put it there because that's the one that's actually clearer. Kind of that side of the image, because the other side is all blurry. So yes, this side, kind of this side, maybe a bit there as well, yes.	Normal picture (S): And then in this one I put it there, but I think that's because it's the centre again, but actually it is difficult to direct the focus, because they're all clear, none of them are blurry. That's why that one was low as well.	Spatial radial blur (D): Umm yes, so it's here. Umm, I think it's mainly the middle one because it's the first one I looked at, Just because that one is clearer. Should it have been there, just because it's not so much blurry.

Participant VSD3:		
		
Spatial radial disorder (V): So, my focus is around, well this balloon, and probably this side at least, because this is all blurred here, so basically kind of makes you think. And this is clearer so your eyes go towards that, and, yes.	Normal picture (S): Umm, in this image there isn't really any kind of directional focus, but because of the position of this balloon and because it is kind of, quite central, and to the front your focus I suppose it is towards, towards this one.	Spatial radial blur (D): And then this image again, umm, so these balloons here are all blurred, they're all blurred these balloons, but they're not, but they're not as blurred as the previous picture, the one before last. Umm, but your focus is still drawn towards this side of the screen because it's much clearer round here.
Figure 3.44a. Transcribed descriptions of participants VSD2 and VSD3, with highlighted conditions.		

Participant SVD3:		
		
Spatial radial blur (D): And then this is blurry, so I'm checking where I started from the first fixation, and then this isn't right because these are blurry, and that's a little off-putting until you get to this side where they become crisp again. So I always start at this point, and work around anti-clockwise I suppose.	Normal picture (S): The central balloon, and the edges are all nice and crisp around there, and then I work away around. I quite like drawing over things. Using the rest of the image, but start in the centre, and then work out.	Spatial radial disorder (V): Then this aggravates because it's gone all fuzzy. The edges are not crisp and that's a little aggravating, ha aha. And that's the same then with the rest of them as you work out, until you get to that side where they start. (Is that helping?) It's repeating where I started with the first picture, and then I'm thinking, oh that's annoying they're not.
Participant DSV1:		
		

Spatial radial disorder (V): I am looking at the balloon directly behind the central balloon, that's drawing me in because of its depth and the fact that the central balloon is immediately in front of it.	Normal picture (S): I am looking at this image again, the central balloon, and again it stands out because it is the only balloon which you can see in full compared the other balloons either side and also to the side of the image.	Spatial radial blur (D): OK, I am looking at the central balloon here, and it stands out because there are two balloons immediately behind it, so I guess it gives it depth, the image depth.
Figure 3.44b. Transcribed descriptions of participants SVD3 and DSV1, with highlighted conditions.		

Question 3 - Summary

In general, participants described the spatial radial disorder condition as having a clear area which their focus moved towards. Although the disorder was described as being irritating and blurrier than the other two conditions, participants described their focus as being directed towards the clear right hand side of the picture (from where the effect originated). Furthermore, the spatial radial blur condition was described as being 'off-putting' when looking directly at blur, but participants found this less problematic in comparison to disorder in the spatial radial disorder condition when their identified focus locations were directed towards the balloons on the right. The normal condition was consistently described by participants as having no directional focus, being the same throughout and presenting difficulty when choosing an identified focus location. It is thought because of this, participants mainly selected an identified focus location on the middle balloon based on its location within the picture, it being whole and its rank order occluding other balloons.

Of importance is that when participants were given extended time to provide an account of which visual information helped direct their identified focus location within each condition, the original identified focus locations shifted towards the clearer right -hand side in spatial radial disorder and spatial radial blur conditions. This evidence suggests that if participants had been previously familiar with spatial radial disorder and spatial radial blur conditions, a greater number of identified focus locations would have been marked closer to the planned focus location in question 1. With this, a higher mean competence rating in the ability to direct participants' focus to the planned focus location might also have been recorded for question 2. However, it is thought that the results for questions 1 and 2 would remain the same for the normal condition as the position of the identified focus location did not change during participant descriptions.

As such, a focus uncertainty may have been sustained because of the unambiguous nature throughout normal condition.

Question 4 - Findings

The fourth question asked participants to highlight a competence rating which reflected the ability of each condition to convey the different locations of the balloons. This Likert comparison data was coded into a ranked number scale (Appendices 4.2) so that a mean opinion within conditions could be calculated. A bar chart illustrating these (Figure 3.45) shows the normal condition as having a marginally higher mean score than spatial radial blur, with both of these conditions having greater means than the spatial radial disorder condition. However, all three conditions received a moderate mean, with the normal and spatial radial blur condition being at the high end of moderate and spatial radial disorder condition being at the low end. In addition, the confidence interval boundaries (95%) for normal and spatial radial blur conditions, indicated a high mean and did not fall below moderate. In comparison, the spatial radial disorder boundaries are reflected by a low mean and did not extend above moderate.

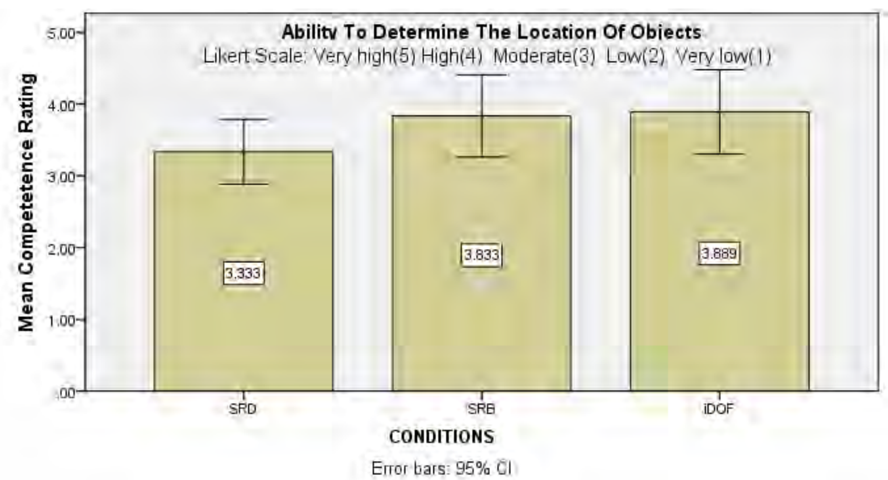


Figure 3.45. Bar chart comparing participants' mean competence rating of each condition to convey the different foreground and background location of balloons - (spatial radial disorder condition (SRD), spatial radial blur condition (SRB) and normal condition without a focus directing image effect (iDOF).

A one-way ANOVA was then applied to compare the mean differences within the three conditions, using statistics software (Appendices 5.2). The results of the one-way ANOVA showed no significant difference (Bonferroni tests, $p>.05$) between the mean competence rating of the ability of each condition to convey the different locations of balloons: F (2, 34) = 1.51, p = 0.24, n^2 = 0.082.

Question 4 - Summary

Even though there was no significant difference between the mean competence ratings of each condition when conveying different locations of balloons, participants felt more certain that they better understood these locations whilst viewing the normal condition. This compares unfavourably with the normal condition not containing a radial focus effect, which is suggested to provide the viewer with an improved understanding of the spatial locality of objects in relation to an object under fixation.

It is thought that when rating the different locations of balloons, a participants' gaze was not maintained on their identified focus location. This was not always the unambiguous planned focus location. As previously discussed in question 3, the visual effects of spatial radial disorder and spatial radial blur produced closer identified focus locations surrounding the planned focus location; yet since this clear focus location was not updated with each new fixation (in real-time), participants would come into direct contact with altering intensities of peripheral blur and disorder. This visual ambiguity is thought to be a valid cause for a greater understanding of different locations of balloons when viewing the clear normal condition.

The only difference between the spatial radial blur and spatial radial disorder conditions is the visual effect of disorder and blur; however, the spatial radial blur mean competence rating was higher than the spatial radial disorder condition. It is thought that the previously-mentioned 'mere-exposure effect', (Zajonc, 1968; Bornstein, 1989) by which people tend to develop a preference for things merely because they are familiar with them, could be a reason for the spatial radial blur condition receiving a higher mean competence rating in conveying the different foreground and background locations of balloons. In addition, the mean competence rating of the spatial radial blur condition closely matched the normal condition; this is interesting as participants should only be familiar with the normal application of blur through depth of field and not be aware of its radial application.

Question 5 - Findings

The fifth question asked participants to observe the three conditions again while recounting the visual information that helped them determine the different foreground and background locations of balloons (Appendices 6.2). As with previous questions, participants were asked to highlight the conditions whilst viewing them, to assist with their verbal descriptions. The transcribed descriptions of participant observations allied somewhat with the results from question four. They portrayed the spatial radial blur and normal conditions as corresponding to some degree with each other, and helping to provide an improved saliency of the location of balloons in comparison to the spatial radial disorder condition. Whilst the normal condition was described as being flat, its clear depiction of balloons and their boundaries allowed participants to make foreground and background judgements of the location of balloons through occlusion cues. Even though blur was mentioned when the spatial radial blur condition was viewed, it was also described as being clear and that occlusion cues were used to determine the location of balloons. However, the spatial radial disorder condition was described as being fuzzy, awkward, confusing, more blurred, and making the determining of the location of balloons more difficult. The descriptive preferences towards the normal and spatial radial blur conditions are shown using the transcribed descriptions of participants DVS3 and DSV1 (Figure 3.46a). The transcribed descriptions of participants SVD1 and VSD1 (Figure 3.46b) convey the normal condition less positively in determining the location of balloons in comparison to the spatial radial disorder condition; however, this was not as frequent as the mean competence rating illustrated in Figure 3.45.

Participant DVS3:

Spatial radial blur (D): Umm, It's this balloon, and this balloon, you can tell that they're in the, in the front and that they're clearly behind. Umm, and that one is clearly in the background to both that one and that one.	Spatial radial disorder (V): Umm, it's a bit more difficult but again this one is a big, perhaps you put it into perspective, those are clearly behind. Umm, I guess that one is in front of the other two, as is this one.	Normal picture (S): These are a bit flatter, but there's clearly overlap again so that one is in front of those two. Umm, and they, again that one overlaps again (sorry I ran out of time).
Participant DSV1:		
		
Spatial radial blur (D): I'm looking at the central balloon, and I notice the two balloons directly behind it. This one here on the right and this one, this one on the left and this one on the right, umm slightly obscured.	Normal picture (S): The clarity of these balloons, the one that I fixated on and also the surrounding ones, it's very clear. There's no blurring of the boundaries so it makes it a lot easier to determine the position of the balloons, in relation to the central one.	Spatial radial disorder (V): The lines of these balloons, the central one, but particularly the ones on the outside are more blurred; this makes it a bit more difficult to tell. Umm, it's the depth isn't it; to determine where they are in relation to the central balloon that I have been looking at.
Figure 3.46a. Transcribed descriptions of participants DVS3 and DSV1, with highlighted conditions.		

Participant SVD1:		
		
Normal picture (S): I guess it's similar to my early description, there's no, nothing that differentiates, oh more difficult. This is larger balloons up there. Up here it would appear to be the front and smaller at the back, but there's nothing in terms of the picture quality that helps you get a sense of depth.	Spatial radial disorder (V): Umm, whereas with this one you got a fuzzy image round the side and clearer, much clearer here, umm, and here to relate.	Spatial radial blur (D): Umm, so yes again, clear, clearer lines help give you a, umm sense of depth.

Participant VSD1:		
		
Spatial radial disorder (V): Yes, so straight away again, I am sort of drawn to this area. Umm, this, the way this sort of, the focus sort of decreases here, draws my eye a little bit, to sort of take that in quickly, and I can see this, this is a bit fuzzy, in front of my vision. Like if something was positioned close to my eyes, you know how it goes a bit out of focus.	Normal picture (S): Again, around here more for this one. I find it a bit confusing, I kind of want to go from here to here and then take in these bits of the side, and umm, yes, it's a bit more difficult to figure it all out, 'cos my eyes are trying to take it all in at once bit it's a bit too much.	Spatial radial blur (D): OK, yes, straight away around here again. Err, this soft focus again I think somehow draws my focus to this part of the image. This feels quite well defined so I feel that this is all close to me, this, this, and this. But the effect, this part here, this feels like the bit I'm being drawn too.
Figure 3.46b. Transcribed descriptions of participants SVD1 and VSD1, with highlighted conditions.		

Question 5 - Summary

Even though participants were asked to maintain their focus, it was established from their transcribed observations that foreground and background locations of balloons were decided through multiple focus locations and the use of occlusion cues. Despite the fact that the normal condition was described as looking flat due to being clear throughout, participants felt they had a better understanding of the foreground and background locations of the balloons. The unfamiliar radial introduction of blur was equally well understood, described as directing focus to the clearer area when deciding on foreground and background locations of balloons and without any reference to it looking flat. Participants continued to give indications of multiple focus locations through whole picture descriptions, but the increasing value of blur outwards from the planned focus location was hardly discussed. This suggests two things: firstly, that participants were barely distracted by viewing increasing levels of peripheral blur when deciding on the foreground and background locations of balloons; and secondly, that participants were able to maintain a prolonged fixation on their identified focus location as asked, whilst giving a comprehensive description. The participant descriptions of the spatial radial disorder condition also narrate its viewing in the same way as the spatial radial blur condition. However, the introduction of disorder became a noticeable distraction to participants when viewed directly and deciding on the foreground and background location of balloons. As mentioned earlier, the clear focus location was not updated with each new fixation (as it would be in real-time); therefore, direct viewing of peripheral information (especially unfamiliar disorder) is expected to be disconcerting in comparison to the participants' familiarity with viewing blur in pictures. Some participants discussed viewing the spatial radial blur and spatial radial disorder conditions whilst looking at the planned focus location. This meant that the spatial intensity of blur and disorder (on the foreground and background locations of balloons) was being viewed as intended - that is, peripherally.

Question 6 - Findings

Question six asked participants to select a competence rating for each condition based on the extent to which they felt 'factored into' the scene. As with the other questions, this data was coded into a ranked number scale (Appendices 4.3) so that a mean opinion could be calculated. A bar chart illustrating these mean competence ratings (Figure 3.47) shows the spatial radial blur and normal conditions attaining a moderate mean, with the spatial radial blur condition being favoured.

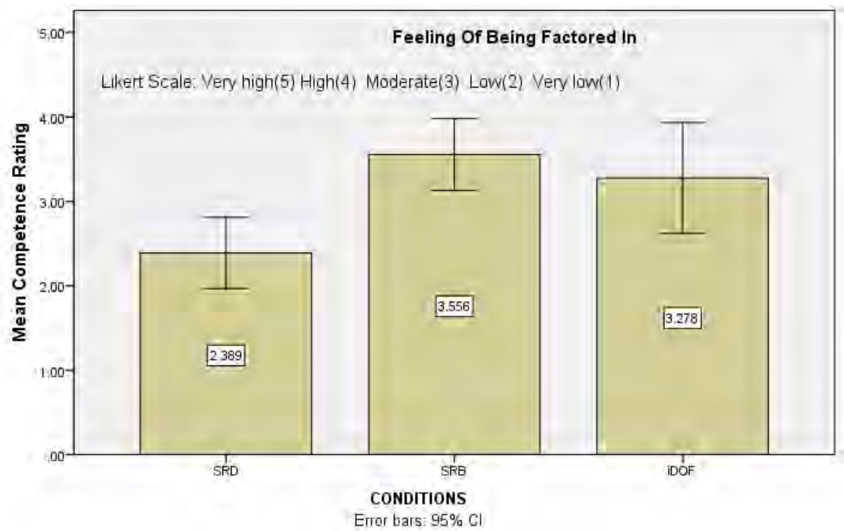


Figure 3.47. Bar chart comparing participants' sensation of feeling factored into each condition - (spatial radial disorder condition (SRD), spatial radial blur condition (SRB) and normal condition without a focus directing image effect (iDOF).

The spatial radial disorder condition received a low mean competence rating; less than the normal condition and also significantly less than the spatial radial blur condition.

Additionally, although the confidence interval boundaries (95%) for the spatial radial disorder condition did not extend above its low mean, they did descend into a very low mean. Furthermore, these boundaries for the spatial radial blur condition did not fall below moderate and also extended into a high mean.

A one-way ANOVA was applied to compare the mean differences within these three conditions, using statistics software (Appendices 5.3). The results of the one-way ANOVA showed a significant difference (Bonferroni tests, $p<.05$) between the Mean competence rating of conditions factoring participants into the scene: F (2, 34) = 4.88, p = 0.014, n^2 = 0.223. A post-hoc test conducted (Bonferoni) showed that there was only a significant difference (p = .001) between the spatial radial disorder and spatial radial blur conditions.

Question 6 - Summary

The spatial radial image effect, which Vision-Space theory suggests is tasked to allow spatial understanding in the moment and accounts for peripheral vision, is received better than and worse than the normal condition, depending on the use of blur or disorder. A higher competence rating was given to the spatial radial blur condition in relation to the extent to which participants felt ‘factored into’ the scene. This was significantly better than the spatial radial disorder condition, which is thought best explained through the familiarity that participants have with viewing blur in pictures instead of disorder. This is based on the psychological phenomenon known as the ‘mere-exposure effect’ (Zajonc, 1968; Bornstein, 1989), by which people tend to develop a preference for things merely because they are familiar with them. Even though there was no significant difference between the mean competence rating of the spatial radial blur and normal conditions, a preference towards the spatial radial blur condition suggests that using a spatial radial image effect to apply disorder is not the distracting factor within the spatial radial disorder condition.

The unambiguous normal condition represents the way in which Vision-Space theory suggests how central attention is tasked. As previously discussed, because participants did not maintain a planned focus location, they came into direct contact with altering intensities of blur and disorder. Therefore, by the normal condition being unambiguous throughout, this could be a reason for participants feeling ‘factored into’ the scene. Even though, in comparison to the normal condition, the spatial radial blur condition did not create a significantly greater feeling of being in the scene, it was favoured by participants. This suggested that the spatial radial image effect can have a positive influence, when the more commonly observed blur effect is applied.

Question 7 - Findings

Question seven asked participants to assign a competence rating to each condition that reflected the ability of each to suggest a sensation of spatial awareness within the scene, which was used as an alternative indication to the perception of depth. This Likert data was coded into a ranked number scale (Appendices 4.4) so that a mean opinion within conditions could be calculated. The bar chart illustrating these mean competence ratings (Figure 3.48) showed the spatial radial blur and normal conditions as receiving a moderate mean, with the spatial radial blur condition being again favoured by participants. The spatial radial disorder condition received a low mean competence rating, which was less than the normal condition and also significantly less than the spatial radial blur condition. Additionally, the confidence interval boundaries (95%) for the spatial radial disorder condition ranged from a low mean and extended into moderate, while the mean boundaries for the spatial radial blur condition did not decrease below its competence and elevated into high.

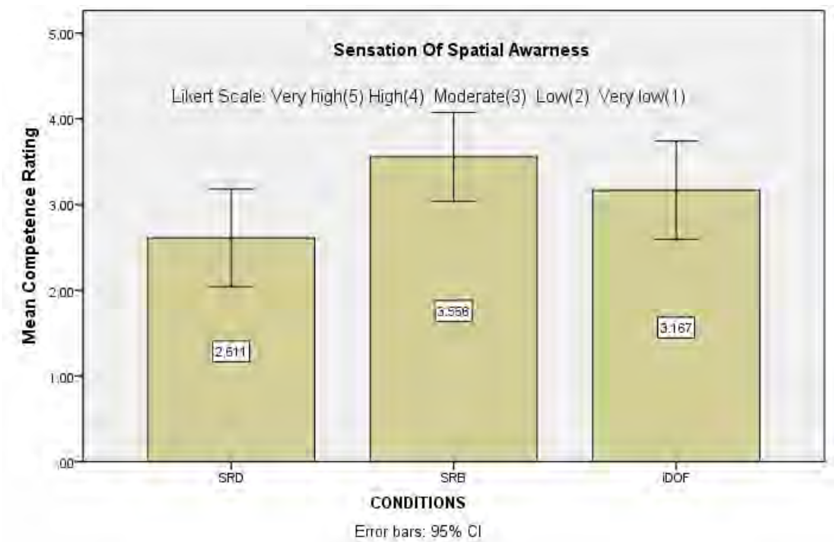


Figure 3.48. Bar chart comparing participants’ sensation of spatial awareness between conditions - (spatial radial disorder condition (SRD), spatial radial blur condition (SRB) and normal condition without a focus directing image effect (iDOF).

