Rupture in the Senses

Getting to grips with perceptual ambiguity, perceptual integration, and interoceptive awareness through multimedia, interactive systems.

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Thesis Summary

This thesis investigates ways in which interactive multimedia art systems can enable the elucidation of the "transparency of experience": the phenomenon by which we find it virtually impossible to focus our attention on the nature of our sensory experience. The thesis does this by first detailing precedents in art and scientific fields that have sought to expand our awareness of perception, either through representative methods (such as cubist or Impressionist painting) or through the development of new technology that allows us to consciously engage with our perceptual systems (such as the stereoscope or VR technology). Next, the main part of the thesis is divided into 3 subsections, each with its own body of artwork. Each subsection details research into a specific perceptual phenomenon, and each body of work shows how media art systems that incorporate these phenomena can help us to better understand our sensory experience. Ultimately, I hope that this thesis proves the efficacy of interactive multimedia art systems in clarifying this "transparency of experience".

The thesis follows an integrated model with the artwork and experiments interwoven into each chapter amongst the research from which they were conceived. There are three main subtopics within the thesis: perceptual ambiguity, perceptual integration, and interoceptive awareness. These subtopics will each be discussed in turn, with the relevant work, experiments, and exhibitions discussed at the end of each chapter. Due to the scientific content of a lot of the research, I felt that it was important to maintain a sense of interconnectivity between the subtopics by using this format. The research is based predominantly in non-arts disciplines, and it spans areas that may be considered disparate from one another from a strictly scientific viewpoint. For this reason I decided against separating the thesis into two broad sections: inquiry and production. I felt that by integrating the artwork into the relevant chapters, the shared themes of human subjectivity and embodied theories of perception, and how these ideas relate to interactive artwork, become more coherent.

The second chapter provides a contextual framework for the thesis. It begins by discussing key concepts such as the transparency of experience and the grand illusion theory. It then proceeds to outline such concepts in a historical context, both in scientific and artistic research, paying particular attention to the ever-increasing areas where the two fields intersect. It also offers precursory explanations of the themes that run throughout the following chapters.

The following three chapters each concentrate on one of the previously mentioned three subtopics. These are discussed in relation to recent findings in neurology, psychology, and philosophy and in terms of possibilities for intervention through media art systems. After this, the relevant bodies of

artwork for each subtopic are introduced, along with the invaluable feedback that was received from exhibiting the work, which allows reflection on what I have learned myself through this process. I am particularly grateful for the observations and feedback gained from consultation with Dr. Shinsuke Shimojo of Caltech Psychophysics Laboratory and Dr. Jane Aspell of Anglia Ruskin University.

Chapter 3 gives a more comprehensive description of perceptual ambiguity and how it relates specifically to the heart of this chapter: stereopsis and binocular rivalry. The various stages of development of my ongoing *Diplopiascope* system are detailed which serves as the first bridge between the theoretical research and practical work.

Chapter 4, perceptual integration, discusses the next topic: sensory integration and cross-modal perception. After this, my ongoing visual-auditory sensory integration project *FOVear* is detailed, including plans for the next stage of development of this project.

Chapter 5, in effect, turns the thesis inside out. While the previous two chapters have discussed outside-in perceptual phenomena, this chapter considers an interoceptive approach. Specifically discussed are recent discoveries in interoceptive-awareness, the physiological awareness of our own bodies' internal systems. The chapter aims to tie the previous two chapters together with concepts that are consistent throughout the thesis such as the transparency of experience.

Chapter 6, aesthetic decisions, provides some clarity in regards to issues that arose during the exhibition stage of the artwork. I detail the constraints I had in terms of making the installation visually interesting without being distracting from the purpose of the research and maintaining an integrity to the principles outline in the thesis.

Chapter 7 consolidates the previous chapters by highlighting what I have learned from this ongoing study. The ways in which my research has helped enable a greater understanding of our perceptual systems, with particular attention to the idea of transparency of experience, is discussed. Lastly, my future plans for the research and work are detailed in order to conclude the thesis.

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Chapter 1 – Introduction

When we look at an object held in our hand, a red ball, for instance, the different views shown to our left and right eyes are combined in our brain allowing us to experience a rich three-dimensional sphere. Light receptors in our eyes translate the frequencies of light waves bouncing off the ball into messages that we interpret and experience as the colour red. Yet when we try to focus our attention on these experiences, what we inevitably end up with is the same perception of the physical features of the ball itself. Even seemingly huge discrepancies in our visual clarity such as the blind spots in each eye, saccadic movements, peripheral colour blindness and low visual acuity, are ignored to the extent that we are unaware of their ubiquity. We find it virtually impossible to consider the experience of seeing itself, a phenomenon that has come to be known as the *transparency of experience*[1]. Various artists have sought to draw attention to this fact by highlighting the emotional effects of perception or through accentuating the representational details of experience.

My thesis engages with this concept from a more direct and interactive approach. I believe that intervention through interactive media-art systems holds huge potential as a way of elucidating this transparency. Through my research into perceptual ambiguities, perceptual integration, and interoceptive awareness, I aim to enable a greater degree of deliberation and awareness of our experience. By deconstructing specific mechanisms of our perceptual system, and, through the development of multimedia systems that allow us to experiment first-hand with such mechanisms, my intention is to provide a means of sensory self-exploration. Ultimately, I hope to make the manipulation of the very parts of brain where perception enters consciousness possible, structures that have been, up until this point, elusive to our grasp in both a physical sense and in terms of our limited understanding of their nature. This heightened awareness of our perceptual experience has implications both from an artistic viewpoint, where an intensified sensory experience holds great value, and in terms of the potential applications in the treatment of various behavioral disorders. My methods and ideas are heavily influenced by recent enactivism and sensorimotor theories of perception, the notion that our physical engagement with our surroundings is so vital to our conscious experience, and this thesis provides both a record for my ongoing research and suggests possibilities for further investigation.

1.1 Structural breakdown

This thesis follows an integrated model with the artwork and experiments interwoven into each chapter amongst the research from which they were conceived. There are three main subtopics within the thesis: perceptual ambiguity, perceptual integration, and interoceptive awareness. These subtopics will each be discussed in turn, with the relevant work, experiments, and exhibitions discussed at the end of each chapter. Due to the scientific content of a lot of the research, I felt that it was important to maintain a sense of interconnectivity between the subtopics by using this format. The research is based predominantly in non-arts disciplines, and it spans areas that may be considered disparate from one another from a strictly scientific viewpoint. For this reason I decided against separating the thesis into two broad sections: inquiry and production. I felt that by integrating the artwork into the relevant chapters, the shared themes of human subjectivity and embodied theories of perception, and how these ideas relate to interactive artwork, become more coherent.

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1.2 Methodology

1.2.1 Art of Science

Conventionally, approaches towards investigating perception have differed between the scientific and artistic communities. While a purely scientific approach may be interested in the mechanisms of the brain or neural processes from which perception arises, artists have preferred to concentrate on the emotional results of perception or the representation of unusual perceptual phenomena. However, in recent years we have seen a considerable degree of overlap between the fields. This is a result of a number of things. Primarily, the increased availability and circulation of findings in the scientific community has made it possible for those on the periphery to research ideas at the forefront of the field. In turn, this has encouraged greater experimentation within the artistic field as the possibilities for assimilating scientific discoveries become apparent. Another reason is the ever-increasing availability of low-cost technology and open-source projects, several of which are incorporated in this thesis (ex., the *Pupil* eye tracking system[2]). This has allowed artists to experiment in areas from which they were previously restricted, both financially and through a lack of access to information. These changes have been instrumental in shaping the way in which I conduct my research and develop the work. Not only has this made it possible to access information in the first place, but also it has made the translation of these ideas into physical systems into a process of abundant possibility.

1.2.2 On Reverse Engineering Perception

The process by which I developed projects throughout my PhD follows a pattern described by Daniel C. Dennett as the *reverse engineering* of perception[3]. Dennett describes the process in industrial design of analysing the way in which mechanisms work through the deconstruction of existing products. This practice is a means of developing new designs. This is a familiar methodology to engineers and designers involved in making brand products. When creating a new model of vacuum cleaner with a state-of-the-art suction mechanisms, the manufacturer may well purchase preexisting models and dismantle them in order to learn how exactly the system works. Dennett argues that the same principles can be applied to cognitive science, and I believe that it can also be applied to the deconstruction of other systems created by Nature such as aspects of our own perception. Of course, the evolutionary design process of our sensory systems is very different from that of a vacuum cleaner. While the latter was designed with a specific goal in mind, which could be called *top-down* design, the former developed with no preset goal or function to fill, a *bottom-up* method of engineering. However, despite the differences in the original design processes, there is no reason why equally fascinating results should not be gained from applying the same analytical techniques to each area. After all, as Dennett points out, we might go so far as to say that biology is ultimately the reverse engineering of natural systems. My work process is to first consider the large scale, general functions of a system, an example being human three-dimensional vision. I then go on to research how the specifications of each part of that system work (stereopsis, binocular rivalry, etc.) and how these individual parts can be manipulated in order to affect the workings of the larger ensemble. Finally, I begin creating devices designed specifically to allow the participant to engage with these systems.

In practical terms, each of my projects began with broad research into areas of perception that stood-out as having potential for development as interesting artwork. After selecting specific topics, I would begin a more thorough investigation of research papers and initial consultations with specialist researchers in the field in order to better understand how the mechanisms work and how they could be manipulated. I would then begin my preliminary experiments and construction of prototype devices, usually involving inexpensive materials. These would then be developed and evaluated through exhibitions. Feedback from these exhibitions, including secondary consultations with the specialist researchers, would inform the next stage of development and refinement of the work.

1.3 Background and Motivation

Previous to 2009, my work mainly consisted of sculptural installations. I was interested optical illusions and how they could be used to manipulate the quirks of our visual system. In my 2005 installation, *Floor*, a poster reproduction of Akiyoshi Kitaoka's peripheral drift illusion *Rotating Snakes* was cut and inserted into areas chiseled into the thick layers of paint on the gallery floor to appear as if it was lying beneath the paint itself. Parts of the poster had been hand painted in elaborate patterns, which clashed with the clean, mechanical precision of the computer image, and rested uneasily on the eyes when the viewer tried to fathom what visual depth they were looking at. Kitaoka is a psychologist who later came to have a big influence on my work, and it is serendipitous that I come to do a PhD at Kyoto City University of Arts (KCUA), a few kilometers from his laboratory at Ritsumeikan University.