A one-way ANOVA was then applied to compare the mean differences within these three conditions, using statistics software (Appendices 5.4). The results of the one-way ANOVA showed a marginal significant difference (Bonferroni tests, $p>.05$) between the Mean competence rating of spatial awareness within conditions: $F(2, 34) = 2.76$, $p = 0.08$, $n^2 = 0.140$. A post-hoc test (Bonferoni) was conducted which showed that there was only a significant difference ($p = .016$) between the spatial radial disorder and spatial radial blur conditions

Question 7 - Summary

Vision-Space theory hypothesises that the spatial radial image effect provides an observer with spatial cues from a fixation point outwards, allowing a range of spatial judgements to be made, improving the perception of depth (in a picture) similar to that experienced first-hand. However, depending on the application of blur or disorder, spatial judgements have been shown to be better and worse received than the normal condition. The participants' higher mean competence rating for the spatial radial blur condition over the spatial radial disorder condition was also significantly different in this question, which is possibly explained by participants' everyday experience of blur, rather than disorder, in pictures. This is based on the psychological phenomenon known as the 'mere-exposure effect' (Zajonc, 1968; Bornstein, 1989), by which people tend to develop a preference for things merely because they are familiar with them. Even though there was no significant difference between the mean competence rating of the spatial radial blur and normal conditions, a preference towards the spatial radial blur condition once again suggests that the spatial radial image effect being used to apply disorder was not the distracting factor within the spatial radial disorder condition.

As previously discussed, participants not maintaining a planned focus location came into direct contact with altering intensities of blur and disorder. This could be the reason for participants better understanding the space presented to them through the unambiguous normal condition. However, even though the spatial radial blur condition did not create a significantly greater sensation of spatial awareness, it was favoured by the majority of participants. As such, this suggests that the spatial radial image effect is more positively influenced by the use of blur. The mean competence rating for the spatial radial disorder condition improved when judging surrounding space, in comparison to the previous mean competence rating for participants feeling 'factored into' the scene. In addition, the mean competence rating gap between the normal and spatial radial blur conditions widened, with a lessening of difference seen between the spatial radial disorder and normal conditions. This could suggest that the spatial radial image effect reduces the prerequisite for the observer to track throughout the scene (thereby not having to make multiple fixations) in order to understand the space being presented, as in normal pictures.

Question 8 - Findings

Question eight asked participants to assign a competence rating to each condition based on how much they felt at ease viewing the scene. This Likert comparison data was then coded into a ranked number scale (Appendices 4.5) so that a mean opinion within conditions could be calculated. The Bar chart illustrating these mean competence ratings (Figure 3.49) shows the spatial radial blur and normal conditions as receiving a moderate mean with the normal condition being favoured.

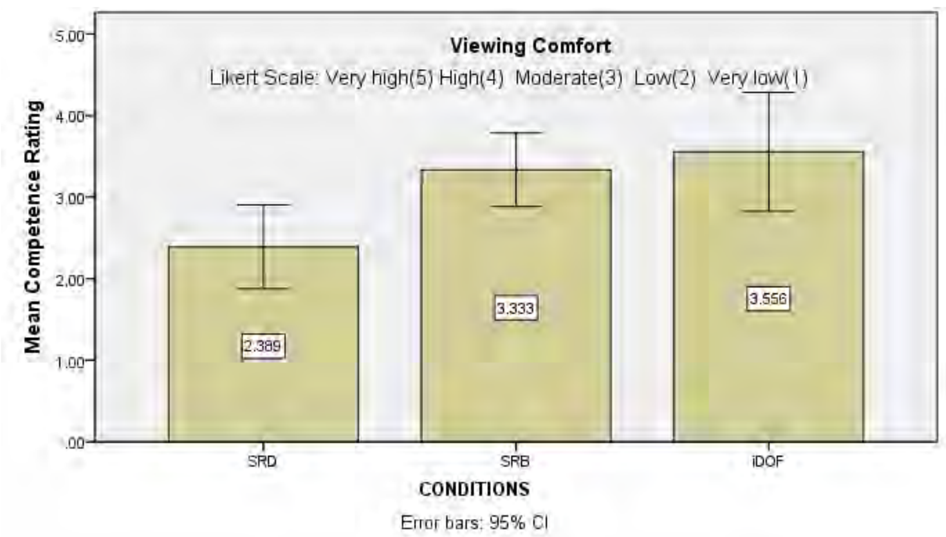


Figure 3.49. Bar chart comparing participants' comfort whilst viewing each condition - (spatial radial disorder condition (SRD), spatial radial blur condition (SRB) and normal condition without a focus directing image effect (iDOF).

The spatial radial disorder condition received a low mean competence rating, which was significantly less than the spatial radial blur and normal conditions. In addition, although the confidence interval boundaries (95%) for the spatial radial disorder condition did not extend above its low mean, they did descend into very low. The mean boundaries for the spatial radial blur condition fell to the same level as the spatial radial disorder confidence boundary and did not extend beyond a moderate competence rating. However, the confidence boundaries were larger for the normal condition, and managed to extend into a high mean.

A one-way ANOVA was then applied to compare the mean differences within these three conditions, using statistics software (Appendices 5.5). The results of the one-way ANOVA showed a significant difference (Bonferroni tests, $p<.05$) between the mean competence rating of the viewing comfort within conditions: F (2, 34) = 4.08, p = 0.026, n^2 = 0.194. A post-hoc test (Bonferoni) showed that there was a significant difference (p = .037) between the spatial radial disorder and spatial radial blur conditions, while a marginal difference was present (p = .063) between the spatial radial disorder and normal conditions.

Question 8 - Summary

Participants unable to locate the planned focus location within the spatial radial blur and spatial radial disorder conditions, would be deciding on a viewing comfort rating whilst searching within each condition. This allowed direct visual contact with altering intensities of blur and disorder, which should have been viewed indirectly in their peripheral vision. This, in conjunction with participants' awareness of their visual attention being unambiguous, led to the highest competence rating being given to the normal condition.

It was surprising to discover that participants gave the spatial radial blur condition a similar mean competence rating to the normal condition. This could be explained by the participants' familiarity with viewing pictures with blur, that the increasing levels of blur were not distracting, and an identified focus location was considerably better maintained. Because there was no significant difference between the normal and spatial radial blur conditions, but a significant difference was found between the normal and spatial radial disorder, it is suggested that disorder becomes more distracting than blur when applied to the spatial radial image effect.

Question 9 - Findings

Question nine asked participants to observe the three conditions for a final time and describe the visual information which contributed to a sense of viewing the scene first-hand (Appendices 6.3). Whilst each condition was being viewed, participants were again asked to highlight the scene in an effort to assist with their verbal descriptions.

A stronger connection was evident between the transcribed participant observations and the viewing comfort results from question eight than was evident from questions six and seven. The normal condition was generally described as encouraging the greatest naturalistic appreciation of the scene. This was closely followed by the spatial radial blur condition, with participants being their least confident whilst viewing spatial radial disorder. The normal condition was described as being without depth of field, making the scene feel flat and having a strong all over sense of focus. However, the consequence of this may explain the balloons being described as sharp and crisp, which made participants feel that this condition was naturalistic. The spatial radial blur condition was described by some of the participants as being slightly uncomfortable, like having an eye problem, but more understandable than the spatial radial disorder condition. Nevertheless, it was said to direct focus to the detail in the unambiguous area and produce a more naturalistic feeling at times than the normal condition. In general, the spatial radial disorder condition was depicted by participants as being the least naturalistic condition: described as less clear, less sharp, less focused, less crisp, more blurred, smudged, awkward, confusing and making more difficult the determination of the peripheral balloons' edges.

The descriptive preference towards the normal and spatial radial blur conditions over spatial radial disorder are shown below using the transcribed descriptions by participants DVS2, SVD3 and DVS3 (Figure 3.50a). In addition, the transcribed descriptions by participant VDS1 show the only positive reaction to spatial radial disorder (Figure 3.50b); while recording an ambivalent reaction towards the spatial radial blur and normal conditions.

<table>
<tr><td colspan="3">Participant DVS2:</td></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td>Spatial radial blur (D): Umm, Only just noticed there’s a string on this particular balloon. That makes it that gives it a detail, it’s a minor detail, but it helps to add to the realism of the screen.</td><td>Spatial radial disorder (V): This one doesn’t feel as, as real. Umm, it could be my eyes playing tricks on me but it looks less focused, less, less crisp and sharp around these points, especially down this side.</td><td>Normal picture (S): Yes, as this one is a lot crisper, a lot sharper. Umm, the only thing that’s not as I would expect, is I’ve got a strong sense of focus on these balloons here, but the wall is also crisp, so the depth of field of (the) perception isn’t what I would perceive my eyes to actually be like.</td></tr>
<tr><td colspan="3">Participant SVD3:</td></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td>Normal picture (S): Umm, this one here feels like you could be holding these balloons, and they are very close to you. You can clearly see exactly where they are in relation to each other, and the background environment. They’re nice and sharp, like they should be, as long as you have your lenses in</td><td>Spatial radial disorder (V): This, this smudging around the edges, I don’t like it, it doesn’t look naturalistic. It wouldn’t look like that. Whereas these do and if. It’s not naturalistic at all. It wouldn’t have these edges if this was a real experience.</td><td>Spatial radial blur (D): This one’s not too bad. This one could be half; one lens in and one lens out maybe. You could, you could be holding these balloons and one of your contact lenses has fallen out, or you need to go and get your eyes checked out. This one isn’t as uncomfortable and slightly naturalistic, but not as much as the first one.</td></tr>
<tr><td colspan="3">Participant DVS3:</td></tr>
<tr><td></td><td></td><td></td></tr>
</table>

Spatial radial blur (D): My eyes are always drawn to here, which naturally puts these into, out of focus which makes it a bit more natural. But then this part here is skewing me a bit, it's a bit too blurred.	Spatial radial disorder (V): Umm, It's too blurry here, here, doesn't feel naturalistic at all. Balloons wouldn't be blurry.	Normal picture (S): Even when I look here, I can tell it's not too burry over there. I guess they're just too flat, there's no depth, if that makes sense (yes). You can tell one's on top of the other there, but there's no depth, no depth to it.
Figure 3.50a. Transcribed descriptions of participants DVS2, SVD3 and DVS3, with highlighted conditions.		

Participant VDS1:		
		
Spatial radial disorder (V): Umm, I think this is slightly naturalistic. Umm, just cos I think when things are really up close to you, like these ones seem like they would be. They're not always that clear, well for me anyway. So I think because they are a little bit like that, it makes it seem sort of more real.	Spatial radial blur (D): Umm, this I suppose doesn't, unless you have bad vision, because they're so blurred. It just doesn't seem natural to me, these ones over here. These, this side of the picture more so, because these are clearer, don't know, just a different kind of blurred, as if you look, you have glasses on and you shouldn't or something.	Normal picture (S): Umm, these seem quite real. Umm, I'm not sure about these over here, just; you can't kind of work out that they're balloons. They just almost look like loads of black lines all next to each other, so it doesn't seem that natural.
Figure 3.50b. Transcribed descriptions of participant VDS1, with highlighted conditions.		

Question 9 - Summary

There is a relationship between participant observations concerning how real each condition appears and the comfort ratings of question eight. The descriptions continue to suggest that participants' gaze moves from an identified focus location, and multiple fixations are used to build depth cues and understanding of each condition. The introduction of disorder and blur when viewed directly in the spatial radial disorder and spatial radial blur conditions became a noticeable unnatural distraction for participants. The disorder was seen as being more disconcerting in comparison to blur, suggested to be due to the psychological phenomenon of the 'mere-exposure effect', (Zajonc, 1968; Bornstein, 1989) by which people tend to develop a preference for things merely because they are familiar with them. If it had been possible to update participant's focus locations whilst viewing spatial radial blur and spatial radial disorder within a real-time setting, the possible effect of familiarity taking place in the experiment might have been removed. Participants' descriptions of the normal condition suggest that this was the most natural and comfortable condition to view, even though there were frequent suggestions that it was without depth and flatter than it would be in real life. However, participants also described the spatial radial blur condition as being naturalistic when their focus was directed to the clear area of the planned focus location, allowing sharp detail to be seen along with an improved understanding of spatial awareness. This outcome is suggested to be caused by the spatial radial image effect (spatial intensity) being viewed peripherally as intended. When viewed in this way, participants are also suggested to have an increased sensation of being 'factored into' the scene and when making spatial judgements, as shown in the results to questions six and seven.

4 Fovography research

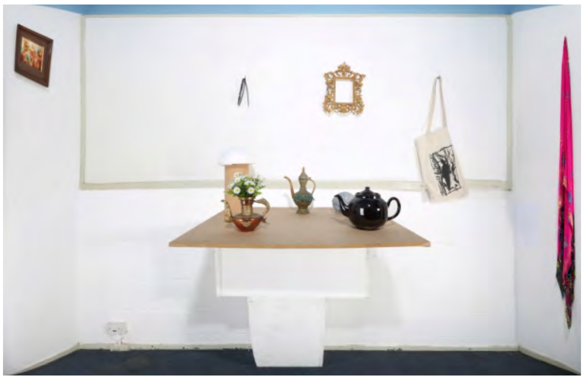
Shortly after the conclusion of experiment 2, at the mid-point in the research, the collaborative relationship between John Jupe and Cardiff Metropolitan University ended. At this time it was decided that the Fovography imaging theory would be investigated in place of the Vision-Space imaging theory in a number of further experiments.

The Fovography imaging theory also proposes an alternative visual experience to linear perspective, in order to improve the perception of depth and for achieving better direction of visual attention in pictures (Pepperell and Burleigh, 2014). A Fovography picture aims to proportionally represent the full scope of the binocular human visual field, which is approximately 135 degrees vertically and 200 degrees laterally (Hershenson, 1999). In comparison to the human visual field, a normal photograph taken with a 50mm lens using 35mm film or a sensor subtends to 43 lateral degrees (Pepperell and Haertel, 2014). This rectangular picture format is used in most everyday media types, and is unable to contain close proximity objects and peripheral information to the same extent as experienced in human vision, which is hypothesised to improve the perception of depth in pictures. In order to test the validity of both claims, experiments were carried out to see if pictures created using the Fovography imaging method improved the perception of depth and directional focus, in comparison to geometrical perspective pictures (normal photographs).

As there are many image effects involved in the Fovography imaging method it was decided to initially study a key variable, namely the compression image effect, and then compare complete Fovography pictures (containing additional image effects) against their corresponding normal photograph. The compression image effect (Figure 4.1) was chosen, based on Pepperell's hypothesis that by including peripheral visual information (normally excluded from photographs) and modifying the proportions of objects (to produce a closer representation of the scope of the human visual field), the directional focus and perception of depth is improved in comparison to a normal photograph.

Two pilot experiments were carried out comprising of normal photographs and compression image effect pictures, both with and without supplementary blur image effects. The task attached to the first of these pilot experiments asked participants to choose within each picture an initial object focused on, to explore if directional focus was improved. The task in the second pilot experiment asked participants to estimate the distance (cm) from the front of a nominated object to the back wall, to explore if the apparent presence of distance in a picture could be measured with improved accuracy. In both of these pilot experiments, the comparative visual tasks provided inconclusive data, which can be seen in Appendices 11.

Normal photograph



Compression picture

Figure 4.1. Showing a normal photograph on the left and a compression layout picture on the right. The compression picture was made through joining multiple photographs together to produce a larger field of view, and then modifying the size of objects to denote the human visual field. Note the additional space that is represented in the peripheral areas of the Compression picture compared to the Normal picture.

Further methodologies were developed which provided significant results from eye tracking data and stimuli predilection. Experiment 3 and 4 explored the compression image effect using stimuli based on a magazine advertisement (Bombay Sapphire), in order to determine whether the Fovography process could be used to improve directional focus, and the perception of depth in advertising pictures. The stimuli were presented in four conditions: two normal photographs and two compression pictures, with one of each including a depth of field blur image effect, commonly used in both film and photography as a depth cue (Lin and Gu, 2007; Nefs, 2012; Mauderer et al., 2014) and to direct visual attention (Wang et al., 2001; Ware, 2008).

Experiment 3 recorded participants' eye tracking data whilst they familiarised themselves with the four conditions. This allowed the participants' visual attention to be measured within areas of interest assigned to matching locations in each of the conditions. A variety of gaze analysis comparisons were made to explore the hypothesis, that the compression image effect picture improves directional focus in comparison to a normal photograph, and considered the influence of the image effect depth of field blur in each case.

Experiment 4 used the same four conditions shown in every paired combination, with participants asked to decide which gave the greatest sensation of background distance from a focus object. This experiment explored whether the compression image effect was able to increase the perception of depth over a normal photograph as hypothesised, and considered the influence of the image effect depth of field blur in each case.

Experiment 5 presented a range of normal photographs each paired with their complete Fovography picture of the same scene (containing the image effects compression, blur and object doubling), and participants were asked to choose which gave the greatest sensation of depth. This offered insight into the combined use of image effects used in a Fovography picture, hypothesised to improve the perception of depth in comparison to normal photographs. Further gaze analysis comparisons were also carried out in order to explore the claim that directional focus would also be improved.

4.1 Stimuli produced for experiments 3 and 4

Whilst the method of digitally generating Fovography pictures (to apply the collective function of various observed visual effects) was first being developed, the range of potential benefits and commercial applications of the Fovography process were discussed with Pepperell. Magazine advertising was one area where it was anticipated that a Fovography picture would increase product promotion through improved saliency of the main object being advertised, and increased perception of depth, and greater visual impact. The Bombay Sapphire advertisement below (Figure 4.2) became of interest during this conversation due to its novel use of blurring, which provided the viewer with a number of unambiguous attention areas such as the text on the bottle, the glass, and the header and footer text. This arrangement of image blur is unlike the conventional use of depth of field blur which underlines a single detailed area within a photograph, and which is analogous to natural vision.

Figure 4.2. The Bombay Sapphire advertisement uses localised object and border blurring. This gives the viewer a number of unambiguous attention areas, which is unlike the single focus area produced by photographs that employ depth of field blur which is similarly produced in natural vision.

It was decided to attempt to remove the header, footer and various areas of localised blurring before adjusting this picture with the compression image effect for comparative visual tests, with and without a depth of field blur image effect. However, it was not possible to amend the blurring of objects used to establish attention areas in the Bombay Sapphire advertisement, nor make the picture contain the full extent of the human visual field. It was therefore decided to create a similar advertisement so that a compression picture with a more naturalistic visual field could be created alongside a normal photograph, for visual comparison with and without a depth of field blur image effect. It is important to mention that Pepperell's documented enlarging of an attended to object within the compression image effect was negated across conditions, as it was appreciated that this image effect would cause additional influences to occur.

To produce pictures with Fovography image effects the approach outlined in Section 1.1.2 was followed, which meant that the Bombay Sapphire scene was staged in the studio and a lighting rig was used to remove unwanted background shadow effects from the environment. Pepperell drew the scene from a seated position, with his attention focused on the upper half of the bottle and rim of the glass. This drawing

(Figure 4.3) shows an enlarging of both these areas and the gradual compression of the surrounding objects, with an increasing amount of disparity towards the peripheral visual field.

Figure 4.3. A drawing of the Bombay Sapphire bottle scene by Pepperell. This drawing shows Pepperell's visual impression of the scene, showing the change in scale of objects within his main focus area (Bombay Sapphire bottle and glass), and information becoming increasingly compressed, doubled and indistinct towards peripheral limits.

Next, multiple photographs of the Bombay Sapphire scene were taken from the same viewed position that the drawing was made. These photographs were then imported into Photoshop, manipulated, and combined to show the same visual field depicted in the drawing, which covered a wider field of view than a can be obtained with a single line of sight photograph. The picture was then further adjusted using Photoshop so that it matched the compression detail in the drawing. To ensure that the Bombay Sapphire bottle and glass in the intended focus area remained the same size between conditions, the line of sight photograph was used as the normal photograph, and the pictured bottle and glass within it were used in the compression picture showing the same picture properties.

Pepperell hypothesises that the compression image effect would improve directed attention to the bottle and glass and increase the awareness of depth in comparison to a normal photograph, due to the amplified sizing difference between objects viewed in the background of the picture, and the intended focus area. Additionally, the compression picture effectively simulates a larger visual field and is therefore able to include more objects within a given picture space than the normal photograph. It was also decided to explore the interaction of depth of field blur image effect, because it is commonly used as depth cue and director of attention in both film and photography and simulates background blurring in the Fovography imaging theory. Nevertheless, without foreground blurring and peripheral information being increasingly degraded towards the edge of the visual field, the compression image effect with its increased visual field might not be effective in directing attention to the intended focus area and improving the awareness of depth in a picture.

In the new Bombay Sapphire pictures, the depth of field blur image effect was created by applying blur to the background, behind the table and objects on it, so that a façade of blur did not cover foreground objects in the intended focus area. It was expected that the depth of field blur image effect (background blur) would enhance the directed attention and depth awareness of the compression and normal conditions. The conditions produced, therefore included two normal photographs and two pictures adjusted with the Fovography compression image effect. The normal photographs and compression pictures were paired, one pair given background blur and the second left unchanged without blur (Figure 4.4). By not including peripheral blur conditions, the comparisons being made between the normal and compression conditions would be more manageable.

1. Normal condition

2. Compression condition

3. Normal background blur condition

4. Compression background blur condition

Figure 4.4. In a Clockwise direction, the Bombay Sapphire stimuli are made up of:
1. Normal condition - which is a line-of-sight photograph.
2. Compression condition - multiple photographs joined and adjusted to match the scene drawing.
3. Normal background blur condition - blur image effect added behind the table and objects on it.
4. Compression background blur condition - blur image effect added behind the table and objects on it.

4.1.1 Stimuli produced for experiment 5

The stimuli used in experiment 5 comprised of complete Fovography pictures paired with normal photographs of the same scene. The Fovography pictures were produced using pictures containing the scope of the human visual field, compressed to match the proportions as experienced from natural vision and given an enlarged attention area. These pictures also contained object doubling and blurring before and behind the object in focus, with both effects progressively increased towards the periphery of the scene. These pictures were used to analyse the extent to which depth awareness is enhanced by Fovography pictures, if any.

To aid in composing these Fovography pictures, Pepperell drew scenes to capture his real world experience of fixating on an object, such as a glass of wine being held (Figure 4.5). His experience of object doubling, which is observed directly behind the object being focused on (this is also relevant to objects in front), and increasing towards the edge of the visual field is relatively simple to depict. More difficult is illustrating the first-person increase in the intensity of indistinctness towards the edge of the visual field, although this indistinctness is expounded as running in parallel with the increasing deterioration of detail through object doubling, and the compression of visual field information being at their greatest in peripheral vision (Pepperell and Burleigh, 2014).

Figure 4.5. A drawing By Pepperell, showing his the fixated experience of a glass of wine being held. The first-hand experience of blur and object doubling behind a fixated object is difficult to record as well as increased peripheral indistinctness.

The compositional approach taken by Pepperell to create Fovography pictures involved photographing the limits of the human visual field of a drawn scene, joining these pictures together using Photoshop and proportionally adjusting this single picture so that the content matched that shown in the drawing. This involved the periphery of each picture being compressed followed by the enlarging of the attention area. Further image effects from the drawing were then added, such as object doubling and blurring before and behind the object in focus, with both effects progressively increased towards the periphery of the scene. This produced a complete Fovography picture of the glass of wine ('Glass') scene (Figure 4.6) and two additional scenes called 'Watch' and 'Teapot'. However, the regularity of object doubling and blurring assigned by Pepperell to these Fovography pictures differed.

Figure 4.6. The glass of wine Fovography picture demonstrates the picture compression increasing outwards from the glass towards edge of the image. Object doubling is only visible behind the enlarged attention area of the hand holding the glass; however, the use of low level background, foreground and peripheral blurring is used.

4.1.2 Participants

A second ethical application had to be submitted and approved (Appendices 7.1) before the study could begin, after which 32 participants from a range of staff and students at Cardiff Metropolitan University were asked to participate in the study via a canvas email (Appendices 7.2). Each participant received a £10 Amazon voucher to encourage an adequate number of participants to volunteer. The participants were made up of 17 male, and 15 female; 22 had normal vision and 10 had corrected vision (glasses/contact lenses). They were aged between 20 and 53 years of age, with a mean age of 31 years.

4.1.3 Apparatus

A Tobii TX300 integrated eye tracker with a removable 23” TFT display (1020x1080 pixels) was used to present the study (Figure 4.7). This equipment was used throughout each participant session, allowing gaze data to be recorded for each displayed condition, along with verbal responses.

Figure 4.7. Tobii TX300 Eye Tracker with TFT display is positioned on a work desk and viewed as a conventional computer display (Tobii®Technology, 2011).

Data entry responses also required participants to be familiar with using a mouse as an input device; this was linked to a computer running Tobii Studio 2.1.13 software controlling the eye tracker. The seating position of participants was defined through the guidelines outlined in the Tobii TX300 Eye Tracker manual (Tobii®Technology, 2011): this sets a viewing distance of approximately 65cm (26") from the display and a viewing angle of no more than 35º enable the entire display area to be tracked (Figure 4.8). This viewing distance was demonstrated in the performance and comfort study by Sheedy and Bergstrom (2002). This study compared a head mounted display (HMD) against four other display conditions and suggested that traditional computer displays are typically viewed at 50 to 70cm.

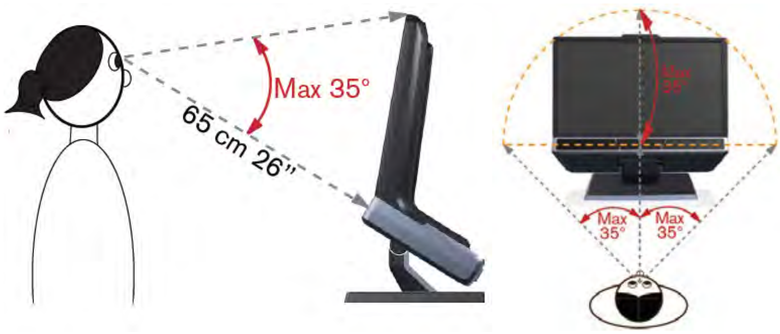


Figure 4.8. General setup guidelines for the Tobii TX300 Eye Tracker (Tobii®Technology, 2011).

4.1.4 Eye tracking procedure

Participants were brought into the testing booth individually and seated at a desk with a Tobii TX300 Eye Tracker in front of them. The participants were naive to the research prior to joining the study. However, an information sheet (Appendices 7.3) containing the clear title of the study and outline of their participation was provided and was also explained so that informed consent could be obtained from each participant (Appendices 7.4). After this brief background explanation, answering questions and explaining the equipment in front of them, the seated participant had their eye movement calibrated to the eye tracker display. The study session was started once a successful visual calibration was made and the participant was asked to read the opening instructions for the first experiment.

4.2 Experiment 3

As there are many image effects involved in the Fovography imaging method it was decided to initially study a key variable, namely the compression image effect. Pepperell hypothesises that by including peripheral visual information (normally excluded from photographs) and modifying the proportions of objects to produce a closer representation of the scope of the human visual field, directional focus is improved in comparison to a normal photograph (Pepperell and Burleigh, 2014). The purpose of this experiment was to record eye tracking data of participants in order to compare their behaviour in relation to given areas of interest within presented stimuli. The stimuli were presented in four conditions: two normal photographs and two compression pictures, with one of each including a depth of field blur image effect, which is commonly used in photographs as a depth cue and to direct visual attention. A variety of gaze analysis comparisons were made in order to test the prediction that the compression image effect would improve directed attention in comparison to a normal photograph, and considered the depth of field blur image effect in each case.

4.2.1 Procedure

Participants were instructed to familiarise themselves with the stimuli being presented concurrently for five seconds each on the eye tracker monitor. The instructions were:

> You are going to be shown four pictures, each for 5 seconds.
> No response is needed for these pictures during their viewing.

For repeated measures, blank intervals of two seconds were added between stimuli and different presentation combinations for each group of participants were used (Appendices 8.1).

4.2.2 Findings

Before participants' eye tracking data could be investigated, an area of interest with the same size net boundaries had to be located on the four Bombay Sapphire conditions. This involved drawing the area of interest net over the intended focus area, which included the upper half of the Bombay Sapphire bottle with the text and the rim of the glass (Figure 4.9).

Normal condition - Bombay Sapphire area of interest group 1, participant group 1.

Compression condition - Bombay Sapphire area of interest group 2, participant group 1.

Normal background blur condition - Bombay Sapphire area of interest group 3, participant group 1.

Compression background blur condition - Bombay Sapphire area of interest group 4, participant group 1.

Figure 4.9. In a Clockwise direction, the Bombay Sapphire condition and area of interest group for participant group 1: Normal condition, area of interest group 1. Compression condition, area of interest group 2. Normal background blur condition, area of interest group 3. Compression background blur condition, area of interest group 4.

The area of interest for each condition then had to be linked to their corresponding area of interest condition group and participant group. It was important to replicate the size and coordinates (locations) of the area of interest net over each condition, so that a reliable comparison between participants' gaze data for the same intended focus area in each condition could be performed. However, after further consideration it was decided that too much background space between the bottle and glass occupied the positioned area of interest nets. The reasoning behind this was that gaze data from background objects would interfere with the foreground bottle and glass gaze data, possibly leading to inaccurate assumptions being made about the intended focus area. The area of interest was therefore split into two parts: one part drawn over the top half of the bottle and the other over the glass. Both were then paired and assigned to the relevant area of interest condition group (Figure 4.10).

Normal condition - Bombay Sapphire area of interest group 1, participant group 1.

Compression condition - Bombay Sapphire area of interest group 2, participant group 1.

Normal background blur condition - Bombay Sapphire area of interest group 3, participant group 1.

Compression background blur condition - Bombay Sapphire area of interest group 4, participant group 1.

Figure 4.10. To make sure that the gaze data from the intended focus area (forefront objects) could be compared against the rest of the image (background), each Bombay Sapphire condition was given an area of interest over the top half of the bottle, and the second over the glass.

4.2.3 Area of interest analysis - foreground intended focus area

The area of interest over the intended focus area in the foreground of each of the Bombay Sapphire conditions allowed for a variety of gaze analysis comparisons. To do this, the ‘Tobii Studio Evaluation Software’ follows a variety of threshold protocols so that appropriate numerical comparisons are drawn using eye tracking data. One of the main protocols relates to fixation information, with the default value of 60ms used to classify a minimum fixation; anything below this value becomes a non-fixation data point and is therefore not included when descriptive statistics are calculated (Salojärvi et. al., and Komogortsev et. al., cited in Tobii®Technology, 2011).

Initially, the Tobii studio software was used to calculate mean descriptive statistics for each intended focus area. These were outputted as bar charts to discuss: Time to First Fixation mean, Fixations Before mean, Visit Duration mean, Visit Count mean, and Fixation Count mean (Appendices 8.2). However, when statistical analysis of the Bombay Sapphire conditions was undertaken, it was noticed that two participants had not fixated on every area of interest across conditions (Appendices 8.3). This effectively meant that when the mean area of interest descriptive statistics had been calculated for analysis, the participant numbers (N count) were different between some conditions. As a result, the sum of each area of interest analysis task (for example, Time to First Fixation mean), was divided by a different number (N count) of participants (Appendices 8.4). In addition to this, because the favoured method of statistical analysis was a one-way within subjects ANOVA design, it was essential that all participants had recorded a fixation on the area of interest in each condition. To overcome the setback of two participants not fixating across all Bombay Sapphire conditions, statistics software was used to structure the data from each analysis task with these participants removed. This allowed mean descriptive statistics to be uniformly calculated, outputted as bar charts, and most importantly aligned with statistical analysis.

The ‘Time to First Fixation’ bar chart (Figure 4.11) shows the mean amount of elapsed time prior to participants’ initial fixations on the area of interest within each condition.

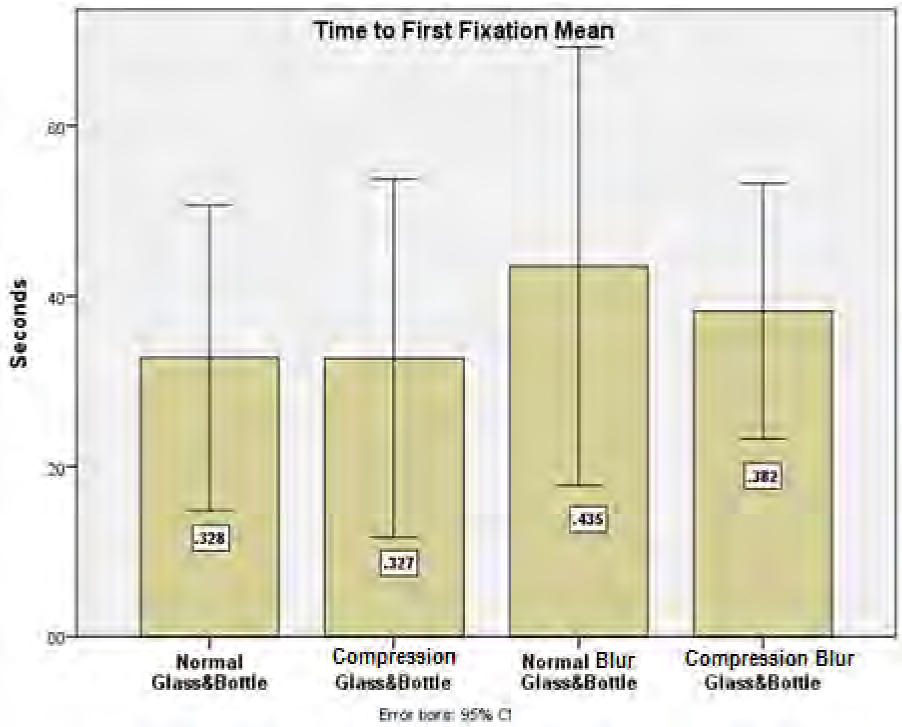


Figure 4.11. Time to First Fixation Mean bar chart: showing the time from the start of the condition display until the test participants' fixate on the area of interest or area of interest Group for the first time (seconds).

The outputted eye tracking data showed that between the Bombay Sapphire conditions, the compression condition and the normal condition gave the least amount of elapsed time before participants' viewed the area of interest on the bottle and glass. These fastest Time to First Fixation means were not as anticipated. The addition of background blur to the normal and compression conditions produced Time to First Fixation means that were higher than the same conditions lacking background blur. The normal background blur condition produced the highest mean amount of elapsed time (before a fixation within its area of interest), suggesting it was the weakest condition of focus directed attention. However, the introduction of background blur has shown the compression condition to produce a faster Time to First Fixation mean than the normal background blur condition. These results are very interesting, as the introduction of background blur in a condition was expected to reduce the Time to First Fixation mean within a foreground area of interest, in comparison to a condition without background blur.

A one-way within-subjects (also known as repeated measures) ANOVA was performed on the Time to First Fixation mean within each condition's area of interest (Appendices

8.5). Mauchly's test indicated that the assumption of sphericity had not been violated: X^2 (5) = 9.350, p>.05; therefore, the relationships between pairs of conditions were roughly equal, and assumed sphericity was used. The results showed that there was little difference between conditions: F (3, 87) = .376, p=.771, partial n^2 = .013.

The 'Fixations Before' bar chart (Figure 4.12) shows the mean number of fixations that participants made prior to fixating on the area of interest within each condition.

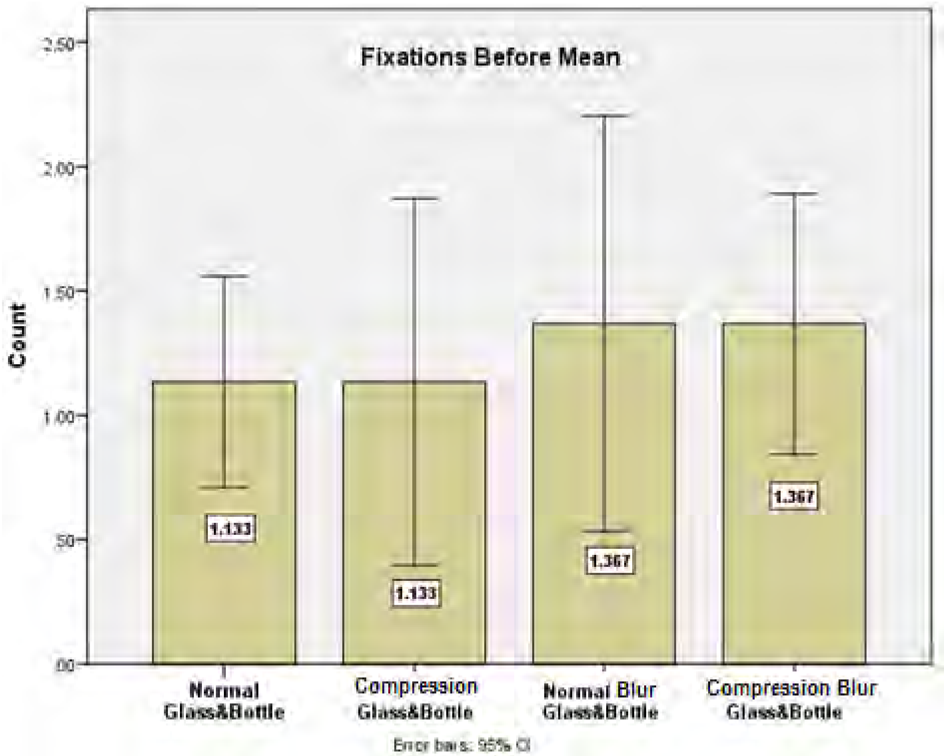


Figure 4.12. Fixations Before Mean bar chart: showing the number of times participants' fixate on media before fixating on an area of interest or area of interest Group for the first time (count).

When comparing the Fixation Before mean counts for the Bombay Sapphire conditions, the normal condition and compression condition received the equal lowest mean count elsewhere before each area of interest was fixated on. The Fixation Before mean counts increased through the introduction of background blur, with the normal background blur condition and the compression background blur condition attaining the same mean count. These results follow the previously discussed trend, in that the introduction of background blur which was expected to reduce the number of fixations elsewhere before fixating on the area of interest did not transpire. In addition, the results show that as the Time to First Fixation mean decreases for an area of interest, so does the number of fixations before focusing on the area of interest.

A one-way within-subjects ANOVA was performed on the Fixations Before mean count for each condition's area of interest (Appendices 8.6). Mauchly's test indicated that the assumption of sphericity had been violated: X^2 (5) = 19.547, $p<.05$; therefore, the degrees of freedom were corrected using Huynh-Feldt estimates of sphericity (E = .830). The results show that there was no significant effect for the type of condition: F (2.491, 72.240) = .245, p=.829, partial n^2 = .008.

The 'Total Visit Duration' bar chart (Figure 4.13) shows the mean total time that participants viewed the area of interest during the five seconds that each condition was displayed.

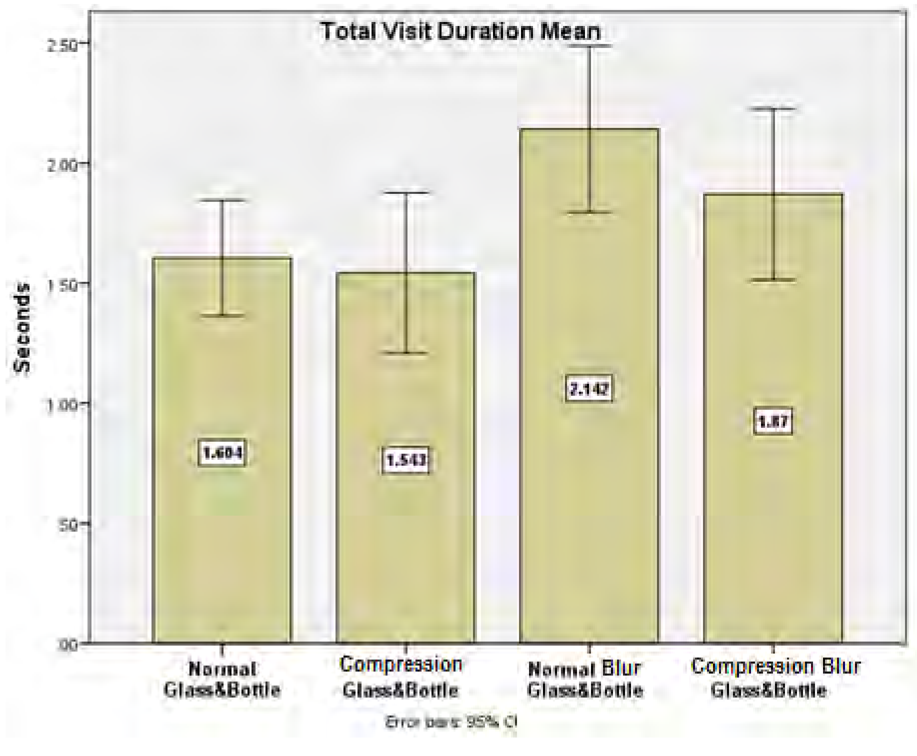


Figure 4.13. Total Visit Duration Mean bar chart: showing the duration of all visits within an area of interest or an area of interest Group (seconds).