It was upon entering KCUA in 2010, and under the supervision of Satoru Takahashi, that my work became more concerned with the experience of perception itself. After reading Paul M. Churchland's discussion on artificial neural networks in his book *The Engine of Reason, the Seat of the Soul*[4], in which he discusses methods of imitating brain functions, I became fascinated with stereopsis and how it can be used as a device to investigate how we see and experience the world. I began to wonder about what such mechanism could reveal about the process of perception, and ways in which they could be incorporated into interactive systems to allow the participants a more engaging experience. Rather than merely illustrating perceptual phenomenon in a representational way, I feel that new and interesting ways of dealing with subjective experiences are possible through media art that is informed by scientific research. Through these methods I aim to allow a greater of deliberation on the very nature of our sensory experience.

Chapter 2 - Conceptual Framework

> *We are so familiar with seeing, that it takes a leap of imagination to realise that there are problems to be solved. But consider it. We are given tiny distorted upside-down images in the eye, and we see separate solid objects in surrounding space. From the patterns of stimulation on the retinas we perceive the world of objects, and this is nothing short of a miracle.*[5] - R. L. Gregory

This chapter offers an introduction to some of the keys concepts that run throughout the thesis. I will begin by discussing what is actually meant by transparency of experience before proceeding to describe how what is known as the grand illusion theory gives explicit examples of this transparency in our sensory lives. I will then continue to give a chronological outline of significant developments within both art and science that have attempted in some way to demystify this notion of transparency, be it through either representational means of describing experience, or through more embodied, interactive ways of recreating elements of perception.

2.1 The Transparency of Experience

The transparency of experience theory is the idea that when we attempt to turn our attention to our experience, seeing, hearing, touching, etc., we almost always end up concentrating on the actual thing that we see, hear, or touch. It is often categorised as one of the philosophical *Problems of Perception*[6], along with visual illusions and hallucinations, which seem to cast doubt on more traditional representational views of how we perceive. Sometimes referred to as the *Snapshot Conception*, representational ideas describe visual sensory perception to be similar to a photographic or televisual process. Some famous examples of this internal representational view of perception are Ernst Mach's field of vision drawings. Mach represents the entirety of his visual field seen from a seated position with one eye shut. His drawing stretches from the farthest point he can see in all directions and includes the left side of his nose and left eyebrow, which together crop the right-hand side of the image. The entirety of the picture is drawn in uniform, high-resolution, as if to portray a visual field that is fully captured in conscious awareness. This seems, at first, to be a perfectly reasonable way of representing how it is to see in an environment. It is true that if we look to the extremes of our nasal visual fields we might become aware of our nose or eyebrows. However, should we do this, and simultaneously pay attention to the rest of our visual field we become aware that visual acuity on the periphery is incredibly poor and nothing like the detailed, uniform representation that Mach presents us with. As will later be describe, our real experience, at least in terms of sensory information, is much more fragmented and sparse, with far less detail than we assume we are presented with. No matter how hard we try, the experience remains elusive to our grasp.

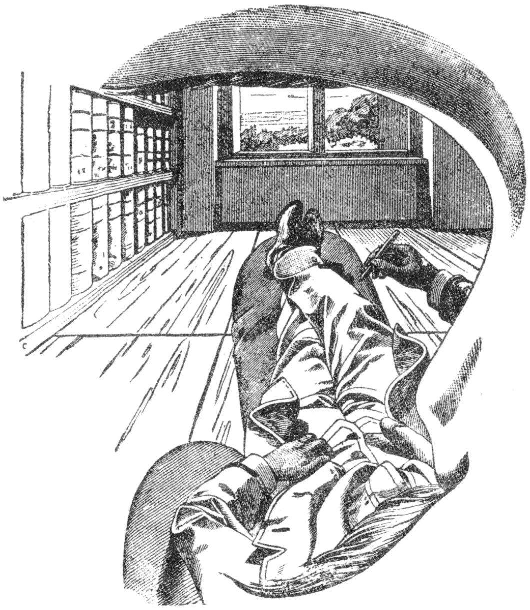

Fig. 1 Ernst Mach, *Picturing the Visual Field*, 1886, shows a clear, high-resolution representation of the visual field in its entirety.

A clear description of the transparent nature of experience is given by Gombrich's[7] description of standing before a steamed-up bathroom mirror and outlining the shape of his head with his finger. The size of the visual image of the head appears unbelievably small in the representation on the mirror, yet this is not how we "see" it in our minds; we perceive the head as the same size as always, that is, head-sized. This can be extended to the way in which we see most objects in our field of vision. A square frame of a painting, for example, will almost never be seen as a perfect square. Due to it being seen from an angle, the shape of the frame is seen as a trapezium of varying proportions, but again this is not how it is experienced. Another example might be the way in which we describe colours or shapes of familiar objects in our experience. A child may well paint a scene in which the grass is a deep green and the sky blue, when in actual fact there may be little green in the grass at all and the sky, in reality, a pale grey.

We seem to experience our surroundings with little regard for how they actually appear, and furthermore, we seem oblivious of this fact. There is a seemingly endless list of such ways in which we find it difficult to reflect upon our conscious sensory experience, and this introduces to us a problem when trying to investigate or describe sensory perception. The capturing of experience itself, in a subjective, phenomenological sense, and the translation of this experience into words or other forms of art, becomes a very difficult task considering the experience itself appears to be transparent. Can there in fact be any real reflection upon how we experience our surroundings? This thesis describes the methods by which I have tried to achieve a more informed understanding of our perceptual experience through media art systems.

Before proceeding to introduce artwork that attempts to deal with this problem of transparency, I feel that first it is necessary to expand on this concept by discussing some explicit evidence of our lack of awareness of the nature of our sensory experience.

2.1.1 The Grand Illusion

> *One of the most striking features about consciousness is its discontinuity – as revealed in the blind spot, and saccadic gaps, to take the simplest examples. The discontinuity of consciousness is striking because of the apparent continuity of consciousness* – D. Dennett[8]

In the previous section I introduced the idea of transparency in our perceptual experience. This concept is in fact a philosophical off-shoot of the more developed and widely discussed Grand Illusion theory in which it is argued that we are mistaken in thinking that we have a detailed and abundant stream of visual information passing through our consciousness. In actual fact, the theory proposes, what we are presented with is jittery, sparse, distorted, and blurred images and this is somehow translated into the rich sensory world that we experience; the visual world, as we know it, is a grand Illusion. There are reasons why visual psychologists believe this to be the case, based on the physiology of the visual system, and recent discoveries in change and inattentional blindness.

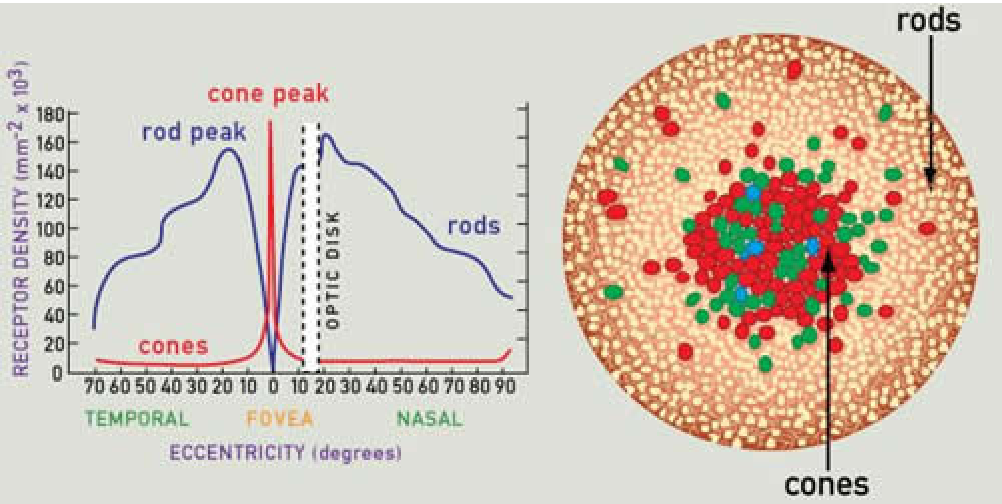

Fig 2 Uneven distribution of photoreceptors on the retina.

The information that we actually receive about our environment is far sparser than what we perceive that we do. To expand, the photoreceptors of the human eye are so unevenly spread on the retina that our peripheral vision is almost completely colourblind and out of focus. Due to the photoreceptors, rods and cones, being crammed into the center of our retina (the fovea), we are only really able to maintain a focused image at around the size of our thumbnail on an outstretched arm. We are presented with not one, but two non-identical versions of these blurred and colourless images, which have already been flipped upside down and distorted through the mechanism of the eye's optics. Furthermore, the images are far from steady. Saccades and micro-saccadic eye movements several times a second mean that the images are in an almost constant state of jittery change as visual information streams across our retinas. Yet further complications are added by the existence of the blind spot: the point on each retina where the optic nerve passes through the optic disk, and where there are, therefore, no photoreceptors; and no vision. How can it be that despite all of these glaring holes in the unity of our visual clarity, we are still able to have such a rich and resolved visual experience? As if these physical shortcomings of the human visual system were not enough, recent findings in cognitive psychology on change and inattentional blindness has shown us just how flimsy our sensory contact with the environment really is.

Recent experiments in what has become known as change blindness and inattentional blindness have given us even more proof that we fail to see, or fail to notice, a surprising amount of our visual world. The most well known example of this is the video showing a group of students throwing around a basketball. The viewer is encouraged to count how many times the basketball is tossed. An easy enough task, we assume, but once the video comes to an end we are informed of the person in a gorilla suit who had danced across the screen mid-way through; we had simply failed to see it. This provides a novel kind of evidence that the visual world may well be a grand illusion.

Fig. 3 Inattentional blindness, Simons and Chabris, 1999

The snapshot conception of what our perceptual experience is like, as illustrated by Mach's visual field drawing, is so pervasive that it is difficult to rethink and consider other models. I aim, through my work, to enable the viewer to reconsider the reality of their sensory experience.