The area of interest Total Visit Duration means for the Bombay Sapphire conditions show the normal condition to be higher than the compression condition; with this pattern repeated and the visit duration increased with the introduction of background blur.

A one-way within-subjects ANOVA was performed on the Total Visit Duration mean for each condition's area of interest (Appendices 8.7). Mauchly's test indicated that the assumption of sphericity had been violated: X^2 (5) = 12.243, p<.05; therefore, the degrees of freedom were corrected using Huynh-Feldt estimates of sphericity (E = .863). The results show that the type of condition significantly affected the total visit duration within an area of interest: F (2.588, 75.065) = 3.712, p=.020, partial n^2 = .113. Bonferroni post-hoc tests revealed that normal background blur condition (Condition 3 Mean= 2.142) had a significant interaction (p<.05) between the normal condition (Condition 1 Mean= 1.604) and the compression condition (Condition 2 Mean= 1.543). No other comparisons were significant (all p>.05).

The 'Visit Count' bar chart (Figure 4.14) shows the mean visits that participants made to the area of interest within each condition.

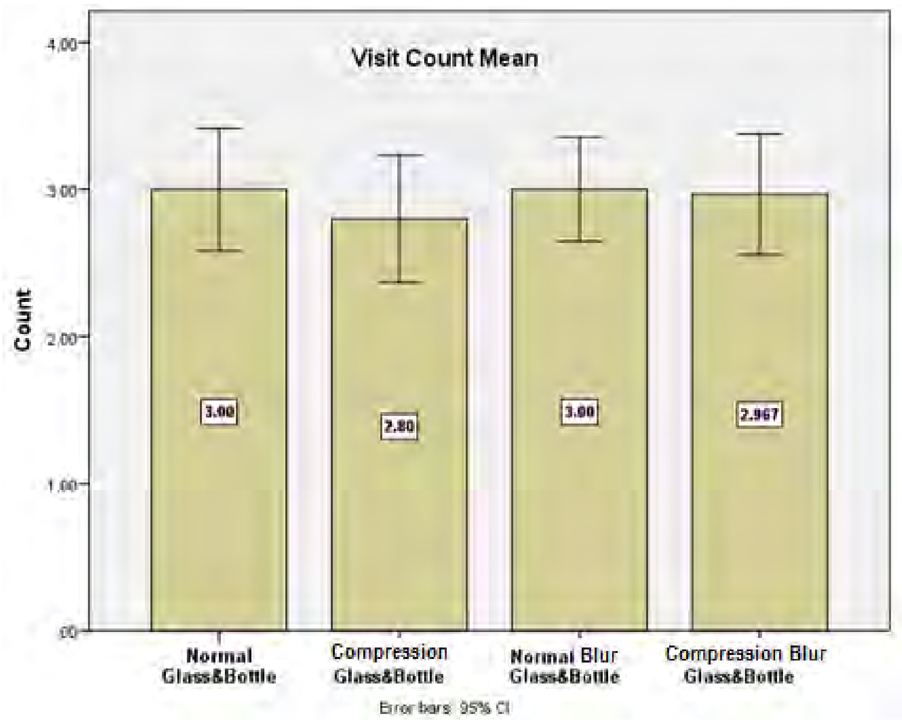


Figure 4.14. Visit Count Mean bar chart: showing the number of visits within an area of interest or an area of interest Group (count).

The Bombay Sapphire conditions show lower Visit Count means for both compression conditions over their equivalent normal conditions, with and without background blur. The same trend was shown in the Total Visit Duration mean bar chart. Interestingly, the normal conditions with and without background blur achieved the highest Visit

Count means across the conditions, but from previous analysis the normal condition showed nearly the lowest Total Visit Duration mean which was just above the compression condition's. In advance of the Fixation Count mean analysis below, the participants' low Fixation Count mean for the normal condition also coincides with it having a low Total Visit Duration mean. This shows that participants' high visit counts within the area of interest are not encouraged to turn into fixations, subsequently not increasing the Total Visit Duration. This trend is also similar for the compression condition.

A one-way within-subjects ANOVA was performed on the Visit Count mean for each condition area of interest (Appendices 8.8). Mauchly's test indicated that the assumption of sphericity had not been violated: X^2 (5) = 2.730, p>.05; therefore, the relationships between pairs of conditions were roughly equal and assumed sphericity was used. The results show that there was no significant effect for the type of condition: F (3, 87) = .326, p=.807, partial n^2 = .011.

The 'Fixation Count' bar chart (Figure 4.15) shows the mean entirety of fixations that participants made within the area of interest for each condition.

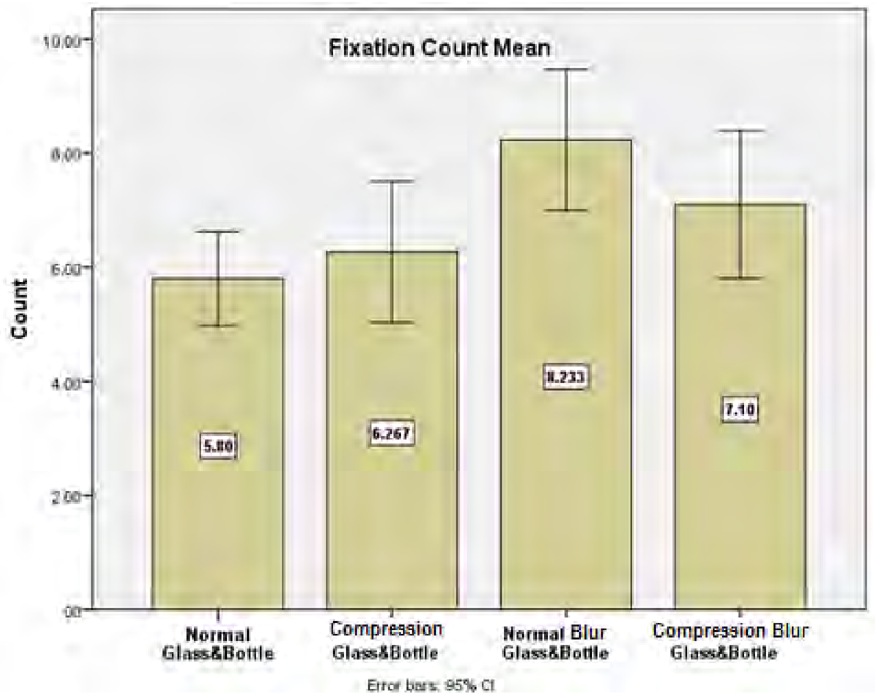


Figure 4.15. Fixation Count Mean bar chart: showing the number of times participants' fixate on an area of interest or an area of interest Group (count).

Without background blur, the normal condition gave the lowest area of interest Fixation Count mean, followed by the compression condition. It is thought that the increased clarity throughout the normal and compression conditions is the reason for their similarly low area of interest Fixation Count and Visit Duration means. This is further supported by the normal and compression background blur conditions both having higher Fixation Count means, which was the trend seen in the Total Visit Duration means. However, these results do not correlate with the previous analysis which showed conditions without background blur producing the fastest time to view the intended focus area, along with the fewest prior fixations made outside of an area of interest. Furthermore, background blur conditions show more previous fixations before viewing the intended focus area and a slower time to the first fixation.

A one-way within-subjects ANOVA was performed on the Fixation Count mean within each condition's area of interest (Appendices 8.9). Mauchly's test indicated that the assumption of sphericity had not been violated: X^2 (5) = 7.920, p>.05; therefore, the relationships between pairs of conditions were roughly equal, and assumed sphericity was used. The results show that type of condition significantly affected the Fixation Count within an area of interest: F (3, 87) = 4.707, p=.004, partial n^2 = .140.

Bonferroni post-hoc tests revealed that the normal background blur condition (Condition 3 Mean= 8.233) showed a significant interaction (p<.05) between the normal condition (Condition 1 Mean= 5.800) and the compression condition (Condition 2 Mean= 6.267). No other comparisons were significant (all p>.05).

4.2.4 Summary

It was unexpected that the background blur conditions would produce longer Time to First Fixation means, and higher Fixations Before means for the unambiguous and contrasting area of interest positioned over the central and foreground locations of the bottle and glass. However, these results were not significantly different to the normal and compression conditions without background blur. Participants' gaze data also showed greater Fixation Count means and Total Visit Duration means being produced by the background blur image effect for the same area of interest, which was as expected. These results showed a significant interaction between the normal background blur condition and the normal and compression conditions without background blur, and occurred even though each condition produced similar Visit Count means. This was thought to be caused by the unambiguous and contrasting area of interest positioned over the central and foreground locations of the bottle and glass. However, throughout the analysis of participants' gaze data, no significant interaction was found between the compression condition with background blur and the other conditions.

4.2.5 Heat map analysis of participants' eye tracking data

The participant's gaze information for the area of interest located over the intended focus area, allowed many important numerical comparisons to be carried out in order to substantiate visual distinctions between image effects. Analysis shows that the areas of interest represent a small proportion of participants' eye movement for each condition. For that reason, 'Heat Map Visualisations' were then produced using the Tobii evaluation software to illustrate participants' visual investigations and their attention durations (interaction over time) whilst viewing each condition.

To begin with, the eye tracking data for each group of participants was visualised into absolute duration heat maps for each Bombay Sapphire condition. It was anticipated that the attention durations on objects in the background of conditions with background blur would be low and sparse in comparison to unambiguous foreground objects. The Group 1 heat maps for the Bombay Sapphire conditions (Figure 4.16) showed this assumption to be true; with background attention durations being fewer, and for less time than on unambiguous foreground objects.

1. Normal background blur condition

2. Compression background blur condition

3. Normal condition

4. Compression condition

Figure 4.16. Group 1: Eye tracking data, was used to generate attention duration heat map visualisations, for the Bombay Sapphire conditions.

1. Normal background blur condition – Normal photograph with background blur.
2. Compression background blur condition – Compression image effect with background blur
3. Normal condition – Normal photograph
4. Compression condition – Compression image effect

Unfortunately, the eye tracking data used to produce absolute duration heat maps for the other three groups of participants (Appendices 8.10) could not be combined using the Tobii evaluation software. To overcome this, the heat maps for each participant group were imported into Photoshop and a ‘grouped’, multi-layered, absolute duration heat map was made for each condition (Figure 4.17). These grouped heat maps for the Bombay Sapphire conditions continued to show the same attention duration patterns previously described using the Group 1 heat maps for each condition (Figure 4.16).

1. Normal background blur condition (Pair 1)

2. Compression background blur condition (Pair 1)

3. Normal condition (Pair 2)

4. Compression condition (Pair 2)

Figure 4.17. Group heat maps are layered together using Photoshop, to show the grouped multi layered, absolute duration, heat map visualisation, for each Bombay Sapphire condition.

The attention durations on objects in the foreground and background of both Bombay Sapphire conditions without background blur also revealed that participants looked less at objects located in the background of the scene. However, these conditions show similar foreground object attention durations on less centralised objects (such as the teapot, armchair, and the vase), when compared to conditions with background blur. It is evident that when the normal and compression conditions are visualised as pairs (pair 1 with background blur, and pair 2 without background blur), background blur influences the locality of participants' visual investigations and their attention durations more than the compression image effect. However, in the second pair of conditions (without background blur), the background of the compression condition shows slightly more focused attention locations than the normal condition. This is thought to be caused by the increased amount of background visual information (larger field of view) which contains a greater amount of visible objects. As previously mentioned, background blur reduces visual investigation and attention duration of these background objects, in favour of being more closely grouped over the bottle and glass.

4.2.6 Multiple area of interest comparisons involving the foreground intended focus area and background objects

Once the heat map analysis for the Bombay Sapphire conditions had been performed, it was decided that the differences in attention between background objects should be further investigated for each condition. It was hoped that additional area of interest analysis would identify how participants' attention on background objects was being influenced by each condition, and show any visual differences between the foreground intended focus area of the bottle and glass.

As previously discussed, when an area of interest in a condition is not fixated on by a participant, he or she is not included when descriptive statistics are calculated. This meant that some conditions had a different number of participants (N count) which were used to produce means for each area of the interest analysis task. In order that the favoured method of statistical analysis (a one-way within subjects ANOVA) could be undertaken, two participants were removed from the previous sample to allow the interpretation of mean descriptive statistics (bar charts) to be aligned accordingly. However, the removal of participants who did not fixate on every area of interest established over background objects within each condition (Figure 4.18) was not viable as all of the participants were unable to fixate at least once on every background area of interest (Appendices 8.11).

Normal condition - Showing foreground and background area of interest.

Compression condition - Showing foreground and background area of interest.

Normal condition with background blur - Showing foreground and background area of interest.

Compression condition with background blur - Showing foreground and background area of interest.

Figure 4.18. Further area of interest established on background objects for each Bombay Sapphire condition.

This meant that the same statistical analysis carried out on previous tasks (e.g. Time to First Fixation mean) could not be produced between background area of interest (using a one-way within subjects ANOVA), or between the foreground and background area of interest (using a two-way within subjects ANOVA).

It was therefore decided to explore the background area of interest in each condition using the mean descriptive statistics produced by the Tobii studio software. This meant that the ‘sum’ of each area of interest analysis task was divided by the different number (N count) of participants included in each condition (Appendices 8.12). This allowed the same set of analysis tasks previously used for the intended focus area in each condition to be repeated: Time to First Fixation mean, Fixations Before mean, Visit Duration mean, Visit Count mean, and Fixation Count mean.

However, the eye tracking data didn’t show any trends between background areas of interest when it was interpreted for each analysis task, and it was decided not to include this further analysis.

After exploring the relationships between background areas of interest from each analysis task, the ‘Percentage Fixated Mean’ bar chart (Figure 4.19) was examined for any relationships between conditions, and the percentage of participants who fixated at least once within an area of interest. All 32 participants fixated on the bottle and glass area of interest in the normal and normal background blur conditions, while 31 did the same under the compression and compression background blur conditions. Of interest is the different number of participants that fixate on an equivalent background area of interest (same objects), between conditions. Furthermore, this data would allow a one-way within-subjects ANOVA to be performed to assess whether attention in background area of interest significantly differed between conditions.

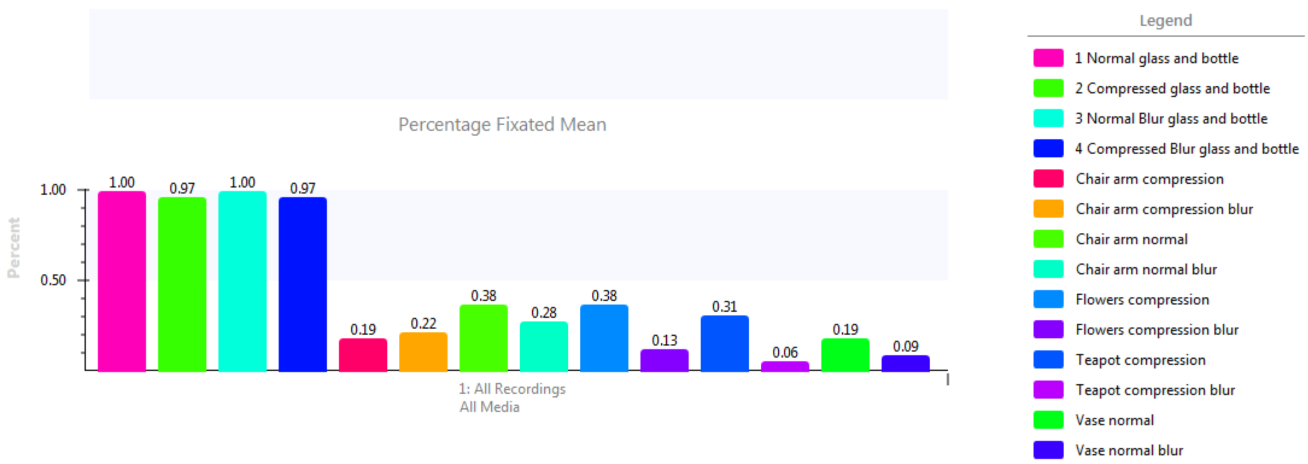


Figure 4.19. Percentage Fixated Mean bar chart: shows percentage of participants that fixated at least once within an area of interest or an area of interest Group (%) – Background area of interest.

Starting from the right and using the Percentage Fixation mean count, the vase in the normal condition is fixated on by 10% more participants than the vase in the normal background blur condition. The only difference between these conditions is the introduction of background blur. The teapot in the compression condition is fixated on by 25% more participants than the teapot in the compression background blur condition. Similar to the vase, the only difference between these conditions is the introduction of background blur. Additionally, this was similar for the flowers in the compression conditions, with the introduction of background blur reducing the number of participants fixating on the area of interest by 25%. These results suggest that the application of background blur reduces the likelihood of a background object being fixated on. Additionally, within all four conditions the chair arm is visible and background blur, in relation to the normal conditions, reduced the number of participants that fixated on the area of interest by 10%. However, between the compression conditions, the introduction of background blur prompted a rise in participants fixating on the area of interest by 3%. This marginal opposite result is thought to be an anomaly. Furthermore, the compression conditions were less fixated on than both normal conditions.

A one-way within-subjects ANOVA was performed on the Percentage Fixated mean for each area of interest (Appendices 8.13). Mauchly's test indicated that the assumption of sphericity had been violated: X^2 (44) = 90.943, p<.05; therefore, the degrees of freedom were corrected using Huynh-Feldt estimates of sphericity (E = .846). The results show that type of condition significantly affected the Percentage Fixated mean within an area of interest: F (7.617, 236.128) = 2.846, p=.006, partial n^2 = .084.

Bonferroni post-hoc tests revealed that the chair arm area of interest in the normal condition (condition 3 Mean = .38) had a significant interaction (p<.05) with the teapot area of interest in the compression background blur condition (condition 8 Mean = .06). No other comparisons were significant (all p>.05).

However, this significant interaction has been disregarded as it compares two unrelated areas of interest (different objects), and in preliminary analysis significant interactions occurred between the intended focus areas of each condition and all background areas of interest. As previously explained, the bottle and glass area of interest were removed from the analysis because importance was placed on the different numbers of participants who fixate on equivalent background area of interest. When the one-way within-subjects ANOVA is performed only for appropriately matched background area of interest (such as the chair arm area of interest, vase area of interest, or the teapot area of interest), all comparisons remain non-significant ($p>.05$).

4.2.7 Multiple area of interest comparisons involving the foreground intended focus area and secondary foreground objects

The heat maps for the Bombay Sapphire conditions (Figure 4.17) also exposed the need to explore attention differences between the foreground intended focus area (bottle and glass) and secondary foreground objects; both of which had not been altered by background blur. These areas of interest could identify whether participants' focused attention differed between secondary foreground objects which either had the same picture properties as the foreground bottle and glass or had applied to them the compression image effect which transforms less central secondary foreground objects to be more centrally located. Furthermore, area of interest attention differences between conditions with and without background blur could be identified. Because the foreground objects in the intended focus area match normal photograph proportions throughout all the conditions, any difference between this area of interest and secondary areas of interest can be suggested due to the introduction of the compression image effect and/or background.

The secondary foreground areas of interest in each Bombay Sapphire condition (pot & peach, other fruit) were established on the same objects situated on the plate; these were then assigned to new area of interest groups for the condition in which they were present (Figure 4.20).

Normal condition - Showing foreground and secondary foreground area of interest.

Compression condition - Showing foreground and secondary foreground area of interest.

Normal condition, with background blur - Showing foreground and secondary foreground area of interest.

Compression condition, with background blur - Showing foreground and secondary foreground area of interest.

Figure 4.20. Additional area of interest established on secondary foreground objects (pot & peach, and other fruit) within each condition.

The most noticeable difference between the foreground objects on the plate and the background objects is that these foreground objects do not have background blur applied to them. In addition, when the compression image effect is applied to a picture, it is evident throughout (with the exception of the bottle and glass which always maintains normal photograph proportions throughout all the conditions). These foreground differences and similarities between conditions are evident when a normal background blur condition and compression background blur condition are displayed side-by-side without area of interest obscuring foreground objects (Figure 4.21). The number and size of area of interest located on background objects (chair arm, vase, flower, and teapot) differed between the conditions, due to the effect of compression (Appendices 8.14).

Normal background blur condition

Compression background blur condition

Figure 4.21. The main difference between the foreground and background areas is that foreground objects throughout the conditions do not have background blur applied to them.

A much higher percentage of participants fixated on all secondary foreground areas of interest (Appendices 8.15), in comparison to the previous background areas of interest. However, statistical analysis was decided not to be robust when participants are removed who did not make a fixation on every secondary foreground area of interest in each condition. It was therefore decided to explore the same set of analysis tasks using the mean descriptive statistics produced by the Tobii studio software. The sum of each area of interest analysis task was divided by the highest number (N count) of participants included in each condition (Appendices 8.16).

However, the eye tracking data didn't show any trends between foreground areas of interest when it was interpreted for each analysis task, and it was decided not to include this further analysis.

After exploring the relationships between the foreground areas of interest from each analysis task, the 'Percentage Fixated Mean' bar chart (Figure 4.22) was examined for any relationships between conditions and the percentage of participants who fixated at least once within an area of interest. A further one-way within-subjects ANOVA was then performed to assess whether the attention of secondary foreground area of interests significantly differed between conditions.

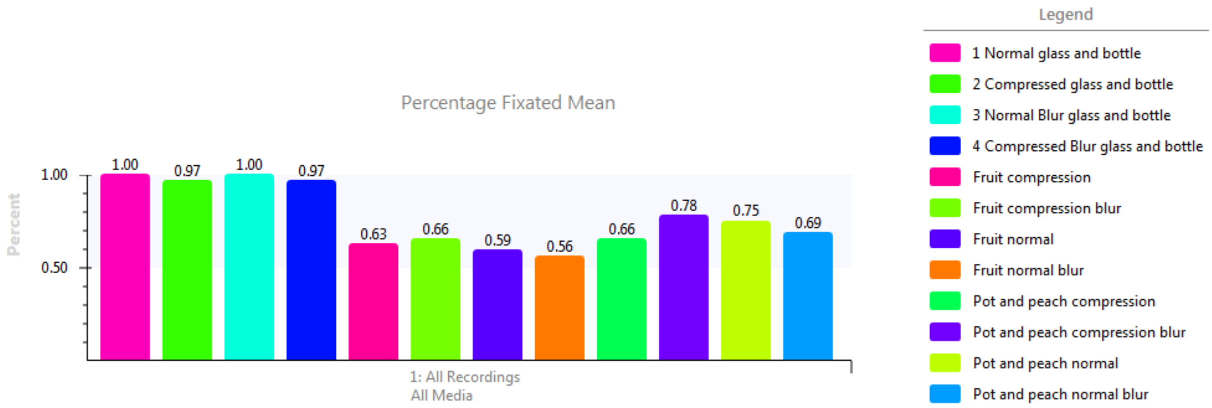


Figure 4.22. Percentage Fixated Mean bar chart: shows the percentage of participants that fixated at least once within an area of interest or an area of interest Group (%) – Secondary foreground area of interest.

With regards to the pot and peach area of interest results on the right-hand side, the normal background blur condition shows fewer participants have fixated on the area of interest in comparison with the normal condition; whereas the results are the opposite for the compression background blur condition and the compression condition. In addition, a similar number of participants fixated on the area of interest in the compression and in the normal background blur condition. Also, a comparable number of participants fixated on the area of interest in the compression background blur and the normal condition. These variations of participants fixating on the pot and peach area of interest within each condition suggests that the introduction of background blur and compression, individually or combined, does not increase the likelihood of foreground objects being fixated on.

There are also similarities between the pot and peach and the fruit area of interest results, with the fruit areas of interest also showing the normal background blur condition to have had fewer participants fixate on it when compared with the normal condition. Interestingly, the compression background blur condition and the compression condition show this result in reverse. The percentage of participants that fixated at least once on the fruit areas of interest was lower than for the pot and peach areas of interest; further suggesting that the central location of the pot and peach make them more prominent. In addition, the fruit area of interest for each of the compression conditions shows a greater fixation percentage than for both the normal conditions; which could be due to the compression image effect transforming less central secondary foreground objects to be more centrally located.

A one-way within-subjects ANOVA was performed on the Percentage Fixated mean for each secondary foreground area of interest (Appendices 8.17). Mauchly's test indicated that the assumption of sphericity had not been violated: X^2 (27) = 24.663, $p>.05$; therefore, the relationships between pairs of conditions were approximately equal, and assumed sphericity was used. The results showed that there was no significant effect for the type of condition: F (7, 217) = .869, $p=.532$, partial n^2 = .027.

It was then decided to ascertain whether there were significant differences between the intended focus area of the bottle and glass (foreground area of interest) and both secondary foreground areas of interest within each condition. A one-way within-subjects ANOVA was performed on the Percentage Fixated mean for the intended focus area of interest and both secondary foreground areas of interest within each condition. The normal, compression, and normal background blur conditions (Appendices 8.18, 8.19 & 8.20) all produced significant interactions ($p<.05$) between the foreground area of interest (bottle and glass), and both secondary foreground areas of interest (fruit, and pot & peach). The compression background blur condition also produced a significant interaction between the Percentage Fixated means within areas of interest: F (2, 62) = 5.034, $p=.009$, partial n^2 = .140 (Appendices 8.21). However, Bonferroni post-hoc tests revealed that whilst the fruit area of interest (Mean

= .66) had significant interaction (*p*<.05), the pot & peach area of interest (Mean = .78) did not *p*=.095 (Figure 4.23).

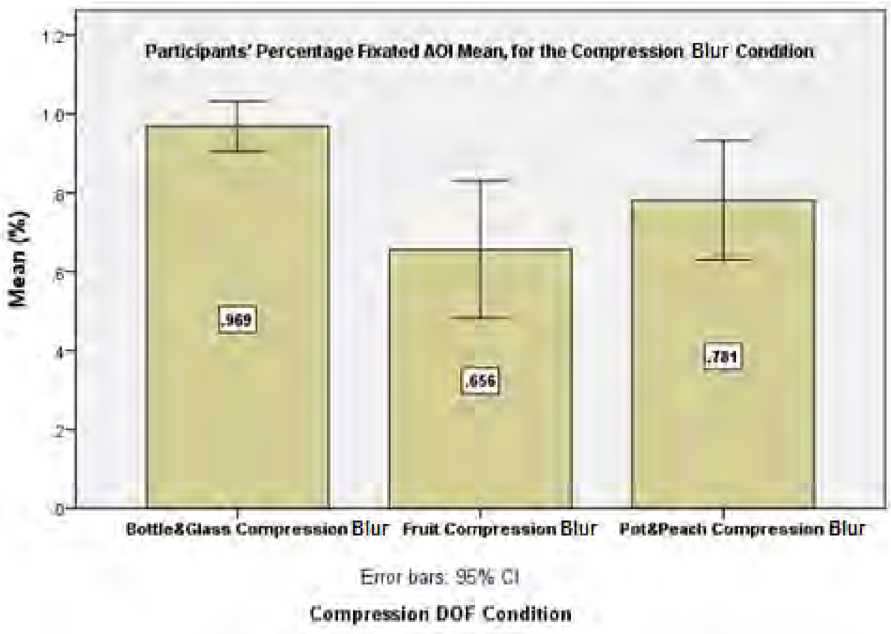


Figure 3.23. Percentage Fixated Mean bar chart: showing the percentage of participants that fixated at least once within an area of interest or an area of interest Group (%) – Compression background blur condition.

The suggested reasoning behind the pot & peach area of interest in the compression background blur condition not providing a significant interaction with the bottle and glass area of interest relates directly to the previous discussion surrounding secondary foreground area of interest. Firstly, because of the central location of the pot & peach area of interest in the condition, a higher percentage of participants fixated at least once on it. The fruit area of interest, on the other hand, was less centrally located. Secondly, a further attention increase could be based on the compression effect which made the fruit area of interest (less central, secondary foreground object) more centrally located, with this awareness being enhanced by background blur. Both consequences are further supported by the Fixation Count means and Total Visit Duration means for the intended focus area (bottle and glass) being higher for the compression background blur and normal background blur condition, than with the normal and compression conditions. The compression image effect with background blur is therefore suggested to further enhance visual attention onto the secondary foreground objects.

4.3 Experiment 4

Experiment 4 was also based on the four Bombay Sapphire conditions, which had been used in experiment 3. The compression image effect was seen as a key variable used in the Fovography imaging method, and hypothesised by Pepperell to improve the perception of depth in comparison to a normal photograph (Pepperell and Burleigh, 2014). In addition, it was considered that a depth of field blur image effect (background blur) would enhance depth awareness of the compression and normal conditions. In order to test this prediction the conditions were observed in paired combinations (Figure 4.24), with participants asked to fixate on the bottle top in each and choose the condition which conveyed the greatest sensation of background distance (focus object to background).

Figure 4.24. An example of paired conditions: participants took it in turns to fixate on the bottle top in both Bombay Sapphire conditions, and then chose which condition conveyed the greater distance to the back wall. The image on the right (compression condition - c), or the image on the left (normal condition - n).

4.3.1 Procedure

Immediately after the short presentation of conditions, the instructions for the task were displayed on the eye tracker monitor and verbally explained. The instructions were:

> Two pictures will be presented next to each other.

Fixate on the bottle top in each, and verbalise which picture shows the greater distance to the wall (right or left)?
Then press the space bar to move forwards to the next slide.

Participants were allowed to spend as much time as they needed to view the paired conditions, before selecting either the one on the right or the one on the left. For repeated measures fairness, each group of participants viewed the paired conditions in different presentation combinations (Appendices 9.1).

4.3.2 Findings

The condition in each pairing (Appendices 9.2) which participants thought conveyed the greatest sensation of background distance (focus object to background) were compiled into a totals table (Table 2) for statistical analysis and discussion.

CONDITION	Compression background blur condition (cb)	Normal background blur condition (nb)	Normal condition (n)
Compression condition (c)	c-10 cb-22	c-16 nb-16	c-29 n-3
Compression background blur condition (cb)	------------------------	cb-24 nb-8	cb-28 n-4
Normal background blur condition (nb)	------------------------	----------------------	nb-23 n-9

Table 2. Total's Table: showing participant preference for greater sensation of background distance between conditions.

When participants viewed the compression and normal condition pairing, they showed an overwhelming preference towards the compression condition as conveying the greater sensation of background distance (Figure 4.25).

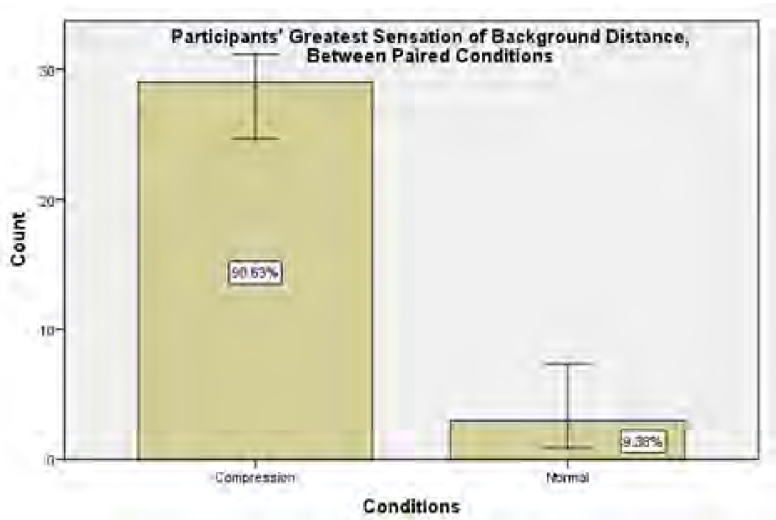


Figure 4.25. Bar chart showing the greatest sensation of background distance (focus object to background), between the compression (c) and normal (n) conditions.

The favoured method of statistical analysis was a Chi-square test of association, which tests for the existence of a relationship between two variables. A significant difference was found between these paired conditions: X^2 (1, N = 32) = 21.125, p=.001 (Appendices 9.3).

This first combination was an important starting point, because the comparison of the compression and normal conditions was not influenced by background blur. The inclusion of background blur was expected to increase the sensation of background distance further, in both conditions, but the proportion within each was unknown.

When participants viewed the paired compression and compression background blur conditions, they showed a preference towards the background blur condition as conveying a greater sensation of background distance (Figure 4.26). A Chi-square test was performed and a significant difference was found between the paired conditions: X^2 (1, N = 32) = 4.500, p=.034 (Appendices 9.4).

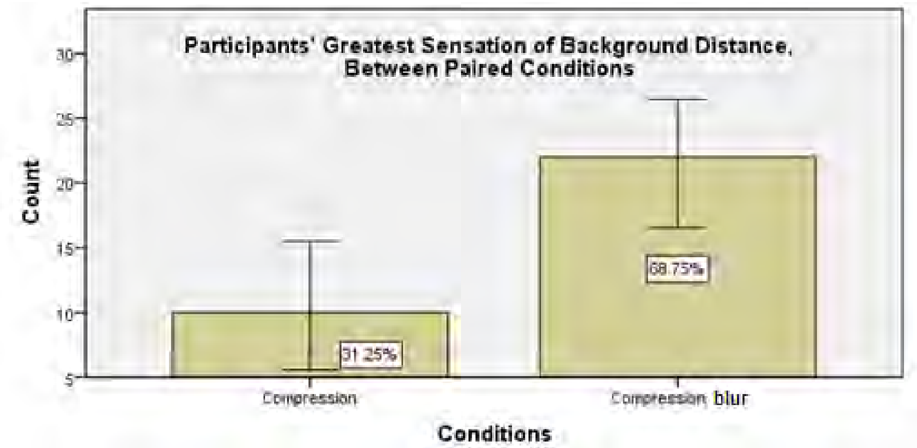


Figure 4.26. Bar chart showing the greatest sensation of background distance (focus object to background), between the compression (c) and compression background blur (cb) conditions.

The opening analysis showed that the compression condition significantly increased the sensation of background distance in comparison with the normal condition. This result shows that the sensation of increased distance, produced by the compression condition, is enhanced further still when background blur is added to it. It is therefore important to understand whether the difference between the normal condition and the compression condition increases when background blur is added to the compression condition.

The comparison between the compression background blur and normal condition showed that participants' greatest sensation of background distance was experienced through the compression background blur condition (Figure 4.27). A Chi-square test was performed and a significant difference was found between the paired conditions: X^2 (1, N = 32) = 18.000, p=.001 (Appendices 9.5).

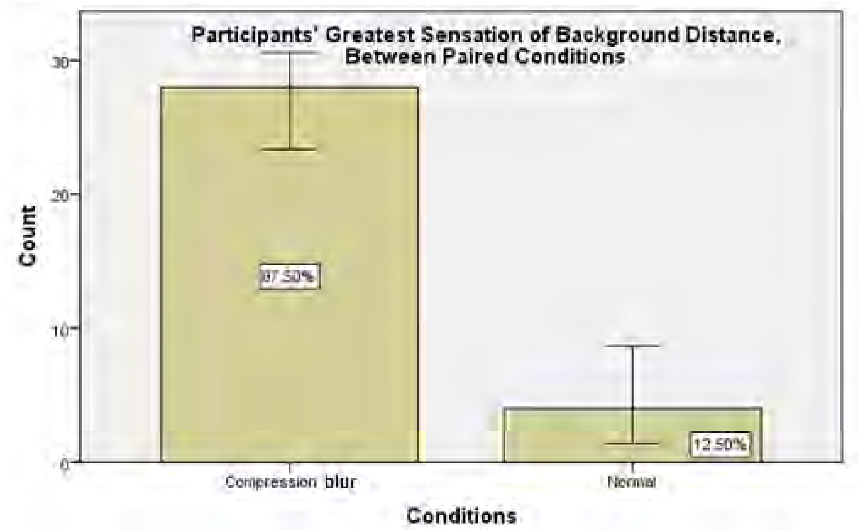


Figure 4.27. Bar chart showing the greatest sensation of background distance (focus object to background), between the normal (n) and compression background blur (cb) conditions.

The bar chart above shows the normal condition to be chosen fewer times than when the compression condition was compared against the compression background blur condition (Figure 4.26). This suggests that the compression background blur condition has greater impact on the dissimilar condition (normal), than the similar condition (compression). These results further reinforce that the compression condition significantly improves the sensation of background distance over the normal condition. Additionally, the inclusion of background blur to the compression condition has not enhanced the sensation of background distance further.

When participants viewed the paired normal, and normal background blur conditions, they showed a preference towards the normal background blur condition producing a greater sensation of background distance (Figure 4.28). A Chi-square test was performed and a significant difference was found between the paired conditions: X^2 (1, N = 32) = 6.125, p=.013 (Appendices 9.6).

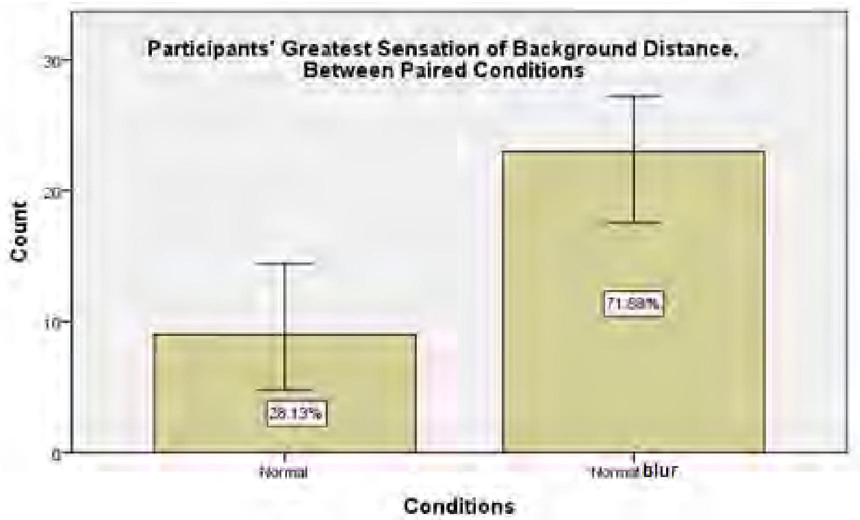


Figure 4.28. Bar chart showing the greatest sensation of background distance (focus object to background), between the normal (n) and normal background blur (nb) conditions.

From previous results, it was found that the compression condition significantly conveyed an increased background distance when compared to the normal condition, and that the compression background blur condition further enhances this impression. The proposal that background blur enhances the sensation of background distance is also supported by the paired normal and normal background blur condition results, with these being similar to the compression and compression background blur condition results.

However, when participants viewed the compression and normal background blur conditions, their conveyed feeling of background distance was the same for both (Figure 4.29). A Chi-square test was performed and no significant difference was found between the paired conditions: X^2 (1, N = 32) = .000, p= 1 (Appendices 9.7).

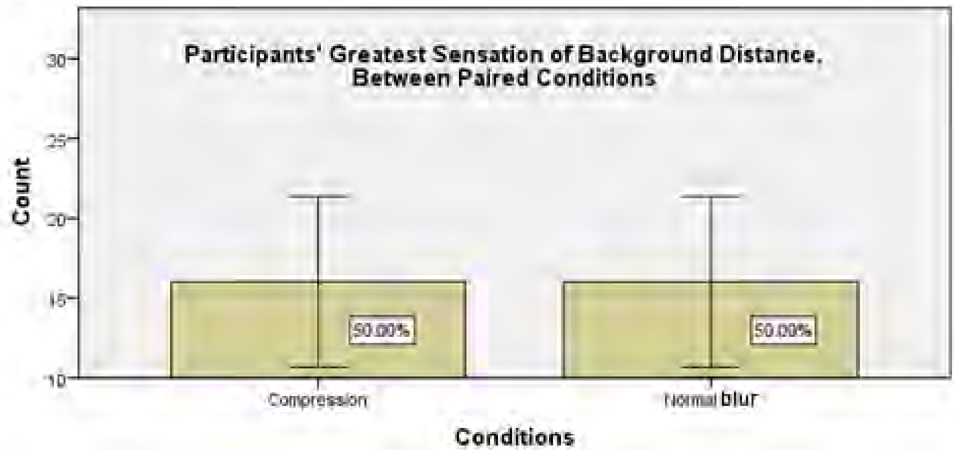


Figure 4.29. Bar chart showing the greatest sensation of background distance (focus object to background), between the compression (c) and normal background blur (nb) conditions.