2.2 Is Experience Evasive to the Artist?

From what has been talked about in this chapter it is clear that this representational, snapshot, model of perception is surely a distortion how it really is to experience. Through recent research into change and inattentional blindness, and more established theories on the problem of vision, it has become apparent that we are undergoing a paradigm shift in how we think about seeing. Yet this brings with it problems. We must now ask if it can ever be possible to recreate or describe experience in an accurate way. Perhaps trying to open up our perceptual mechanism for analysis is simply a futile quest. I do not believe this to be the case, at least not entirely. I will now introduce some milestones in the history of art and science and current methods in which these issues are being tackled.

2.2.1 A Time-Line of Transparency - devices to see vision

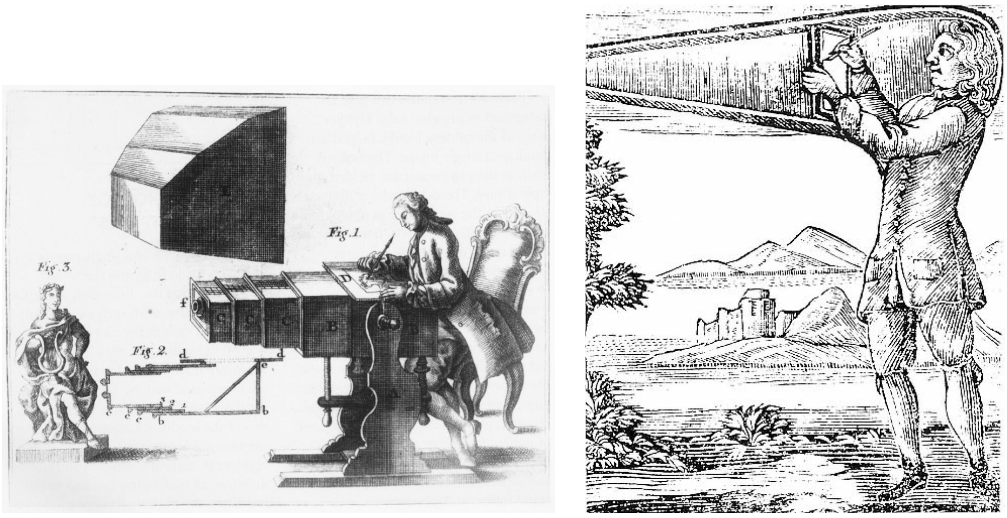

Fig. 4 and fig. 5 Portable camera obscura devices from the 1700s were used both for making more realistic reproductions and for analysing the mechanism of vision itself.

In the Techniques of the Observer, Jonathan Crary describes the invention of several philosophical instruments of amusement in the 18th and 19th centuries as being of a period of unrivalled change in how we think about seeing. The first significant invention was the camera obscura. Although the principles behind the camera obscura had been known for at least two thousand years, it was the development of the portable devices in the 18th century that had the greatest impact. Based upon the invention of linear perspective in the Renaissance period, the portable camera obscura existed not only as a device to create pictures, it also served to 'shine light' on the very nature of vision. This was the first time, we must remember, that a virtual image of movement had been represented by an optical device. It is also important to recognise how deeply rooted in optical theory (such as linear perspective) the contraption was, and, in this respect, how far it went in decrypting the nature of vision.

The second invention was much more accessible due to its low cost, but in no way any less significant. The thaumatrope, or "wonder-turner", was made famous by Dr. John Paris in London in 1825. It served as both a toy and as a visual exposition of the research into afterimages by physiologist Jan Purkinje. Two dissimilar but related images, a bald man and a wig, or, a bird and a cage, were placed on either side of a small disk which is then spun by winding and pulling string tied to either side. Due to the principles of persistence of vision, as proposed by Purkinje, the images would appear together in the eye (or mind, to be clear) of the observer; the man would appear to have hair and the bird would be in the cage. Several other similar devices soon followed, such as the phenakistiscope and the zoetrope, and they are often thought of as steps in an evolutionary timeline, leading to the ultimate, dominant, and perfect form of cinema. While this may be true in many ways (certainly the ubiquity of cinema as an art form is indicative of its success), the significance of these less-known devices must not be understated in relation to the idea of transparency of vision.

Fig. 6 Thaumatrope with visualisation of experience, 1874

What was witnessed through the popularisation of these toys was a shift in the role of the viewer from that of a mere observer to an actual component in the mechanism of experience. This experience that these toys enabled was not simply present as a representation, in fact it was not present at all (in any complete sense) in the devices themselves, rather, to gain a unified optical experience required the internal synthesising capabilities of the participant. It was resolved inside the mind of the observer. This led, as Crary notes, to the introduction of *temporality* in vision as seeing became evermore tied to the body in the early 19th century[9].

The most significant development in how we think about seeing in the 19th century was surely the invention of the stereoscope. This was another instrument of looking that was deeply grounded within vision research, to the extent that it served both as a product of the research, and, through its use as a tool of experimentation, as a means of furthering the research itself. The two central figures behind the stereoscope boom of the 1850s, Charles Wheatstone and Sir David Brewster, had both written a great deal on visual phenomenon. In fact, Wheatstone himself had translated Purkinje's 1823 thesis on afterimages. The stereoscope succeeded in translating the visual phenomenon of binocular vision into an externalised mechanism that could be poked and prodded in order to see how it functions by changing its parameters. Previous to 1800, people were certainly aware of the fact that we saw different images with each eye, and theories existed as to why we didn't experience two different views, but it wasn't until the 1820s, when surgical experiments into the nature of the optic chiasma, where the optic nerves cross behind the eyes, that the problem began to be resolved. By tweaking his findings from his experiments on binocular disparity and applying them to his machine, Wheatstone discovered that he was able simulate the actual presence of an object. This conjuring of a solid form is an important distinction from the representation that was found in painting up until this point.

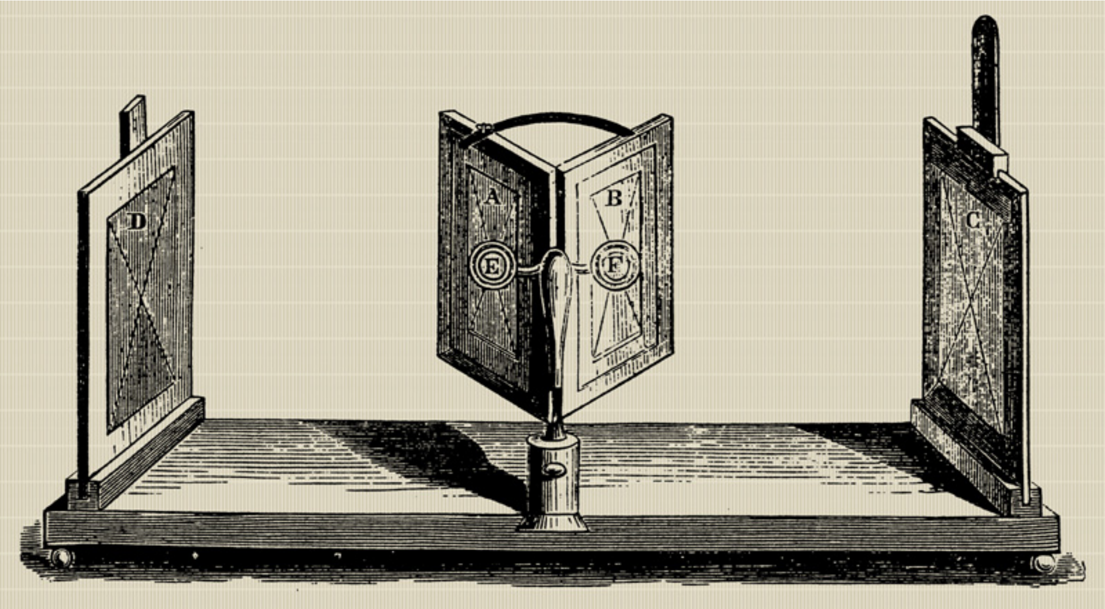

Fig. 7 The original Wheatstone Stereoscope design did nothing to disguise the fabricated nature of experience. The experience was synthesised by the observer.

The implications of the stereoscope were huge and its impact on art, and especially cinema, are easy to see. Everything from the View-Master toys of the 1980s, to 3-D film in its various forms, and the recent explosion in virtual reality gaming hardware such as the hugely successful Oculus Rift, can all be traced back to the simple mirrored device designed to deconstruct vision. An important note here is that the influence of the stereoscope was not only limited to artistic fields, it also led to the development of 3-D surgical imaging devices, and has been used widely by the military in order to better analyse aerial photographs. These devices, however, are distinct from the original idea of the stereoscope in that they purely seek the real quality of the 3-D image, in a graspable, phenomenological sense, and disregard the mechanism of how that image is created. Especially in the case of 3-D film viewing methods, such as polarised and active shutter glasses, the mechanism is completely hidden in order to present the viewer with the most persuasive experience of reality possible. Wheatstone's original stereoscope required the viewer to place their eyes in front of two mirrors set at 90 degrees so that each eye was looking in opposite directions

This made clear the fact that this reality was a construct that existed only within the brain of the observer.

> *…the process of perception itself had become, in various ways, a primary object of vision* – J. Crary[10]

What these 19th Century devices provided was a change in the observer-object-image relationship. They allowed the observer to appreciate the role of their own physiological sensory mechanisms in perceiving the environment. They did this by removing the image from its unified position within the object, and placing it inside the mind of the observer. These philosophical toys made explicit the role of the viewer as experiential rather than simply observational and paved the way for more interactive developments that would come later.

Artist, we should remember, had also been aware of the ways in which they could exploit our physiological perceptual systems to produce interesting and effective artworks. I will briefly detail some ways in which this has been achieved, both in historical and contemporary; representational, and experiential artworks.

2.2.2 Representational Investigation

The laws of perspective were finally understood in the Renaissance period due to developments in geometry and scientific study of the human visual system. Artists realised that light travels in a straight line and that we only see the rays of light that enter our eyes through the pupil. It took so long for this realisation to arise because of how skilled our perceptual systems are at converting visual information to depth perception; again highlighting the fact that often we fail to perceive what it is we actually see. Once this discovery had been made, however, it became the only mode of expressing depth in painting for several centuries. Artists would use various techniques and devices to help them see a two-dimensional representation of a three-dimensional space, which they would then apply to canvas in order to be interpreted by the viewer as realistic depth.