This can be explained by reviewing the earlier results, which have already established that the compression condition produces a significantly greater background distance than the normal condition. Additionally, by including background blur in either condition, a further sensation of background distance is produced, which is again significant. It is therefore reasonable to infer from these results that adding background blur to a normal condition enhances the sensation of background distance to the same level as the compression condition without background blur.

The concluding comparison between the paired compression background blur and normal background blur conditions showed that a greater sensation of background distance was being conveyed by the compression background blur condition (Figure 4.30). A Chi-square test was performed and a significant difference was found between the paired conditions: X^2 (1, N = 32) = 8.000, p=.005 (Appendices 9.8).

This final comparison emphasises that the sensation of background distance in a compression condition is also enhanced by background blur. However, whether the proportion of enhancement by background blur is more than that found in the normal condition is unknown, as the compression condition has already been shown to be higher than the normal condition. Nevertheless, the previous results showed the compression condition without background blur to have the same sensation of background distance as the normal background blur condition.

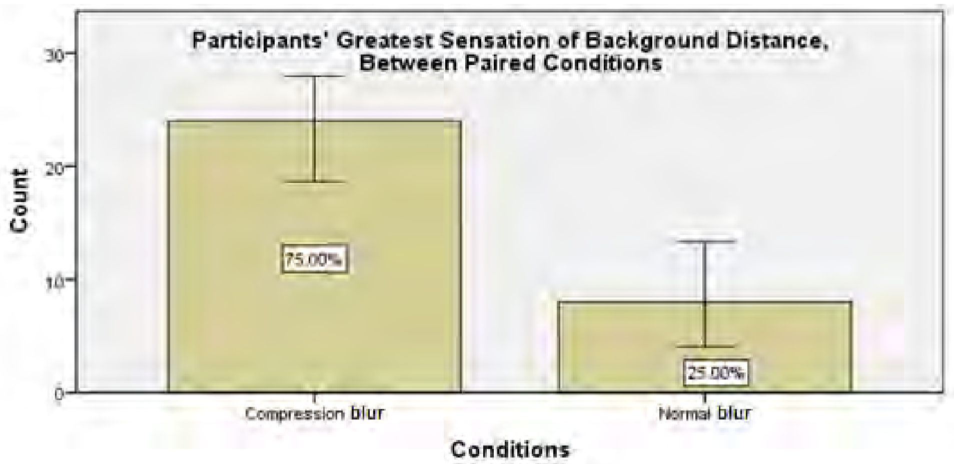


Figure 4.30. Bar chart showing the greatest sensation of background distance (focus object to background), between the normal background blur (nb) and compression background blur (cb) conditions.

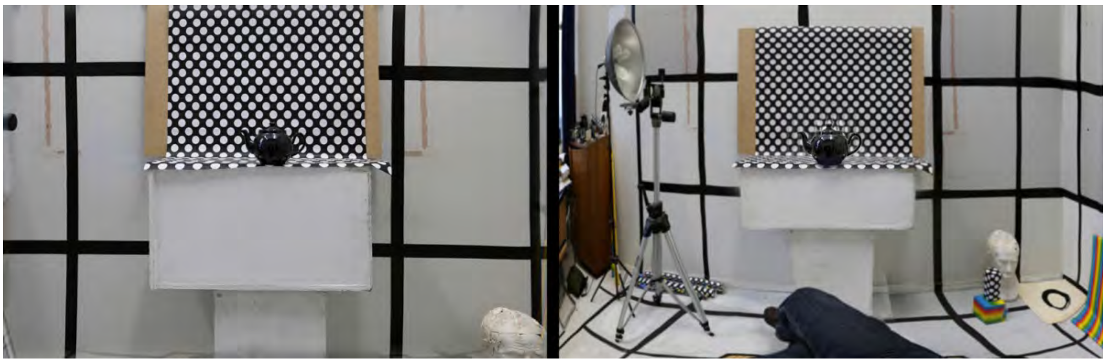
4.3.3 Summary

The analysis of this task found a significant difference in all but one of the paired conditions (normal background blur and compression). It was established that the compression condition consistently communicated a significantly greater sensation of background distance in comparison to a normal condition. In addition, background blur was shown to significantly enhance the feeling of background distance in both the normal and compression conditions. However, the compression background blur condition was significantly preferred by participants over the normal background blur condition. As such the normal background blur condition recreated the same level of background distance as the compression condition without background blur.

4.4 Experiment 5

Paired conditions were also used in the final experiment, with stimuli containing a complete Fovography picture alongside its equivalent normal photograph of the same scene (Figure 4.31).

Glass stimulus



Teapot stimulus

Watch stimulus

Figure 4.31. Without guidance to a focus object, participants look from side to side between a Fovography condition and a normal condition of the same scene; deciding which condition provides the greater environment depth for each of the stimulus (condition on the right, or the left).

The Fovography pictures were given an equivalent amount of compression image effect as used in the Bombay Sapphire compression pictures, and there was negligible enlarging of the intended focus area. However, varying intensities of object doubling and blurring before and behind the intended focus area and peripheral indistinctness (blurring) were used for each scene. It is hypothesised by Pepperell that the combined use of Fovography image effects in pictures, improves the perception of depth and achieves a better direction of visual attention in comparison to normal photographs (Pepperell and Burleigh, 2014). In order to test these predictions, participants were asked to view stimuli (without guidance to a focus object) and decide which of the two conditions provided the greatest sensation of depth. Furthermore, without guidance to an intended focus area, insight into the validity of the Fovography picture to improve directional focus can still be carried out. This was achieved using eye tracking data of participants' behaviour in relation to given areas of interest within presented stimuli.

4.4.1 Procedure

The instructions for the task were verbally explained whilst being displayed on the eye tracking monitor. The instructions were:

> Two pictures will be presented next to each other.
> Verbalise which provides greatest sensation of depth (right or left)?
> Then press the space bar to move forwards to the next slide.

Participants were told to spend as much time as they needed viewing each stimulus before deciding which of the two conditions (the right or the left), presented at the same time, provide the greatest sensation of depth. It was hoped that a distinction between both conditions (Fovography picture and Normal photograph) being displayed as a glass, watch and teapot scene at the same time would find in favour of the Fovography condition. In each case, after a choice had been made between conditions, participants would give a short verbal explanation for their decision. The normal condition was positioned on either the right or the left of the Fovography condition and for presentation fairness a different viewing arrangement of stimuli was used for each group of participants (Appendices 10.1).

4.4.2 Findings

The condition that provided participants with the greatest sense of depth in each stimulus were compiled into a results table for statistical analysis (Appendices 10.2) and the verbal explanations for each chosen condition were transcribed (Appendices 10.3). When participants viewed the teapot stimulus, they showed an overwhelming preference towards the Fovography condition producing a greater impression of depth in comparison to the normal condition (Figure 4.32).

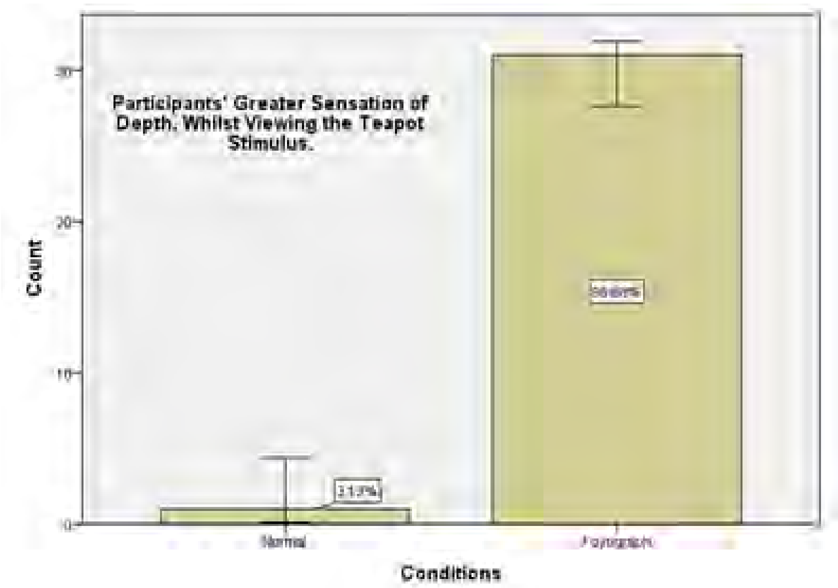
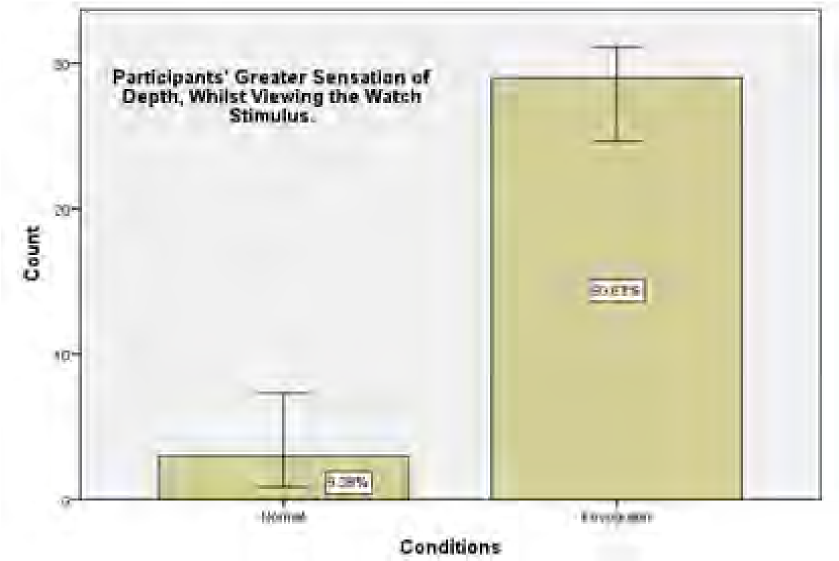


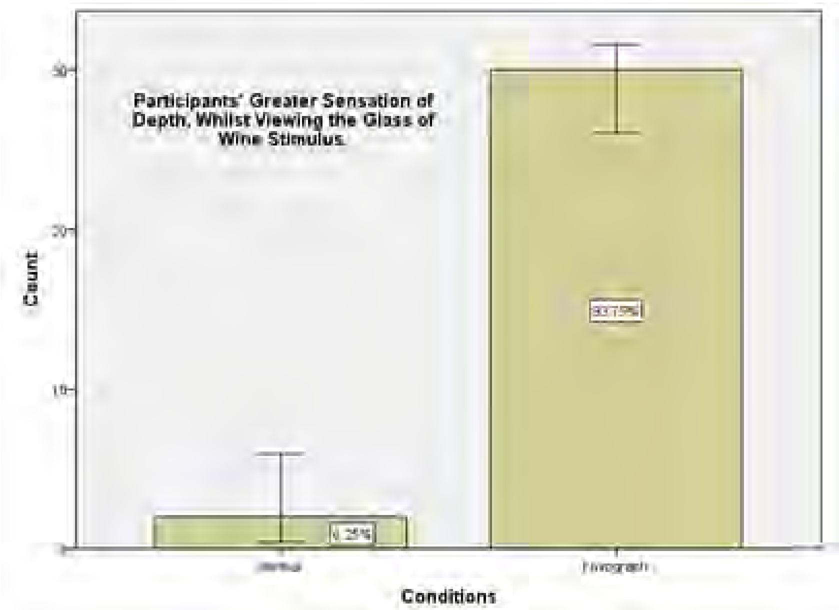
Figure 4.32. Sensation of Depth bar chart: showing participants' decision between the Fovography and normal condition, for greater sensation of depth, in the teapot stimulus.

Using the Chi-square test of association, a very significant interaction was found between the paired teapot conditions: X^2 (1, N = 32) = 28.125, p=.001 (Appendices

10.4). In addition, very significant interactions *p*=.001 were also found in favour of the Fovography condition for the watch and the glass stimuli (Figure 4.33).



The watch stimulus produced a very significant interaction in favour of the Fovography condition X^2 (1, N = 32) = 21.125, *p*=.001 (Appendices 10.5).



The glass stimulus produced a very significant interaction in favour of the Fovography condition X^2 (1, N = 32) = 24.500, *p*=.001 (Appendices 10.6).

Figure 4.33. Sensation of Depth bar charts: showing participants' decision between the Fovography and normal condition, for greater sensation of depth, in the watch and glass stimuli.

Because there were an odd number of stimuli (three) and their outcome fixed to either a normal or Fovography condition, participant preferences were calculated into a conditions totals table by way of favouritism (Appendices 10.7). As expected, the results showed an overwhelming preference towards the Fovography condition producing a greater overall feeling of depth in comparison to the normal condition (Figure 4.34).

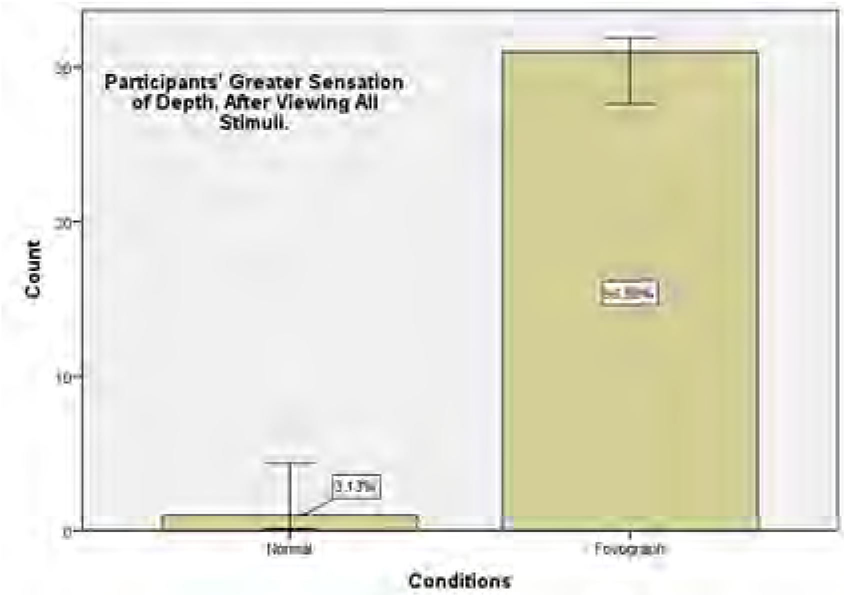


Figure 4.34. Bar chart comparing participants overall preference between the normal and Fovography conditions, in representing a greater sensation of depth, from viewing all stimuli.

A Chi-square test of association was performed on the overall choice of condition and a very significant interaction was found between conditions: X^2 (1, N = 32) = 28.125, p=.001 (Appendices 10.8).

4.4.3 A selection of participant explanations

The following participant explanations offer insight into the characteristics of the complete Fovography condition, which was overwhelmingly chosen over the normal condition as producing a greater awareness of depth.

Participant G1a Group 1 (Stimuli order **-** glass, watch, and teapot)

Left = Fovography: “The hands look pretty much the same size, but the table and the objects in the background, they seem smaller, more drastically smaller, and also you can see further on the ones on the left, the ones on the right seem a bit close.”
Right = Fovography: “Again you can see a lot more in the background; you can see a further distance. Also your focus is drawn to the watch, because of the clarity. So looking at it there you can see that there is something in the distance.”
Right = Fovography: “A lot more going on in the picture and your attention is brought to the one on the right, and the objects on the left, the cupboard they seem a little curved, that gives it a greater sense of depth I think. The left image seems a little bit flat.”

Participant G4c Group 4 (Stimuli order - teapot, watch, and glass)

Right = Fovography: "Because there is more going on in the picture and you get more of a sense of depth, because there are other things in the picture (list items), and the things in the right hand corner. Depth is relative to the objects around it, so that's why the right image appears deeper, and I have a greater sense of depth with that one because it is relative to other objects whereas the other one is relatively straightforward."
Right = Fovography: "I think there is more going on in the picture. The blurred background gives me a sense that it is a much deeper image. Whereas because the watch and wrist is more in focus, it almost feels like the rest of the picture is further away. Right image seems to have more depth than the left image. There is a lot more going on in the right picture as well."
Left = Fovography: "Because there is a lot more colour and a lot more going on, so it's relative to what I am focusing on straight away is the glass, but I am looking at the glass but there is so much going on around it. The way the glass is tilted gives it an impression that it is a deeper picture, but it is just different to the right hand picture. The leg is blurred in the left hand picture, which almost seems like the glass if further away than the leg so I think that's more depth. I am more going on there is a lot more, there are a lot more objects in that picture, richer colours and stuff like that."

Participant G5d Group 5 (Stimuli order - watch, teapot, and glass)

Right= Fovography: "Because I can see more of the room, the watch is up close, and I can see more behind it. Whereas on the other one it's all up close, and you can't see anything behind."
Right= Fovography: "There is more stuff in it. So that makes me feel that I can. There is more depth; I am seeing more going back, my visual field is. There is more in my visual field so that's why I feel that it's, I can see further back whereas the left hand one is up close, so it doesn't feel like my visual field as much, because I don't feel I can see back as far., and it just seems closer (the image on the left).
Left= Fovography: Same reason again I suppose. Because I can see further down the room, so it seems deeper."

Participant G6c Group 6 (Stimuli order - watch, glass, and teapot)

Right = Fovography: "Just because the background objects are, appear to be further away. It is a bit confusing at first to make sense the image is a bit fuzzy in a sense, but if you compare the oriental teacup that's much closer in that image, than it is on the image on the left than it is on the right. More information range."
Left= Fovography: "It is to do with the view you have on the surrounding environment. I am tilting my head back a little in the left one, not that I usually wear leggings obviously. Both I think are believable, certainly more believable than the first one, the right (previous images) I struggle to find it so believable; but the left image gives you a more realistic sense of depth in this round of images, but it feels like everything is a bit further away. Yes the image on the left."
Right= Fovography: "Just because there are more clues in the image about the depth, the visual depth if you know what I mean. There are more things to make a reference; more objects in the background, so you have the bust for example

in the bottom right, and then you have the other things in the background like right in the corner there, you have some sort of cupboard. I find it difficult to make my decision, because something about the composition on the image on the left sort of conveys a certain sense of perspective, a feeling of depth, but because there is less information in it to sort of refer to, and because you sort of have this wide angle field of view in the right image. I went with the one on the right."

However, participants who favoured the normal condition in some stimuli still described a positive response towards the complete Fovography condition producing an awareness of depth.

Participant G1b (Group 1 - Stimuli order - glass, watch, and teapot)

> **Right = Normal:** "Because I could see more I think. It was less blurry."
> Right = Fovography: "Because I can see more of the room."
> Right = Fovography: "For the same reasons; I can see more of the room. The teapot is drawing my focus inwards, because it is less blurry than the background."

Participant G4h (Group 4 – Stimuli order - teapot, watch, and glass)

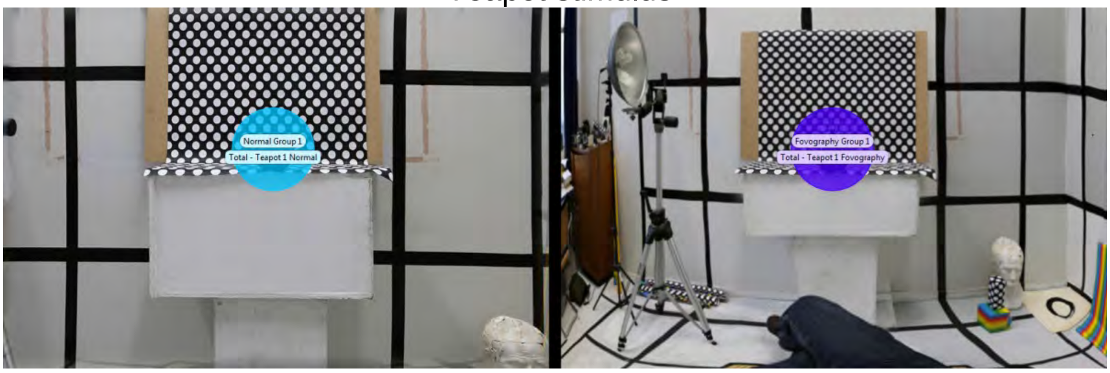
> Right = Fovography: "Because it seems that it is taken from further away, so there is more distance in the, there is more depth in the image. So the main thing is the size of the grid, so the teapots are the same size, but the grid here (left image) is closer, and in this one it is further away (right image) slightly smaller."
> Right = Fovography: "There is, similar to the last one in a way. So there is, I get a greater sense of things being further away, partly because there are more things there, and they are smaller."
> **Right = Normal**: "It's difficult. Everything seems a little flat in the one on the left. So, whilst there are more things and they are smaller, in a further away and distance kind of thing. They also could just be on a screen that is flat. There is more distance represented in the left image, but it seems more flat."