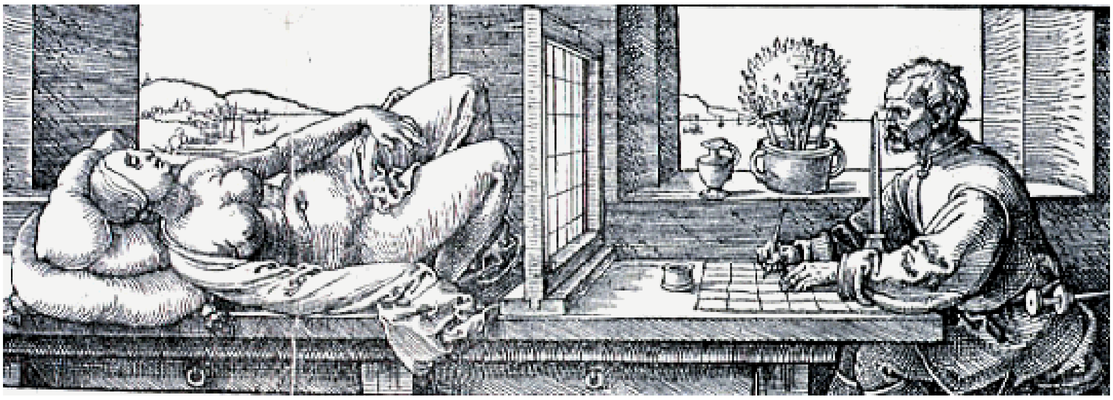

Fig. 8 Draftsman Drawing a Vase, Albrecht Durer, 1525

This mode of representation, based upon the perceptual experience of the viewer, was a novel kind of perceptual realism, one in which the experience of depth is consciously described by the artist onto a two-dimensional surface. The viewer is invited to accept this representation as reality, and, in doing so, suspend their knowledge of the flat surface of the painting as an object and unconsciously interpret it as real physical depth. There is a complexity to this relationship between the artist and viewer as participants in an experience, and this dynamic can be thought of a precedent to more interactive experiential artwork to come later.

If the Renaissance heralded a mode of true representational depth in painting, it can be argued that the Impressionism movement of the late 19th and early 20th centuries was successful in translating the *experience* of seeing.

Fig. 9 and fig. 10 Impression Sunrise (1872), Claude Monet, in colour and monochrome with disappearing sun

The sun depicted in Claude Monet’s Impression Sunrise appears to glow and pulsate before our eyes; suggestive of the radiant nature we associate with our sensory experience of the looking at the sun. Yet when the painting was first exhibited it caused an outrage due to the dark nature of the sun, which should, if painted realistically, be much brighter than the surrounding sky. Recent research[11] by Harvard neurologist Margaret Livingstone has produced a theory to explain why the sun seems to shimmer in the sky of Monet's painting: equiluminance.

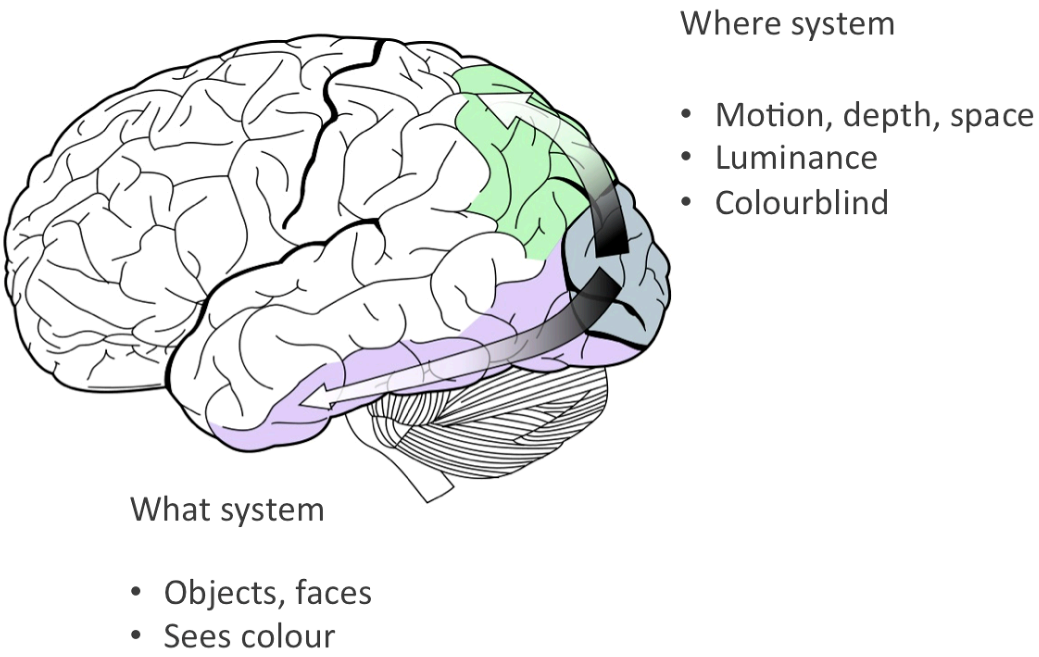

Fig. 11 The *What* and the *Where* pathways of visual processing: a way of explaining Monet's shimmering sun

Our visual system consist of two subdivisions, known as the What and the Where pathways, that are responsible for processing different kinds of visual information, spreading out for the primary visual cortex (V1) to higher areas of visual processing. The What system is responsible for object and face recognition and is able to perceive colour. The Where system, on the other hand, perceives motion, depth, and spatial organisation, and is colourblind yet sensitive to luminance. We can see by looking at the black and white version of the painting in fig. 10 that the sun disappears when the colour is removed, showing that it is exactly the same luminance as the surrounding grey clouds. This is not a strict representation as the sun should always be brighter than the sky, by a huge degree. However, what Monet must have been aware of was that through this equiluminance, he was able to create the experiential quality of light; making the sun appear to glow. What Livingstone's research does is give a scientific explanation to how this was achieved. Referring to the different processes of the What and the Where system, we can understand that the What system can see the sun very clearly due to the colour difference between the orange and the surrounding grey, yet the Where system, being colourblind and only sensitive to luminance changes, is not able to position it at all. Livingstone believes that it is this conflict between the two visual systems that leads to the strange shimmering effect when we look at Monet's painting.

Monet's *Impression Sunrise* is just one example of Impressionist artwork that attempts to translate the perceptual experience of seeing light into painting. This idea of trying to authentically represent our sensory lives extends into depth perception in painting of the time, most famously in Cubist painting that simultaneously showed multiple viewpoints of a scene as a way of better describing our spatial experience. Although these artists were surely unaware of any neurological activity to explain the effects they were producing, it is fascinating to note that experience in art was no longer limited to the narrow representative descriptions of the previous centuries. These developments should be remembered in the context of the popularisation of previously mentioned visual devices.

2.2.3 Experiential Investigations

The artists detailed above created work of huge significance in the role of our understanding of perception and experience. However, they were limited in their understanding of the sensory mechanisms behind the phenomena they so successfully represented. Furthermore, they were limited in their resources in terms of being able to recreate these phenomena for the understanding of the viewer.

Carsten Holler is a Belgian artist who makes work that questions our knowledge and familiarity of perception. He does this through a non-representational, experience-led practice that encourages the audience, as participants, to experiment on themselves. In this manner, his exhibitions become a mode of scientific inquiry and are reminiscent of laboratory environments. His work is not only interactive, but it incorporates recent developments in perceptual scientific research and translates this into direct experiences that participants can feel for themselves.

Fig. 12 and fig. 13 Carsten Holler's *Giant Psycho Tank* and inverted lenses gallery tour, 2000

Some of his more notable works have included a floatation tank (*Giant Psycho Tank*, 2000) in which participants can experience weightlessness in the water of a sensory deprivation pool, and his inverted lenses gallery tours where the work is seen from a distorted perspective requiring the audience to adapt both visually and in their proprioception to the altered experience.

This work, inspired by scientific research and experiments in perception, is aimed at altering the audience's physiological and psychological experience of the environment. Various changes in the past decades have made this possible such as the dissemination of scientific research, which is now available for free to anyone through the internet, and technological advances that make low-cost high-tech devices a possibility. Outside of the art world, the implication of these changes can be seen in gaming technology such as the hugely successful Oculus Rift virtual reality environment. It is in this availability of technology and scientific findings that, I feel, are the optimum conditions for the development of interactive multimedia systems for the investigation of perceptual experience.

Now that a simple contextual framework has been illustrated, the next three chapters will proceed to describe in detail some specific perceptual phenomena that I have investigated in my research; beginning with perceptual ambiguity.

Chapter 3 - Perceptual Ambiguity

In this chapter I will define perceptual ambiguity and place it in the context of its usefulness in elucidating the transparency of experience. I will proceed to discuss one specific kind of perceptual ambiguity that is of particular interest, binocular rivalry (and the more familiar related phenomenon of stereopsis), before detailing the various stages of my *Diplopiascope* body of work that incorporates the principles behind this fascinating quirk of our sensory lives.

3.1 Contextual Definition of Perceptual Ambiguity

Perceptual uncertainly is very common in our daily lives, and exists across the full range of our senses. Rarely, however, does this discrepancy in the clarity of our sensory experience affect our conscious perception of the world. In almost all cases we are unaware that any ambiguity is present and are certainly rarely troubled by any conflicting possibilities in what we might be experiencing. Despite its prevalence across the range of our senses, in this chapter perceptual ambiguity refers primarily to that of vision.

3.1.1 Variations of Perceptual Ambiguities of Vision

One kind of perceptual ambiguity that is particularly well documented is that found in the subtle narrative nuances of art. The multiple possible interpretations of the facial expressions on da Vinci's smiling *Mona Lisa*, or Vermeer's sitter for *The Pearl Earring*, at once erotic, yet stern, or perhaps even distant, have been the subject of countless studies and publications. It is only in recent years, however, that neuroscientists such as Semir Zeki, Margaret Livingstone, and Vilayanur S. Ramachandran have approached the subject from a scientific point of view, analysing the neural mechanisms behind, what they believe, influence our perception of images. This has led to both a large amount of positive interest and significant opposition and debate on whether this neuroaesthetic approach to art is reductionist[1]. These kinds of uncertainties of interpreted emotions are often known as *higher levels* of ambiguity[12] and seemingly stem from one of the functions of the brain being to instill meaning into the world. Due to the existence of several possible meanings, viewers find

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[1] One notable example of the kind of contentious opposition to neuroaesthetic analysis of art can be found in the reaction to Ramachandran's *The Science of Art, A Neurological Theory of Aesthetic Experience*, Journal of consciousness Studies, 6, No. 6-7, 1999, pp. 15-51

themselves in an uncertain emotional position and have considerable difficulty deciding upon one solution. At this higher level, factors as complex as memory, experience, and learning have a deep impact on how the ambiguous expressions or relationships are interpreted. This uncertainly of emotions and subtle ambiguities are a narrative game that the artist plays, and a characteristic of many great works of art. However, according to Zeki, this is not an artistic invention and not something that is unique to art:

> *…the characteristic of ambiguity in art is not special to art. It is rather, a general property of the brain which is often confronted with situations or views that are open to more than one, and sometimes several, interpretations. The artist, rather than creating ambiguity, thus uses, sometimes to exquisite effect, this potential of the brain. Equally, the viewer uses this same potential in providing different interpretations.*[13]

This kind of neuroscientific analysis of art is clearly going to create controversy, especially when attempts are made to break art theory down into universal laws or principles and "it is questionable whether the theories can capture the evocativeness or originality of individual works of art."[14]

My interest in ambiguities of perception comes from an area into which there is more empirical evidence, that of multistable perception. In the case of the Necker cube, the ambiguities in question are not on an emotional interpretational level, yet they are no less complex than the top-down examples listed above. The information presented to us in the form of 12 intersecting lines is sparse, yet there are many different ways in which the brain can interpret it. Some lines might be on a plane closer to us than other, as is our natural assumption (there are two possible three-dimensional shapes that this could form), or the lines could all be on the same plane, as is actually the case due to the two-dimensional nature of the image, or all of the lines could be on different planes altogether and we are just very lucky to be seeing them from the exact perspective that forms the image of a cube. Our natural assumption is the first, and we find that if we look at the image for long enough, an interpretational flip-flop (known as a Gestalt Shift) begins to take place.

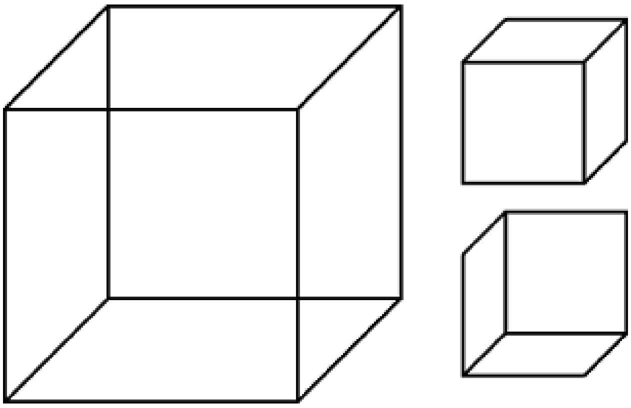

Fig. 14 Necker cube perceptual ambiguity

This phenomenon is known as multistable perception, and it comes about when the brain is presented with more than one possible interpretation of an image. A spontaneous switching occurs between which way we interpret the three-dimensional image. Even though there may be several different ways of interpreting the image, experience in our everyday perceptual lives[15] has informed us to discredit all but the first one: a cube floating in space that can be seen from one of two angles. We find that the cube will shift very regularly from one interpretation to the other and it is impossible to see both at the same time. The solidity in which we see each interpretation is entirely convincing in a phenomenological sense. This multistability is possibly an accidental effect of the mechanics of our perceptual systems and is dependent on the integration of lower-level stimulus driven factors and higher up cortical areas responsible for our evolutionary survival. The argument put forward by Leopold and Logothetis (1999) is that our sensory systems regularly ‘refresh’ themselves as a way of making sure we do not miss any dangerous realities in our misinterpretation of ambiguous real-life situations; the oft-cited example being the disguised shape of a crouched tiger ready to pounce at us from long camouflaging grass. It is suggested that this refreshing happens very often yet it normally delivers the same results (rarely are we confused by ambiguities in real-life situations[16]) and for this reason we are unaware of the mechanism. What multistable images like the Necker cube do is present us with a situation in which the brain is unable to reach a resolve, both interpretations being of equal validity, and so it will flip back and forth ad-infinitum. What is fascinating is that these perceptual ambiguities are not just random behavior; they give us a glimpse into the organization of the brain and the way in which it resolves information in our sensory experience. This is how we see, but we are simply unaware of this fact.

3.2 Stereopsis and Binocular Rivalry

Binocular rivalry is the phenomenon experienced when different visual patterns are presented simultaneously to both eyes. In actual fact, due to the 6-7cm horizontal separation of our eyes, the binocular parallax, our retinas always see slightly different images of the same scene. However, provided the images are not too dissimilar, they can be fused through a process called stereopsis and by this we are able to see the world in rich three-dimensions. When binocular rivalry is simulated in controlled experiments, the subject's conscious perception will flip between the different images in a similar way as it does when looking at the Necker cube. We find it impossible to see the two images simultaneously and instead we will see them in an alternating and seemingly uncontrollable sequence. In actual fact, there are various factors have been proven to have an effect on the frequency of the flip between interpretations of multistable images like the Necker cube and there is a significant degree to which the viewer can control the flip by voluntary means: trying to see the cube in one way often proves successful, for a limited time. Similarly, in binocular rivalry the role of "signal strength"[17] has a large impact on which of the two stimuli will dominate perception. The blurriness, colour contrast, and luminance[18] all contribute to the selection of one over the other. As well as other top-down factors such as semantic association and information from other sense modalities[19].

In the 1990s, neuroscientist Nikos Logothetis conducted a number of experiments on monkeys to find out what patterns of brain activity occurred during multistable perception. Monkeys were chosen because they share the same brain organization as humans, and presumably share the same mechanics of consciousness, and they can be tested on with more invasive techniques than would be allowed with human experiments. The monkeys were subjected to binocular rivalry simulations and were trained to pull a lever when they experienced the flip in conscious perception from one image to other. The monkeys' brain activity was monitored and enabled the scientists to trace the neural activity that corresponds to the changes in conscious perception.

As predicted, the monkeys reported the perceived stimulus shifting sequentially from one to the other over time, despite the unchanging images being shown to each eye. Correspondingly, spikes in the monkeys' brain activity were noted momentarily before the monkey reported the shift. The fascinating discovery of Logothetis' experiments was the areas in which this spiked brain activity took place. While there was predictable activity in the visual cortex (V1 and V2) that correlated with the monkey's subjective perception (20%), there was considerably more activity in 'higher' visual areas of the brain such as the middle temporal area (MT)(40%), the medial superior temporal sulcus (MST)(40%), the inferotemporal cortex (IT)(90%) and the superior temporal sulcus (STS)(90%).

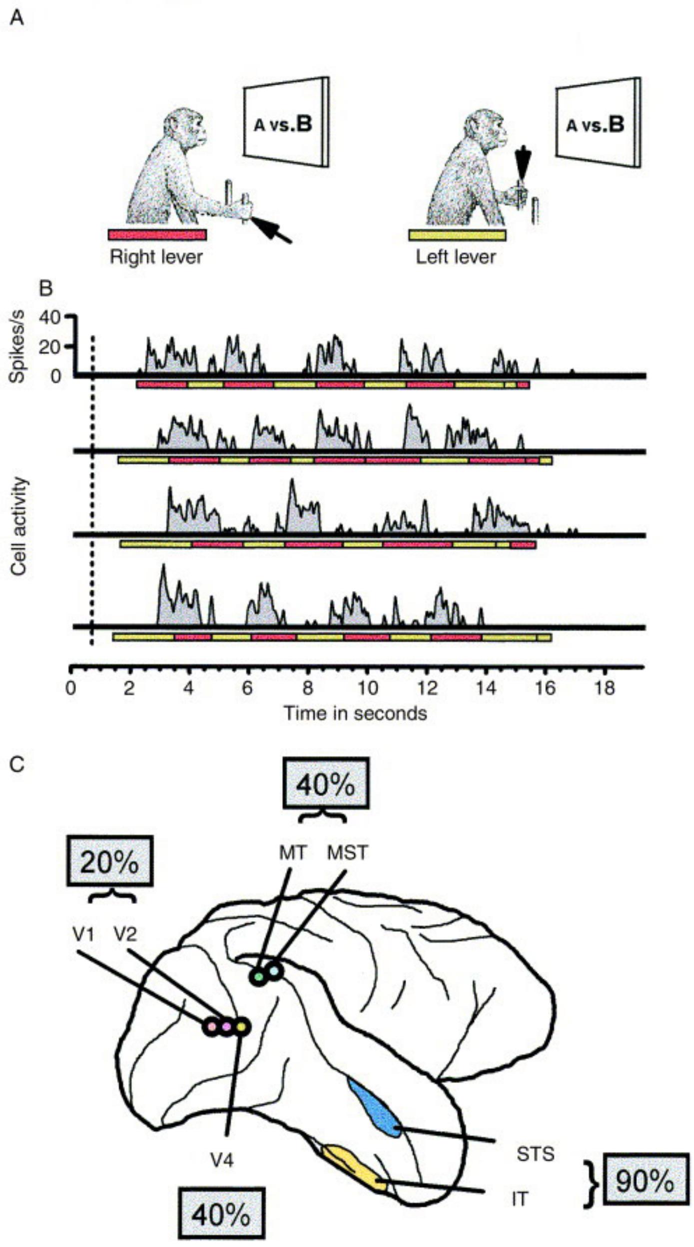

Fig. 15 Nikos Logothetis binocular rivalry experiments on monkeys 1990s showing brain activity in higher areas of visual processing corresponding to the 'flip' in perception brought on by ambiguous stimulus.

What is interesting here is that these higher areas of the brain on the ventral and dorsal streams are much further along the visual processing chain and are not associated with stimulus driven changes like is being simulated through binocular rivalry in this experiment. Furthermore, recent human experiments using functional magnetic resonance imaging (fMRI) found activity resulting from perceptual ambiguous changes not only in these higher visual areas of the brain, but also in areas outside such as several frontal and parietal areas normally linked to cognitive behavior.