4.4.4 Area of interest analysis between foreground focus areas

In addition to participants explaining why the condition they selected produced the greater sense of depth, area of interest analysis could be carried out using eye tracking data. Each stimulus was given two areas of interest, which matched in size across the paired conditions; one was located over the object in the intended focus area within the complete Fovography condition, and the other area of interest over the same object in the normal condition (Figure 4.35).

Glass stimulus

Teapot stimulus



Watch stimulus

Figure 4.35. An area of interest is positioned over the object in the intended focus area in each of the paired conditions, allowing comparative eye tracking analysis to be carried out for the watch, glass, and teapot stimuli.

The Tobii studio software was used to calculate mean descriptive statistics for each area of interest, which were then outputted as bar charts for discussion: Time to First Fixation Means, Fixations Before Means, Visit Duration Means, Visit Count Means, and Fixation Count Means (Appendices 10.9). However, the area of interest data showed that a different number of participants had fixated on conditions across stimuli (Appendices 10.10). For the watch stimulus, all 32 participants fixated at least once on the Fovography condition area of interest, but only 28 of these participants fixated on the normal condition area of interest. This meant that the sum of each area of interest when outputting mean descriptive statistics (such as the Time to First Fixation Mean) were being divided by a different number (N count) of participants (Appendices 10.11). Because of the repeated measures design of the task and stimuli which involved the comparison of two different conditions at the same time, a paired t-test was chosen as the best method of statistical analysis. It was therefore necessary that the number of participants who recorded a fixation on both areas of interest in stimulus was the same. This allowed mean descriptive statistics to be calculated, represented by bar charts and, most importantly, matched with statistical analysis.

4.4.5 Findings

The ‘Time to First Fixation Mean’ bar chart (Figure 4.36) shows a smaller Time to First Fixation mean before participants viewed the area of interest in the Fovography condition, in comparison to the normal condition. This is seen across all stimuli and suggests that the Fovography condition achieves a greater amount of directed attention towards the intended focus area in comparison to the normal condition.

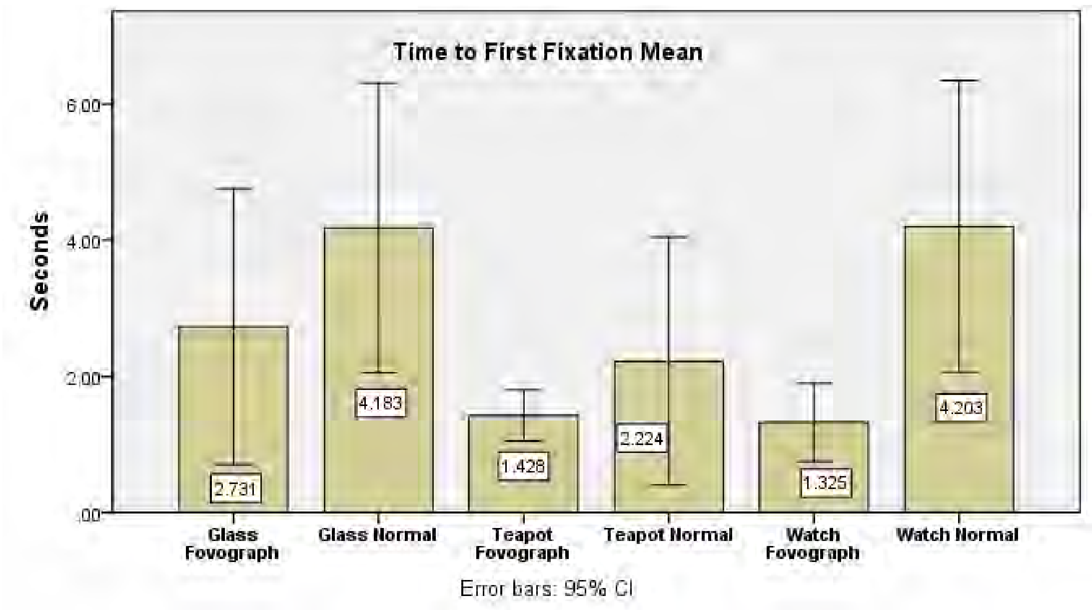


Figure 4.36. Fixations Before Mean bar chart: shows the number of times participants fixate on the media before fixating on an area of interest or area of interest Group for the first time (count).

The paired t-tests for Time to First Fixation means (Appendices 10.12) showed that there was no significant interaction (p>.05) between the glass Fovography and normal conditions: t = -.092 df = 28, p = .927, d = .02, and the teapot Fovography and normal conditions: t = 1.467, df = 30, p = .153, d = .26. According to Cohen (1988), the effective size for the glass stimulus was negligible (a small effect being .10), whereas the teapot stimulus produced a small effective size, just below a medium effect (.30) (Appendices 10.13). However, the paired t-tests showed a significant interaction (p<.05) between the watch Fovography and normal conditions t = 2.839, df = 27, p = .008, d = .54. According to Cohen (1988), a large effective size was produced (.50).

The Fixations Before Mean bar chart (Figure 4.37) gives a very similar pattern to that illustrated in the Time to First Fixation Mean bar chart (Figure 4.36). It demonstrates that participants fixate within the Fovography area of interest with fewer previous fixations being made elsewhere in comparison to the area of interest in the normal condition.

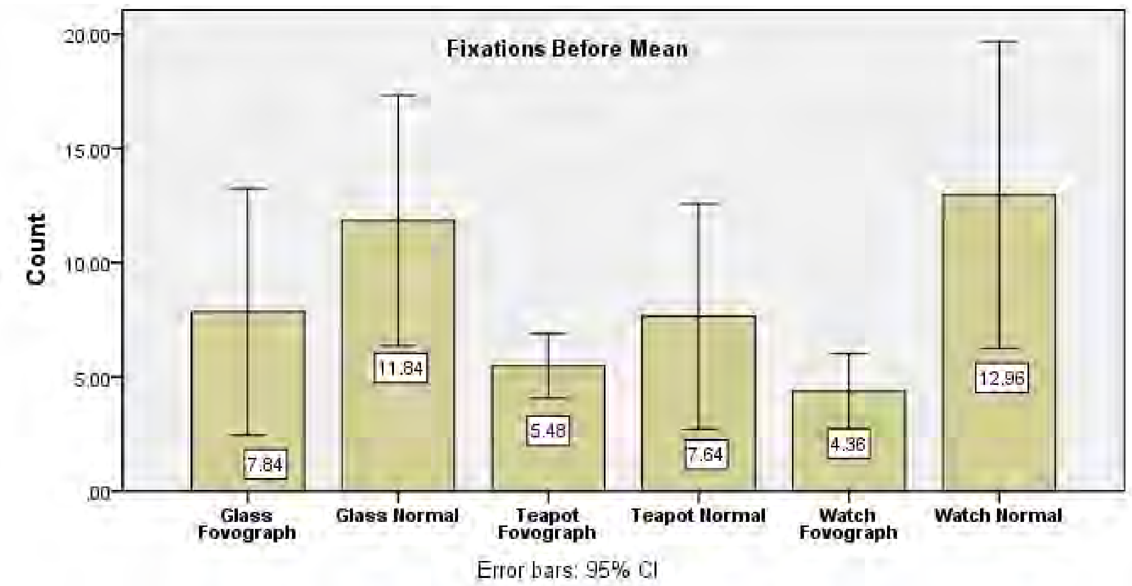


Figure 4.37. Fixations Before Mean bar chart: shows the number of times the participants fixate on the media before fixating on an area of interest or area of interest Group for the first time (count).

The paired t-tests for ‘Fixations Before Means’ (Appendices 10.14) showed that there was no significant interaction (p>.05) between the glass Fovography and normal conditions: t = -.412 df = 28, p = .684, d = .08, and the teapot Fovography and normal conditions: t = 1.444, df = 29, p = .159, d = .26. According to Cohen (1988), the effective size for the glass stimulus was negligible (a small effect being 10), and the teapot stimulus also produced a small effective size, just below a medium effect (.30) (Appendices 10.15).

The paired t-tests showed a significant interaction (p<.05) between the watch Fovography and normal conditions t = 2.839, df = 27, p = .008, d = .54. Whereby, according to Cohen (1988), a large effective size was produced (.50).

4.4.6 Summary

Analysis of participants' eye tracking data for both matched areas of interest situated over the foreground intended focus area in the watch, glass, and teapot conditions, further reinforces the significant preference that participants knowingly gave towards the Fovography condition rather than a normal condition during the depth proficiency task. By changing the side by side viewing arrangement of the Fovography and normal conditions and their altered presentation orders for the participant groups, removed experimental bias during the presentation of stimuli. In addition, both side by side conditions of the matched scene occupied the same amount of space with corresponding luminance and hue values. With these conditions being displayed simultaneously, participants had an unbiased opportunity to explore each stimulus at the beginning of their presentation, and view either condition in the same way before deciding which (the right or the left) provided the greatest impression of depth. With this in mind, the Time to First Fixation mean and Fixations Before mean calculated using the eye tracking data (obtained from the same sized area of interest in the centre of each picture) is very encouraging.

The remaining descriptive statistics outputted for the Visit Duration means, Visit Count means and Fixation Count means are not discussed further. This is due to the inherent recording bias produced by participants giving a verbal explanation for each chosen condition, without a time constraint being enforced. Participants further examined each scene and talked about the condition they preferred; this meant looking at the Fovography condition for a disproportionate amount of time in the majority of cases.

The participants' visual investigations, and their attention durations whilst explaining their preference for Fovography conditions over normal conditions were outputted using the Tobii eye tracking software. These heat map visualisations for the teapot, glass and watch stimuli (Appendices 10.16) showed increased peripheral investigations with extended durations across the Fovography conditions, in comparison to the normal conditions in this task and previously visualised Fovography conditions with a constrained viewing time. For this reason, they are also not discussed further. Nevertheless, the Visit Duration Mean, Visit Count Mean, and Fixation Count Mean bar charts (Appendices 10.9) show favour towards the Fovography condition's ability to direct participants' focus, as eye tracking data is only outputted from within each area of interest.

5 Discussion and conclusion

5.1 Introduction

This concluding chapter begins by revisiting the aims of the research, the founding of research objectives used to design experiments to explore the claims of Vision-Space and Fovography pictures, as well as the requirements to accomplish these experiments. The findings are then discussed from experiments that examined Vision-Space and Fovography image effects in isolation and in combination to meet established research objectives. A final conclusion follows, discussing the validity of explored viewing advantages that Vision-Space and Fovography imaging theories hypothesise, in comparison to pictures of equivalent scenes created using geometrical perspective.

5.1.1 The research aims and developing objectives

The key aim of this research is to test whether imaging methods based on the way artists have perceived and depicted visual space (at times adopting theories about the visual system from visual science) can be used to improve the perception of depth compared to conventional pictures generated by optical devices such as cameras.

In order to meet the key aim of the research and explore the validity of other hypothesised viewing advantages, four objectives were identified in relation to the study of Vision-Space and Fovography imaging theories. As a result, in addition to investigating complete Vision-Space and Fovography pictures (which use a combination of image effects), a significant part of the research involved isolating key image effects proposed as being critical to hypothesised viewing advantages in each imaging theory. This was important when developing new stimuli, reducing confounding variables in experimental analysis from pictures containing multiple image effects. Moreover, it was hoped that the testing of specific image effects in isolation would allow the provision of more usable feedback for the developers interested in further optimisation of the imaging methods.

In order to meet the objectives identified in the research, a substantial amount of time had to be spent on self-development within various specialist areas. This involved learning how to accurately generate Vision-Space and Fovography pictures, using various computer aided design systems and a post-production tool for Vision-Space pictures. Next, combinations of stimuli had to be produced to allow meaningful analysis from questions designed within each experiment. This also meant becoming skilled with appropriate experimental equipment such as eye tracking systems, learning observer software for the analysis of eye tracking data, developing proficiency in a variety of statistical analysis methods and the Statistical Package for the Social Sciences (SPSS). Additionally, in order to enrol participants and run experiments, each methodology had to be reviewed and satisfy an ethical approval process by Cardiff Metropolitan University.

5.2 Vision-Space: Findings and discussion for experiments 1 and 2

The research objective explored in experiment 1 was to compare a Vision-Space picture against a geometrical perspective picture, to see whether a number of viewing advantages such as improved perception of depth are experienced from a picture using a combination of Vision-Space image effects, as Jupe (2002) hypothesises.

As with pictures created using linear perspective, Vision-Space pictures are constructed around a specific fixation point in order to simulate the point of view of an observer looking at a given point in space (Kubovy, 1986). A Vision-Space picture is designed to direct the attention of the observer to this point by the inclusion of several image effects, among them being the use of spatial radial disorder around the periphery (Jupe et al., 2007). These image effects are used with the aim of more faithfully matching the experience of natural vision and enhancing the perception of depth. The analysis of experiment 1 supported the main hypothesis: that a Vision-Space picture is able to significantly increase pictorial depth in comparison to a geometrical perspective picture produced using conventional imaging methods. As well as the reported perception of depth being significantly increased, participants showed a significantly increased feeling of being ‘factored into’ (present in) the Vision-Space picture, which resulted from an improved proximity to the object under fixation. Although an improvement was found in participants’ focus being directed (maintained attention) on a planned focus location and their understanding of location differences between surrounding objects, both were not significantly improved in comparison to the normal picture. In addition, the normal picture was judged to depict the scene in a way that was more ‘realistic’ than the Vision-Space picture, although not to a significant degree. This was largely due to the normal picture being clear throughout, that is, lacking the disorder effects, which is how participants reported their own visual experience to be. Pirenne (1970) discusses that an extended clear detailed scene is experienced during perception as a result of continuous eye movements which allow attention parts of the scene within the fovea, creating the false impression that our entire visual field is equally clear. Additionally, distortions caused by the eyes optics are removed by the visual system and are not apparent to the observer during perception (Palmer, 1999). However, due to the psychological phenomenon of the ‘mere-exposure effect’, (Zajonc, 1968; Bornstein, 1989) by which people tend to develop a preference for things merely because they are familiar with them, we might expect normal pictures to be significantly preferred over Vision-Space pictures, which by comparison are less familiar. The fact that no significant preference for the normal picture was found suggests the Vision-Space picture containing multiple image effects appear, to some extent, as ‘real looking’.

Whilst learning about image effects used in Vision-Space pictures during the design of experiment 1, Jupe discussed in person that a higher falloff value of spatial radial disorder would have corresponded closer to his own documented experience of a focused-on foreground object. However, the Vision-Space pictures had been designed to be as familiar looking as possible (less off-putting) to commercial clients. The use of a higher falloff value would have increased the intensity of disorder in all directions surrounding the fixation point whilst reducing the extent of the clear focus area. Through further discussions with Jupe in person, he proposed that this adjustment would promote an increased directed (maintained) focus on a planned focus location and bring with it a heightened understanding of peripheral object locality. However, without the availability of real-time eye tracking to update each new focus area clearly, it was thought likely that being able to view the increased disorder, which was peripherally intended, could further reduce the visual appreciation of a Vision-Space picture. This is similar to the importance placed on blur effects being applied through real-time, point of focus eye tracking systems to produce a realistic visual experience

(Rokits, 1996). Additionally, the amplified prominence of disorder may have a negative effect on the confirmed improvement in perception of depth, and feeling of being ‘factored into’ (present in) a Vision-Space picture.

The research objective explored in experiment 2 was to examine the spatial radial disorder image effect, critical to a Vision-Space picture, which Jupe (2002) hypothesises to provide a number of viewing advantages, such as an improved perception of depth compared to the experience of blur in a picture.

The spatial radial disorder image effect was seen as a key Vision-Space pictorial depth cue, which led to the study of this imaging effect in isolation. It was decided to compare the spatial radial disorder image effect against the familiarity of blur in pictures which is used to produce a sensation of depth through representing the depth of field limitations of the eyes (Lin and Gu, 2007; Nefs, 2012; Mauderer et al., 2014). Blurring caused by the depth of field limitations of the eye’s optics is accepted as producing depth cues in human vision (Atchinson and Smith, 2000; Mather and Smith 2002; Ciuffreda et al., 2007). Experiment 2 was carried out using pictures with matched ‘Spatial Radial’ values of disorder and blur. Furthermore, because the spatial radial disorder and spatial radial blur pictures remained the same size as the geometrical perspective picture (normal picture devoid of additional image effects) they were reprocessed from, the normal picture was included as a further comparative condition.

Experiment 2 was designed to find out if a normal picture with either disorder or blur spatial radial image effects (increasing image effect value outwards in all directions from a central fixation point) is able to improve the experience of depth in comparison to the normal picture, and whether disorder performs better than blur. As with experiment 1, it was decided to find out if participants’ directed focus was improved and a number of other hypothesised viewing advantages of the Vision-Space imaging theory were also studied. In addition, the normal picture would offer insight into the suggestion that computer generated pictures that do not use depth of field blur can look artificial (Hillaire et al., 2008), with the spatial radial image effects of blur and disorder being used in its place.

The participants' identified focus locations were mainly centrally positioned for each of the three conditions. This is thought to be caused by a number of possible reasons, such as the central fixation bias where fixations cluster around the centre of scenes (Zelinsky, 2012), that the sky and wall background being clearly understood allowed improved depth ordering and increased prominence of objects in this area (Finkel and Sajda, 1992) or, as found in experiments by Nuthmann and Henderson (2010), that participants prefer to fixate within the center of objects in scenes: this might be a reason for the complete and more visible occluded balloon being selected the most. However, the planned focus location which was the same off-centre balloon in each condition was occasionally chosen in the spatial radial disorder and spatial radial blur pictures. Furthermore, the normal picture which was devoid of additional image effects was given some of the farthest identified focus locations from the planned focus location. With blurring being a common design technique used to direct viewer's attention to a more detailed and clearer area within a picture (Ware, 2008), it was expected that more of these identified focus location differences between the normal picture and the spatial radial image effect pictures would have been found. Even though the spatial radial image effect produced some identified focus locations close to the planned focus location, neither disorder nor blur pictures could be shown to be an improvement over each other or the normal picture. This was because methods to quantify absolute distances from the planned focus location to the identified focus locations were not attainable using the original computer generated scene or its coordinates. Additionally, the confidence rating that participants gave to their identified focus location being correct proved non-significant between the conditions. However, the confidence rating was found to be higher when viewing the spatial radial blur picture rather than the spatial radial disorder picture, with both of these being received more positively than the normal picture. The low confidence rating given to the normal picture devoid of image effects follows Kenny et al's. (2005) confirmed importance of image blur in first-person shooter games, to direct and hold participants' attention in clear areas during game play.

The findings of the participants' experience of how well they could determine the different locations of objects after viewing each condition, indicated that the apparent presence of distance was better understood in the normal picture, closely followed by the spatial radial blur picture, and then the spatial radial disorder picture. Nonetheless, the results proved non-significant. Additionally, the spatial radial image effect was hypothesised to improve the observer's feeling of being 'factored into' (present in) the scene and, even though spatial radial blur performed better than the normal picture, this difference was marginal and proved non-significant. However, the spatial radial blur picture performed significantly better than the spatial radial disorder picture, suggesting that blur is more enriching than disorder in factoring the viewer into a picture. Furthermore, from an identified focus location the spatial radial blur picture was found to improve the sensation of spatial awareness (which was used as an alternative indication to the perception of depth) the most, followed by the normal picture, and lastly the spatial radial disorder picture (which performed significantly worse than the spatial radial blur picture). This finding further demonstrates that the spatial radial presentation of disorder is not an improvement over blur, and that the spatial radial image effect which is suggested to provide the viewer with an increased apparent presence of distance (spatial awareness), between the planned focus location and the three-dimensional location of objects does not improve the perception of depth over a normal picture (which was devoid of additional image effects).

The participants' experience of visual comfort when viewing each condition showed the normal picture as being slightly better received than the spatial radial blur picture, and that the spatial radial disorder picture was again significantly less comfortable to view than the spatial radial blur picture. This continued the trend of blur being preferred to disorder and suggests that the spatial radial application is not an improvement over a normal picture. The visual comfort of each condition also related to how 'real looking' each condition appeared to participants, with the normal picture being preferred the most and the spatial radial disorder picture experienced as being less authentic in comparison to the spatial radial blur picture. These results indicate that the spatial radial image effect might not follow Hillaire et al's. (2008) similar recommendation that computer generated images that use depth of field blur can look artificial. In addition, these results do not corroborate Jupe's hypothesis that the depth cues produced from the application of spatial radial disorder (which progress the original two-dimensional concept outlined by Koenderink (2001)), more closely represent the spatial structure of natural vision within a picture compared to the use of blur. The overall trend towards blur being preferred to disorder can be attributed to the psychological phenomenon called the 'mere-exposure effect', by which people tend to develop a preference for things merely because they are familiar with them (Zajonc, 1968; Bornstein, 1989) - in this case the familiarity that participants have viewing pictures with blur over disorder. Nevertheless, even though the spatial radial application of blur outperformed disorder throughout experiment 2, both were described by participants as being noticeable unnatural distractions. This relates to the predilection towards the normal picture, associated with it showing an extended clear detailed scene as experienced during perception due to continuous eye movements which allow attention parts of the scene within the fovea (Pirenne, 1970), and the visual system removing distortions caused by the eyes optics (Palmer, 1999).

The significant increase in participants' directed attention to a planned focus location and understood locality of peripheral objects, discussed in experiment 1, did not take place when spatial radial disorder was amplified and used in isolation in experiment 2. In addition, neither did it take place with the isolated application of blur using the spatial radial image effect in comparison to a normal picture. Moreover, throughout experiment 2 the spatial radial application of blur outperformed the same application of disorder and at times this difference was significant. The normal picture also showed visual improvements over the spatial radial disorder picture throughout experiment 2, with the exception of the confidence rating given to the spatial radial disorder picture in directing attention towards a planned focus location.

5.3 Fovography: Findings and discussion for experiments 3, 4 and 5

The third research objective carried out was to explore the compression image effect, critical to a Fovography picture, which Pepperell hypothesises to provide an improved directional focus and perception of depth, compared to a picture based on geometrical perspective (Pepperell and Burleigh, 2014).

Similar to Vision-Space, the Fovography imaging method assumes a given fixation point within a picture, in relation to which the rest of the picture is said to create a sense of depth. Experiment 3 examined directional focus through eye tracking analysis, and experiment 4 examined the subjective perception of increased depth in pictures, through participants making stimuli predilections to reflect their experience towards an experiential description.

In experiment 3, participants were instructed to familiarise themselves with stimuli being presented concurrently for five seconds each, which included normal pictures and compression pictures, both with and without depth of field blur (background blur). The resulting analysis of the eye tracking data showed similar visit count means within the foreground intended focus area for each condition. These similarities are perhaps due to either the central fixation bias, where fixations cluster around the centre of scenes (Zelinsky, 2012), or the improved depth ordering and increased prominence of the central attention object (Finkel and Sajda, 1992). However, both conditions with background blur resulted in increased fixation count means and visit duration means within the foreground intended focus area. This is as expected as photographers often use depth of field to sharpen an area to put emphasis on a certain object (Wang et al., 2001). Lin and Gu (2007) also talk about the depth of field effect as an important visual cue used in photographs and computer graphics pictures to demonstrate focus of attention and depth perception. Furthermore, Kenny et al. (2005) confirmed the importance of image blur in first-person shooter games, reporting that participants' attention was held in clear areas in the centre of the screen. Consequently, it was unexpected to find the normal and compression pictures without background blur providing faster time to first fixation means and lower fixations before means for the foreground intended focus area in comparison to both pictures with background blur. However, no significant difference was found between the conditions. The overall analysis of the foreground intended focus area across all four conditions, revealed that the compression picture was unable to produce a significant improvement over a normal picture in directing participants' attention. Moreover, when background blur is included, compression and normal pictures are similarly enhanced and degraded in directing attention to the foreground intended focus area.

Heat map analysis of the participants' gaze behaviour was also carried out. This analysis confirmed that the main duration of attention for normal and compression pictures with background blur lay within the foreground intended focus area. It also showed visual investigations elsewhere in the pictures to be sparse and low in duration. A similar pattern was also produced by the normal and compression pictures without background blur, possibly due to the central fixation bias where fixations cluster around the centre of scenes (Zelinsky, 2012) or the improved depth ordering and increased prominence of the central attention object (Finkel and Sajda, 1992). However, an increased number of investigations were shown on the now clearly visible background objects, along with attention durations in the background becoming greater and a slight increase in attention durations found on less centrally located foreground objects (foreground objects peripheral to the foreground intended focus area). It was also noticeable that slightly more background visual investigations were found in compression pictures (with and without background blur) than in normal pictures (with and without background blur). However, these investigations were on new objects, now able to be seen due to an increased amount of background provided by the compression picture. The overall heat map analysis of participants' visual investigations, showed a continuation of background blur having a greater influence over the locality of visual investigations, with the duration of attention being more on the foreground intended focus area, in comparison to the compression image effect.

Further analysis was conducted on background area of interest regions in the pictures, as defined using the eye-tracking software. Unfortunately, area of interest data showing differences of attention between background objects, could not be statistically analysed for the same set of analysis tasks previously used for the intended focus area. Nevertheless, the percentage fixated means continued to show reduced attention on background objects in compression and normal pictures with background blur, evidenced by a drop in the number of participants who fixated at least once on these areas of interest. The visual effect of blur is discussed by Ware (2008), as common design technique used direct the viewer's attention to a more detailed and clearer area within a picture. Additionally, irrespective of background blur, the compression image in comparison to the normal picture showed an ability to reduce the number of participants who fixated at least once on the same background object. This suggests that Pepperell and Haertel's (2014) method of depicting the full scope of the human visual field, with peripheral information being increasingly compressed (in this case discounting the enlargement of an object held in attention) may lead to less attention being directed to background areas of pictures.

The difference of attention between secondary foreground objects which are situated in front of background blur, were also unable to be statistically analysed for the same set of analysis tasks used for the intended focus area. Nevertheless, the percentage fixated means for the bottle and glass in the foreground intended focus area and secondary foreground objects advocate that centrally located objects uphold visual attention. As expected, the bottle and glass in the central and foreground intended focus area received considerably more attention than secondary foreground objects, and centrally located secondary foreground objects more so than those less centrally located. In conjunction with the already discussed central fixation bias where fixations cluster around the centre of scenes (Zelinsky, 2012), these results link with discriminating objects based on occlusion relationships in the foreground intended focus area (Finkel and Sajda, 1992). Additionally, the compression pictures with and without background blur, produced greater percentage fixated means for less centrally located secondary foreground objects, in comparison to the normal pictures with and without background blur. It is important to note that the compression picture with background blur is actually free from the compression image effect in the foreground intended focus area which contains the bottle and glass. However, the compression image effect is applied to secondary foreground objects in isolation and then combined with blur in the background. The compression image effect is therefore attributed with making secondary foreground objects, which are less centrally located in normal pictures, become more centrally located in compression pictures, with these objects increasingly being attended to in comparison to those in normal pictures of the same scene (effectively the same object brought more central).

Statistical analysis using the percentage fixated means revealed that the compression picture with background blur produced the only non-significant interaction between the bottle and glass in the foreground intended focus area, and the centrally located secondary foreground objects. This finding suggest that, in addition to the central fixation bias where fixations cluster around the centre of scenes (Zelinsky, 2012), both compression and background blur image effects are required in combination to improve the focused attention of secondary foreground objects within the centrally located foreground intended focus area.

In experiment 4, where participants had to decide which condition produced the greater perception of distance between a background and a focused-on object, the compression picture was significantly favoured over the normal picture. This result suggests that Pepperell and Haertel's (2014) method of depicting the full scope of the human visual field, with peripheral information being increasingly compressed (in this case discounting the enlargement of an object held in attention) within the format size of a normal photograph, improves pictorial depth beyond that of a normal photograph. In addition, the use of background blur significantly enhanced the sensation of depth between compression and compression background blur pictures, and normal and normal background blur pictures. These results further demonstrate that blur is an important perceptual depth cue (Nefs, 2012). Furthermore, the compression picture with background blur was significantly favoured over the normal picture with background blur, which could only match the sensation of background distance produced from the compression picture (without background blur). Therefore, it is suggested that the larger visual field represented using the compression image effect, is capable of improving the perception of depth (increasing the apparent presence of distance) in pictures equivalent to the effect of background blur. The use of the compression picture format in comparison to normal depictions of the same scene have also been shown to depict space in a significantly more natural looking way (Baldwin et al., 2014). This study and a second unpublished study (Baldwin et al., In Press 2015) which explores the apparent size of objects in the peripheral visual field, further support the appropriateness of the Fovography compression image effect (Appendices 12).

The research objective explored in experiment 5 was to compare Fovography pictures against geometrical perspective pictures, to see whether improved directional focus and perception of depth are experienced in a picture using a combination of Fovography image effects, as Pepperell hypothesises (Pepperell and Burleigh, 2014).

Experiment 5 examined the subjective perception of increased depth between three normal pictures and their paired Fovography pictures. Participants made stimuli predilections to reflect their experience towards an experiential description. Additionally, through eye tracking analysis, directional focus towards an intended focus area was examined.

For each Fovography picture Pepperell applied an equivalent amount of compression image effect to that used in the Bombay Sapphire compression pictures, and there was negligible enlarging of the intended focus area. However, varying intensities of object doubling and blurring before and behind the intended focus area, and peripheral indistinctness (blurring) were used for each scene. The unified visual image created from binocular vision is discussed by Hershenson (1999); Palmer (1999); Agarwal and Blake (2010) as producing stereopsis within Panum's fusional area which enhances the sensation of depth. This fused area of disparity is roughly the size of the focus of attention; however, outside this area, the images projected onto the retina of each eye are unable to be seamlessly fused together and creates a doubling effect to peripheral viewed objects. The visual effect of double vision was detailed by Pepperell and Ruschkowski (2013) as a pictorial depth cue, and an important image effect which enhances the representation of depth. Fovography pictures also use blurring to demonstrate peripheral information becoming increasingly degraded towards the edge of the visual field. This simulates visual science theory that the retinal image loses sharpness towards its periphery, due to the receptors having a different sensitivity to the ones in central vision (Pirenne, 1970; Palmer, 1999; Snowden et al., 2006; Wolfe, 2000; Bruce et al., 2010). As well as reduced visual resolution driven by retinal processes, additional visual science theory about the visual system suggests an accompanying process; that the ability to selectively attend to a specific location gets worse in peripheral vision, due to attentional resolution diminishing away from central vision (Eriksen and James, 1986; He et al., 1996). Blur is also applied before and behind the intended focus area (object in focus) in the Fovography picture. Blurring caused by the depth of field limitations of the eye's optics is accepted as producing depth cues in human vision (Atchinson and Smith, 2000; Mather and Smith, 2002; Ciuffreda et al., 2007), with Nefs (2012) demonstrating depth of field blur as an effective perceptual depth cue in photographs.

The analysis showed that even when object doubling and blurring before and behind the intended focus area and peripheral indistinctness (blurring) levels were low, the participant's experience of depth was significantly greater for the Fovography picture, in comparison to the normal picture of the same scene. This further suggests that the larger visual field presented using the compression image effect enhances the perception of depth in pictures, compared to pictures produced using conventional imaging methods. However, because the compression image effect is used in combination with object doubling, blurring before and behind the intended focus area, and peripheral indistinctness (blurring), it is unclear to what extent these image effects individually impact on the pictorial depth qualities of the compression image effect.

Nevertheless, in gaming experience experiments by Hillaire et al. (2008) peripheral blur in addition to background and foreground blur was found to enhance player performance, in areas such as presence and realism.

Since each paired normal and Fovography picture of the same scene were displayed at the same time, participants had an opportunity to look at and explore either condition in the beginning of their screening, before deciding which (the right or the left) provided the greatest experience of depth. With this in mind, the eye tracking data analysed from same size area of interest nets placed over the intended focus area in the centre of each picture was surprising. The time to first fixation mean data showed that participants voluntarily chose to fixate on the intended focus area in the Fovography picture much faster than for the normal picture throughout the paired conditions. For the Watch paired condition stimuli, this difference was significant. Additionally, the Fixations Before mean data gave the same positive results across the Fovography pictures, with the Watch Fovography picture receiving a significantly lower number of fixations away from an intended focus area before fixating on it. As previously mentioned, the depth of field effect produced in vision and real optical systems is valued as an important visual cue used to illustrate focus of attention and depth perception in computer graphics pictures and photographs (Lin and Gu, 2007). Wang et al. (2001) also note that photographer's use a small amount of depth of field to put emphasis on a certain object. Furthermore, the application of blur is discussed by Ware (2008) as a common design technique used to direct attention to a clearer and more detailed area within a picture. The object doubling and blurring before and behind the intended focus area and peripheral indistinctness (blurring) levels were more apparent in the Watch Fovography picture. However, it is unsure to what extent these additional image effects used in combination with the compression image effect individually impact on directing visual attention within a Fovography picture. Nevertheless, the results support the complete Fovography picture as improving directed attention towards an intended focus area in comparison to a normal picture produced using conventional imaging methods.

5.4 Conclusion

It has been proposed by many experts that geometrical perspective is the only accurate way to represent the three-dimensional world on a two-dimensional plane, because it is based on the behaviour of light and the laws of geometry (Gibson, 1971; Gombrich, 1960; Pirenne, 1970; Rehkamper, 2003; Ward, 1976). They argue that the role of geometrical perspective is not to record how we perceive a scene in natural vision but to present the eye with the equivalent pattern of light that would emanate from the scene. When a geometrical perspective picture is presented correctly the observer is said to be unable to tell the difference between the picture and the reality it represents.

This PhD has investigated two previously untested imaging methods, Vision-Space and Fovography, in comparison with conventional pictures based on geometrical perspective. This explored whether pictures based on the way artists have perceived and depicted a scene (at times adopting theories about the visual system from visual science), can be used to improve the perception of depth and a number of other hypothesised viewing advantages.

Contributions to knowledge:

Evidence from the experiments undertaken has shown that representing visual experience through new and historic artistic insights, and drawing on theories about the visual system from visual science, creates observations in which a number of different types of pictorial experience are heightened, these being, depth, directional focus, and feeling ‘factored into’ (present in) a picture. These findings challenge the widely accepted claim that conventional pictures (photographs and computer generated renders) based on geometrical perspective are the best way to accurately represent the three-dimensional world on a two-dimensional plane.

- The Vision-Space contributions to knowledge:

The Vision-Space artistic method discussed here which uses an image effect extended from a novel visual science theory (that visual information could be disordered across the visual field instead of blurred), was found to produce an increased experience of depth and feeling ‘factored into’ (present in) a picture, in comparison to a geometrical perspective picture of the same scene. However, the isolated observation of spatial radial disorder, which is employed as a critical Vision-Space image effect demonstrated less impact on the viewer, than the spatial radial application of blur and a geometrical perspective picture of the same scene (devoid of image effects).

These findings show that the observation of multiple Vision-Space image effects which are derived from the way artists have perceived and depicted a scene (essentially without relying on visual science theory), can increase the perception of depth and the feeling of being ‘factored into’ (present in) a picture. Both of these hypothesised viewing advantages occurred even though the visual system is able to process Vision-Space image effects, meaning that these pictures are viewed as being distorted in natural vision. It is possible that, as Jupe claims, this may be because the overall artistic depiction is closer to a representation of the apparent or subjective properties of natural vision, than the objective properties of light or space depicted in a geometrical perspective picture.

- The Fovography contributions to knowledge:

The Fovography imaging method discussed here which is a confluence of artistic depictions based on visual science theories about the visual system, was found to produce an increased experience of depth and directional focus (towards an intended focus area in a picture), in comparison to a geometrical perspective picture of the same scene. Moreover, the isolated observation of the compression image effect, critical to a Fovography picture, was shown to have a continued impact on the perception of depth compared to a picture based on geometrical perspective. Additionally, the combined use of compression and background blur image effects demonstrated further impact for both hypothesised viewing advantages, with the perception of depth experienced from the compression image effect shown to be at least equal to that produced from background blur.

This research found that the observation of Fovography image effects derived from visual science theories about the visual system, have increased the perception of depth and directional focus within a picture, even though the visual system of the viewer is aware of the Fovography image effects. Despite these pictures are viewed as being distorted in natural vision, both of the hypothesised viewing advantages occurred. It is possible that, as Pepperell claims, that this may be because the overall artistic depiction is closer to a representation of the apparent or subjective properties of natural vision, than the objective properties of light or space depicted in a geometrical perspective picture.

5.5 Research implications

The significance of this research shows that imaging technologies which depart from the conventional geometrical model and turn to more artistic or experiential modes of depiction, can achieve a heightened awareness in a number of different types of pictorial experience.

The implications of this research are that future designers of depth sensing technologies or imaging systems, such as cameras, may wish to become familiar with and use some of these techniques in order to increase the perception of depth, directional focus and feeling ‘factored into’ (present in) pictures. Some potential areas that could benefit from both imaging methods might be product advertising, smartphone photography, cinema, television, animation, visual effects, computer games, simulation and immersive virtual reality.

Having found that some artistic methods increase depth perception in pictures, it may mean that there is more artistic knowledge about depth that we are currently not aware of. This would involve the development of further methodologies to attain improved empirical measurements of the structure of the human visual field. Use of this analysis of the human visual experience would help to further develop imaging technologies in order to recreate a more natural depiction of visual space and improved perception of depth.

This research project was originally focused around the Vision-Space imaging method developed by the artist-researcher John Jupe, which creates a novel way of representing visual experience using digital imaging technology known as a post-production tool (Jupe, 2002). However, during the course of the research the collaboration between Vision-Space and Cardiff Metropolitan University ended, thus leading to the investigation of the Fovography imaging method developed by Robert Pepperell. This second imaging method, was based on his own artistic insights about the phenomenal experience of seeing which included vision science knowledge about the visual system (Pepperell and Burleigh, 2014). Through ongoing development of Fovography as a commercially viable technology for use in imaging media, it is hoped to further challenge the idea of pictures based on geometrical perspective as the best method to depict depth in pictures.

5.6 Further possible research

In addition to investigating complete Vision-Space and Fovography pictures which use a combination of image effects, steps were taken in the research to isolate and explore image effects which were seen as key components in each theory. This exploration was crucial in minimising confounding variables in experimental analysis from pictures containing multiple image effects. For the Vision-Space imaging method this involved exploring the effect of disorder on its own, and for the Fovography imaging method the compression image effect was explored on its own and with blur.

These key image effects were established using a single property value in each case, perceived as being optimum for their observation (by the inventor in each case). Therefore, to bring about more usable feedback for the optimisation of key image effects, it is necessary to explore additional property values in each case. Founded on the methodologies already used this would involve the observation of additional conditions, allowing further comparisons to be made between the same key image effects with reduced and amplified prominence, thus extending understanding of appropriate property values.

Moreover, there is a need to carry out further research, especially on the impact of individual effects (monocular depth cues) within compression, for increasing the experience of depth. Subjectively, looking at the results obtained for the compression image effect, people experienced increased perception of depth. However, objectively there are four possible reasons that could have caused this result. These comprise of more objects being present in the scene, reduced size of objects, positional change of objects on the mid line, and that the shape of objects are distorted. Therefore, an experiment to do next would be to find out exactly how each monocular cue impacts on the perception of depth when they are taken out. This experiment would resolve the issue of whether increased depth is associated with distorting the visual field or a monocular cue. A likely outcome is that size constancy (that objects get smaller the further they recede into the distance), which is a consequence of compression would be found as a main cause. Moreover, if the effect of depth through the consequences of compression are titrated out, we may, or may not, have a further interesting result.

There are many possible real-time uses that could be researched for Fovography media such as mainstream gaming, as well as commercial and medical applications. One such example is in the field of Ophthalmology, where it could be explored as a diagnostic and therapeutic tool for individuals with visual defects or deficits. These people often lose their macular vision, which could be compensated for by designing an eye tracking system that enlarges the area being impaired and producing a much clearer picture. Furthermore, by including the peripheral area that is normally excluded with visual impairment, it is expected to give users a greater sense of fixation and depth perception. Ultimately, the goal of the Fovography theory is synthetic vision, whereby looking at a Fovography picture creates the same experience as if viewing first-hand.

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