> *…the results suggest that…(binocular rivalry) entails widespread changes in the neural representation of the sensory input, and further suggests the possibility that these changes are in some way coordinated with brain activity lying outside the visual system.*[20]

V.S Ramachandran has taken this idea further, suggesting that the higher cognitive areas that become active during this perceptual shift are "qualia laden" and are heavily linked to what we might call our subjective experience, or consciousness.

At this point, it is useful to take a step back and reassess what has been discussed. Logothetis has proven through a series of experiments that certain higher cognitive areas of the brain become active during the perceptual flip that occurs in binocular rivalry. These higher areas are not driven by changes in direct stimulus but are associated with object location (in the case of MT and MST); form, object representation and memory (in the case of STS and IT); and even higher cognitive functions that we associate with elusive notions of subjective consciousness. Furthermore, several factors that contribute to which stimulus dominates conscious perception have been identified. My aim at this point was to create an environment in which viewers can directly experience these phenomena. I hoped that the devices that I proceeded to make would allow a simulation, rather than representation, of binocular rivalry and to provide a platform from which we can better appreciate our perceptual experience: one that is so familiar yet at the same time entirely elusive to our grasp.

3.3 *Diplopiascope*[2]

The *Diplopiascope* is an on going project that exploits the principles of stereopsis and binocular rivalry to allow participants to experiment and interact with their perceptual process, gaining a greater awareness of how we see and interact with our environment. The *Diplopiascope* has, in fact, gone through many different stages of design, but at its core is the aim to enable the viewer to better understand their visual perception.

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[2] Further details and system specifications of the *Diplopiascope* can be found at http://www.instructables.com/id/Interactive-stereoscopic-installations-visual-rup/

3.3.1 Research and Methods

In its most basic design, the *Diplopiascope* consisted of a simple mirrored device that allowed the user to see in two different directions at the same time. Much like the Wheatstone stereoscope mentioned in the previous chapter, this simple device was designed to illustrate how external visual stimulus is synthesised in our minds to form the rich experience we perceive.

Fig. 16 Basic design for binocular rivalry simulation, 2011

I began a series of experiments testing out various forms of this device to find the most interesting effects. I found that by combining a simple Wheatstone stereoscope design with elements of binocular rivalry, a very unusual sensation could be created in which the brain struggles to make sense of the solid unity that comes from the successfully stereoscopically fused areas of the image and the areas that it cannot fuse, namely the coloured text that is different in each picture.

Fig. 17 Stereoscopic elements combined with binocular rivalry, 2011

I soon discovered that by applying this principle of experiential synthesis and rivalry to stereoscopic video, the effect could be heightened even further. The videos of the drummer used in the installation below were shot with two cameras from a fixed position. The videos were then looped and played through two small monitors independently. The videos are viewed through a lensed viewing device, similar to a Wheatstone stereoscope, the left eye being shown the footage from the left camera, the right eye the footage from the right.

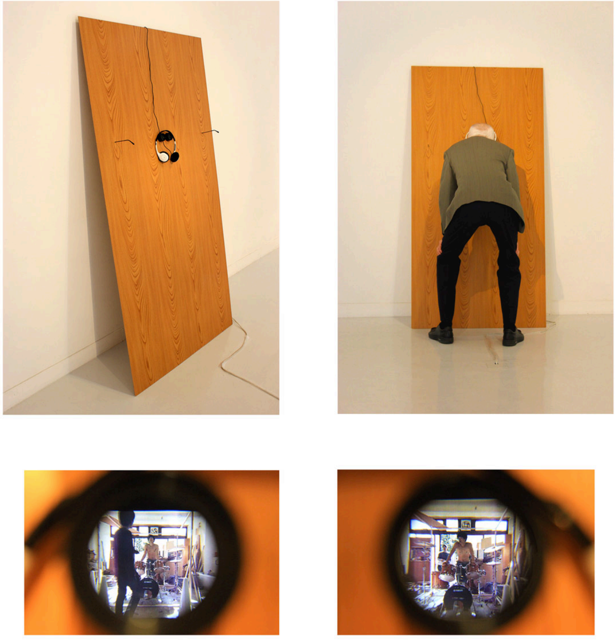

Fig. 18 Stereoscopic video combined with binocular rivalry, 2012, Kyoto Art Centre

Another early design, consisting of a live web-cam installation, was developed to enable two participants to work together as if they were one visual system. Two web-cams (positioned 7cm apart to simulate binocular disparity) are connected to two monitors via a PC running a maxMSP patch. The monitors are viewed simultaneously with a mirror system, giving the effect of 3-D due to stereopsis. One of the monitors displays a live stream from one webcam, while the other displays an altered output that randomly switches between 3 inputs: live-stream, delay, prerecorded stream. This produces an unfamiliar sensation as the percept switches inexplicably and uncontrollably from unified 3-D to a corrupted vision while the brain tries to compensate for the divergence of input. It is this balance in the perceptual process between the synthesis and rivalry of information that I hope participants can experiment with. The webcams are attached to a helmet worn by one participant (who becomes the *eyes*) while the other participant sits and perceives the relayed information (the *brain*).

Fig. 19 Diplopiascope eye-brain machine, 2012

3.3.2 An Enactive Method of Viewing

Until now the role of the viewer in the devices had been passive: the viewer would simply sit and observe. While this was not without interest, I was determined to see whether a more active role might produce more interesting results. It was at this point that I began to consider ways in which the viewer might be able to voluntarily change which of the stimuli dominated their conscious perception. As I mentioned above, some ways in which one stimulus would dominate the other are colour, form, and movement. Another important factor, as highlighted by Logothetis, is the link between perception and motor responses. I began to question whether some form of physical interaction on behalf of the viewer might have some interesting effects on what they perceive. Specifically I was interested in seeing if the 'flip' between the two conflicting images could be controlled by the participants' dynamic physical interaction with their environment. I investigated this by using prerecorded stereoscopic films that could be controlled by various input devices.

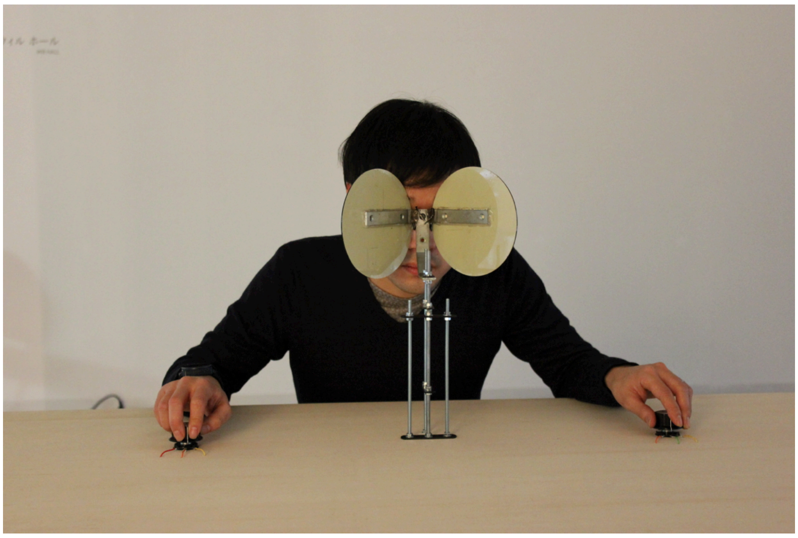

Fig. 20 Physical interaction by the viewer affects their conscious perception

In fig.20 the viewer controls the speed and direction of the videos through an analog device connected to the PCs via two arduino. There are two speakers, one from each PC, and the audio matches the videos and is also controlled by the dials. Because of this, the stationary objects in the video (the drum set, wooden frame, cones, walls, etc.) are seen in crisp stereoscopic 3-D; however, the moving objects (the drummer, people, etc.) will be seen in double. This produces a strange effect as the brain switches uncontrollably between which information it perceives, jumping randomly from the left eye to the right dominating perception. How this appears to the viewer is difficult to explain, but the moving objects take on a very strange phantom-like presence in the realness of their solid stereoscopic surroundings. While the majority of the field of view remains fixed in pleasant 3D, the figure of the drummer seems to jump in and out of time frames and consciousness itself.

I continued to develop this idea of a more physically interactive system with the latest *Diplopiascope* (fig.21). In this work, the movements of the viewer to control what they see are much more appropriate to the content they are seeing. The films are initially playing at one-tenth normal speed, and the speed of the films is controlled by accelerometers inside two boxing gloves. The viewer can move their arms while watching the films in a motion similar to the content they are watching and in doing so the film will respond to the movement and speed up to normal speed. I hope that the viewer is able to control which of the two conflicting images they consciously perceive through this physical interaction with the environment. Furthermore, I hope that they can experiment with tricking the very part of the brain where perception enters consciousness: a mechanism that is normally uncontrollable and elusive to our grasp (in both a physical sense and in terms of our limited understanding of its nature). I feel that it is this direct contact and exploration of our surroundings that is so essential to our experience.

Fig. 21 *Diplopiascope*, 2013

3.3.3 Evaluation, Audience Response and Feedback

My primary goal through the *Diplopiascope* body of work was to recreate the experience of binocular rivalry. I felt that this visual phenomenon is so present in our daily lives, but one that we rarely are aware of, I wanted to highlight its prevalent existence and allow the viewer to interact with, and ultimately control, this fascinating quirk of our perceptual experience. I feel that this was achieved with a considerable amount of success in the later designs of the system, especially in the 2013 version that is controlled by movements similar to what is being seen in the video. However, it become clear to me through this process of development that achieving watertight goals does not always equal interesting artwork. To clarify, audience feedback from the earlier stages of the *Diplopiascope* was often more enthusiastic than in the later stages, despite the later work being closer to what I had hoped to achieve. This was especially true of the 2012 work that involved the camera helmet. Even though this work can now been seen as a tangent from the evolution of the project, and not fitting in with the targets I had set myself at the start of the work, it was arguably the most interesting. This was an important lesson for me and made clear the potential difficulties that come from creating work that intersects both scientific and artistic fields.

I was also particularly grateful to get feedback from Dr. Shinsuke Shimojo from the California Institute of Technology who commented on technical aspects of the later, 2013, system. He informed me that the interesting ‘phantomlike’ effect that I was trying to achieve by simulating this kind of perceptual ambiguity could only exist up until a certain point, after which the effect is lost. In terms of the boxer video, the differences between the times of video should not be more than a split second, anything longer than this will result in the effect being too strange and we will simply ignore one or other of the images and binocular rivalry will cease to exist.

The work had proved to me that there is great potential in investigating perceptual phenomena through interactive art as a means of bettering our understanding of our sensory experience. It became clear that by altering certain parameters in the binocular rivalry simulation devices the viewer was able to discern through direct experience how it is we truly perceive our environment. I was positive that my approach so far had been successful and I was keen to apply a similar methodology to the next stage of my research: perceptual integration.

Chapter 4 - Perceptual Integration

In the previous chapter I discussed ways in which ambiguities in our perceptual lives can be investigated as a means of elucidating the nature of our experience. This investigation, and the *Diplopiascope* artwork that developed out of it, was focused on visual perception. In this chapter I will widen the scope of the thesis to look at how the senses interact dynamically with each other and their ability to adapt to changes in stimulation at all levels of the perceptual process. I will do this by first introducing general concepts of perceptual plasticity before discussing some related case studies in experimental psychology and neuroscience, considering the theoretical implications of these findings and real-life applications in assistive technology. I will conclude by introducing my own *FOVear* body of work, which is based on the discoveries that I made through this research.

4.1 Contextual Definition

The idea of plasticity refers, in this context, to the ability of the brain to adapt to changes in the environment, such as sensory deprivation, damage caused by brain injury, or the deterioration of a sense. Many modern neuroscientists believe that the brain is an organ capable of surprising plasticity, the ability to alter its role in perception, and this can manifest itself in many ways such as priming, adaptation, and perceptual learning[21]. A clear example of this is the recorded neural activity in the occipital cortex of congenitally blind patients during Braille reading and other perceptual tasks[22]. The notion that the brain activity of a defined function is not limited to the location at which it is normally associated has huge implications in the treatment of brain damage and has been at the forefront of scientific enquiry for the past few decades. My interest in this idea of a malleable brain function is primarily from an artistic point of view. Specifically, how scientific findings through empirical research into this topic can be incorporated into my work as a way of facilitating new levels of self-inquiry through heightened emotional response.

4.2 Types of Perceptual Integration

4.2.1 Perceptual Adaptation - Stratton and Kohler

In the 1890s, a hundred years before fMRI techniques had come to dominate brain-mapping research, George M. Stratton, a psychologist at the University of

California, developed ingenious techniques using lenses and mirrors to demonstrate the brain's remarkable ability to adapt to changes in sensory information. His most famous experiment consisted of Stratton himself wearing inverting goggles that turned his visual world upside-down, and his discovery that after prolonged use of this device, after around two days, his vision would re-invert itself. This notion of perceptual plasticity inspired Ivo Kohler of the University of Innsbruck to do his own extended versions of Stratton's experiments in the 1950s and 60s; wearing his self-designed glasses for prolonged periods while he went through everyday activities such as walking through the city and even riding his motorbike.

Fig. 22 Ivor Kohler's inverted glasses experiments tested during everyday activities.

Kohler noted several specific stages in the process of his perceptual adjustment to the glasses. These can be summarised as follows:

1. Initial experiential blindness.
2. Accustomisation: once the subject gets somewhat used to the lenses, objects above will appear to be below, and vice versa, what can be referred to as content inversion.
3. Normalisation: content above now seems to be as it should, despite it appearing below in terms of retinal and visual cortex stimulation. [23]

Most fascinating are the strange perceptual observations that Kohler reported in the early stages of wearing the glasses when his vision had not yet re-inverted itself. He found that by physically interacting with objects in his visual field he could make them appear the right way up; even simply touching an object with a stick would make it flip to how it would normally be perceived. This seems to be in line with sensorimotor theories of perception and the enactivist view that perceptual content is determined by our understanding of how it would change as a result of our physical engagement with the immediate environment. It certainly suggests an integrated and dynamic model of perceptual processing. As Stratton observed in 1899:

> *The different sense-perceptions, whatever may be the ultimate course of their extension, are organized into one harmonious spatial system. The harmony is found to consist in having our experiences meet our expectations…* [24] - R.L. Gregory

4.2.2 Sensory Substitution – Paul Bach-y-Rita

This idea of the brain as an organ capable of remarkable changes in its function was pursued by neuroscientist Paul Bach-y-Rita in the field of assistive technology for the blind. His belief was that while the eyes may be sensory organs, they are just one way of channeling information to the nervous system and can be bypassed completely by taking a different route. Sensory substitution was developed in the 1960s by Bach-y-Rita as a way of using one sensory modality to gain information used by another. The most well known example of his work is the Tactile-Visual Sensory Substitution (TVSS) system, which consists, in its early designs, of a vest to be worn over the front or back and a camera attached to the user’s forehead. Studded into the vest is an array of hundreds of tiny mechanical vibrators that, when activated, the wearer is able to feel through their tactile sense. The point-of-view feed from the camera is sent to a small computer worn at the hip, which converts the signal into tactile information via the vibrators in the vest. The devices are designed to be worn by people who have lost the ability to use their eyes. Because the visual processing pathways are still intact, they are able to bypass the eyes through their tactile sense and still experience subjective images; they are able to see though touch.

The truly transformative effect that the tactile-visual sensory substitution has on perceptual consciousness has become clear through fMRI studies to monitor brain activity while the devices are used. They show that there is a limited amount of activity in the visual cortex, in a similar way to activity stimulated through Braille reading, but the majority of the activity occurs in the somatosensory cortex, the touch part of the brain. What is so unusual about this is that the reported perceptual experience of the user is not that of touch, it is of a definite visual experience of the immediate environment; it feels like vision. This is an important distinction to make: through these sensory substation devices, blind people are not *seeing* in the strictest sense of the meaning, rather they are *perceiving* to see. Seeing in the traditional sense comes through the use of one modality, but the perception of seeing as evoked by sensory substitution is a result of cross-modal interactions. [25]

Fig. 23 Paul Bach-y-Rita's TVSS system.

Bach-y-Rita's research showed that areas of the brain are capable of changing their function for consciousness. What this implies is that the mind does not discriminate too highly about where our sensory information comes from, provided that it falls into a roughly recognizable pattern; in this case the pattern of the vibrations is recognized as it follows the same rules as vision. To refer back to the principles of sensorimotor theories of perception, it can be deduced that the somatosensory cortex is able to adopt the functional role of the visual cortex through this dynamic physical interaction with the environment. Our senses may have become more refined and specialised over our evolutionary development, but this work suggests that they are not as compartmentalised as we often presume them to be.

Bach-y-Rita and several other teams of researchers have developed many other designs of the TVSS system that employ other areas of the body sensitive to tactile stimuli, including the fingertips, abdomen, forehead, and tongue (which is often reported to be the most accurate and practical). In actual fact, the principles behind sensory substitution are not limited to tactile or visual senses. While the TVSS may be the most well known, other research have proven the viability in the substitution of other modalities such as tactile-auditory, tactile-vestibular, and auditory-visual substitution.

At this stage it is becoming clear that the plasticity of our brains, is made tangible though an equally plastic perceptual experience. Stratton and Kohler's inverted lenses experiments illustrated the adaptive potential of our perceptual process, and Bach-y-Rita's sensory substitution research show how parts of the brain can alter their function.

4.2.3 Multimodal Perception

Multimodal integration, also known as multisensory integration, is the study of how our different sense modalities are integrated to produce a coherent and unified perceptual experience. It seems that our perceptual system is not made up of strictly compartmentalised modal pathways but is, in fact, a far more integrated, adaptive, and dynamic matrix of signals. The senses do not work in isolation. Rather, signals from different senses are combined via the neural process of sensory integration[26]. There are a number of perceptual phenomena that suggest this to be the case.

The most ubiquitous multisensory illusion, known as the ventriloquism effect, shows how the dominance of the visual sense can influence where we perceive a sound to be coming from[27]. Closely related to this is the McGurk Effect[28], which illustrates the way in which two individual sensory stimuli (visual and auditory) can produce an entirely different perceptual experience that is not equal in quality to the sum of its parts. In the experiment, subjects are seated facing a video recording of a person repeatedly saying the word 'gah'. However, the audio coming from the video has been dubbed over to play back the sound 'bah' in synchronization with the mouth movements of the person in the video. What is fascinating is that the subject perceives to hear neither 'gah' nor 'bah', but a third hallucinatory syllable 'dah'; showing a clear example of auditory-visual sensory integration[29].

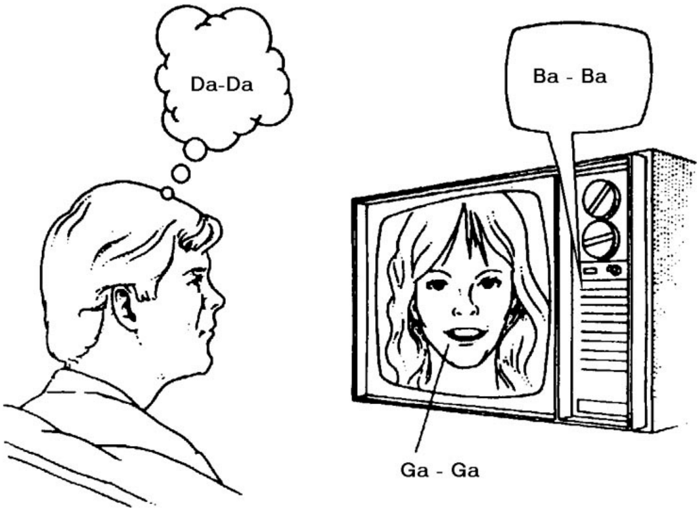

Fig. 24 The McGurk Effect demonstrates the integration of vision and hearing in speech perception.

While these illusions clearly illustrate the ability of visual stimuli to influence our auditory perception, there is also evidence, in the form of the 'double-flash illusion'[30], that the relationship can be reversed. It has been proven through fMRI studies that we can be tricked into perceiving multiple visual flashes on a screen when they are accompanied by audio beeps of a higher number. The standard experiment presents participants with a combination of one to four flashes and simultaneously zero to four beep sounds. They found that illusory flashes would be reported when the number of beeps was higher than the number of flashes. Also, aside from these visual-auditory examples, the rubber hand illusion[31] is an example tactile-visual sensory integration. This experiment consists of the participant looking at a dummy hand being touched while their real hand, hidden from view, is touched at the same time and in the same place. The reported experience is that of real sensation coming from the dummy hand, and even a sense that it is part of their body, and clearly illustrates the existence of tactile-visual multimodal integration.

In actual fact, the phenomenon of multimodal integration is pervasive in our perceptual lives and not at all limited to controlled experiments. Our sense of balance and our visual sense work together at such an elemental level that it is often taken for granted. The vestibulo-ocular response (VOR) is the eye rotation that compensates for head movements and helps keep our vision stable during motion. While research into this mechanism is not new, dating back to 18th century studies by William Charles Wells, modern medical techniques and brain imaging technology has allowed for a greater understanding of how the VOR functions. The vestibular system (that controls our balance) consists of circular canals filled with fluid that flow in directions depending on the movement of the head. These canals are connected to the eyes via reflex pathways. When the head rotates in one direction, signals are sent to the eyes that cause them to rotate in the opposite direction, and in this way to compensate for the movement and maintain a steady retinal image.

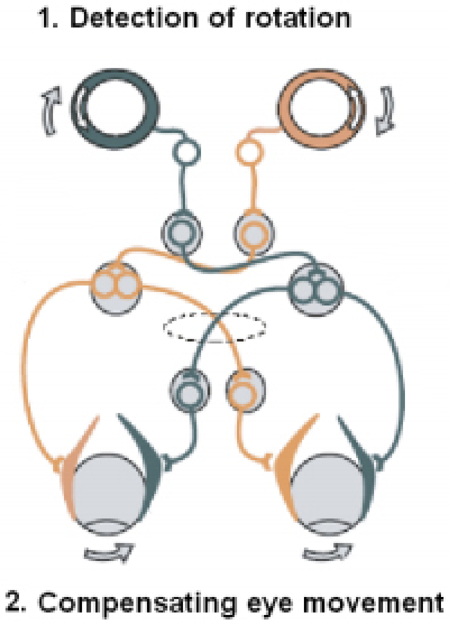

Fig. 25 The vestibulo-ocular response (VOR) is a clear example of the pervasiveness of multimodal integration in our sensory experience.

4.3 *FOVear*

The examples detailed above are in no way a conclusive list of perceptual integration, however, they do prove the pervasiveness of these phenomena and mechanisms in our sensory lives. Through this research, and my previous study into perceptual ambiguity, I became fascinated with the possibility of integrating two sensory modalities and what kind of sensation this might produce in the participant. My doctoral research thus far had been focused predominantly on vision, but the later developments in my *Diplopiascope* project, incorporating both visual and proprioceptive elements, indicated the potentially interesting effects of taking a more multimodal approach to my investigation. I began to reassess what it was that had first attracted me to vision as a topic of investigation and I realised that it was due to the very nature in which our visual system operates. I began to wonder whether it would be possible to transfer the essence of vision to hearing, and, if so, what effect this might have on our perceptual experience. I began to think about what the essential characteristics of vision and hearing are.

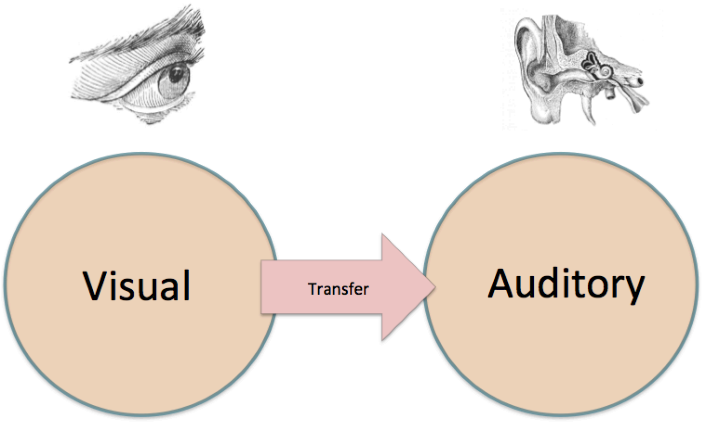

Fig. 26 Is it possible to transfer the essential qualities of vision to hearing?

Seeing is active and capable of providing very selective attention. Our eyes are surrounded by 6 oculomotor muscles, which pull at the eye, both voluntarily, and in the form of uncontrollable saccades and micro-saccades. Our visual system has developed to dynamically hunt out information through its ability to move the eyes in this way. Through the simultaneous movement of both eyes in opposite directions, known as vergence, we are able to maintain a crisp and rich three-dimensional image. Moreover, through the reflex action known as accommodation (ciliary muscle contraction) we are able to alter the shape of the lenses in our eyeballs and perceive a detailed focus on an area of interest. The area of visual acuity on the back of our retina, known as the fovea, illustrates further just how adept our vision is at selecting areas of interest and ignoring the rest. Hearing, by contrast, is relatively passive and unselective. There are no muscles to pull our ears to direct them at the source of the sound; moving are heads is the best we can do. The funnel shaped form of the ear is a reflection of the lack of control we have over the selectiveness of our hearing; they are designed to allow as much audio stimulus as possible to be received and have no powers of focus.

4.3.1 *FOVear* System

Fig. 27 A participant tests the early development of the FOVear system, April 2014.

I designed the *FOVear* system as a way of investigating what we would perceive when the sensory qualities of vision were transferred to hearing. The system works by tracking the user's eye movements with the open-source Pupil eye tracker[3]. Blob recognition software tracks the position of designated objects in the scene and combines this with the user's gaze position to calculate what they are looking at and when they look at it. Different sounds are triggered when the user looks at objects. In essence, the user becomes able to direct their auditory attention, much in the same way as comes naturally with vision. There are essentially three sections to the system: environment, device, and experience (see fig. 28). The user receives visual information from the environment as he/she looks around the scene. At the same time the eye tracking device receives the same visual information as well as the coordinates of where the user is looking. This information is processed in maxMSP to identify when the user is looking at specific objects that are identified by the colours red, green and blue. By designating sounds to each object, the system is able to trigger audio signals when the user looks at a certain object. The objects in question were generally those relating to musical performance. In an early installation of the system I used three mannequins wearing red, green, and blue hooded sweatshirts. The red clothed mannequin stood holding a microphone, the green holding a guitar, and the blue was seated behind a keyboard. By breaking-down an audio track to its 3 component parts (vocals, guitar, and drum and base) and assigning each of those sound files to its relevant colour, I was able to create an environment in

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[3] More information about the Pupil open source mobile eye tracking platform can be found at http://pupil-labs.com/pupil/

which by looking at the red figure the user would hear the vocal element of the song, looking at the blue figure would trigger the drum and base, and the guitar could be heard by looking at the green figure (see fig. 29).

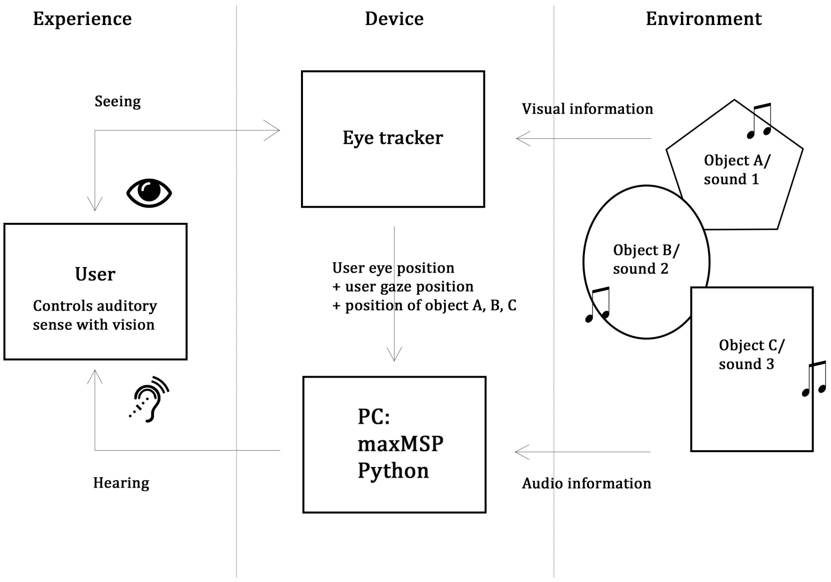

Fig. 28 Schematic diagram of the FOVear system.

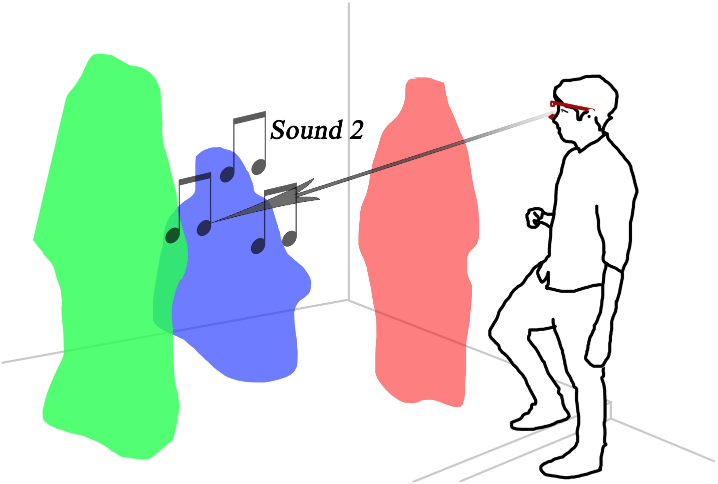

Fig. 29 Hearing with vision: the user hears the sounds by looking at the objects.

This third-version of the *FOVear* system incorporates the principles established in the earlier systems – transferring the qualities of vision to hearing – but this model presents a more engaging performance, not only for the user themselves, but also for those observing the experiment. The idea behind this development is to enable a greater understanding of this first-hand experience for those who are not directly using the system. In this latest design, the eye movements and position of the user are processed to work out which of the coloured balls they are looking at, showing where their visual attention lies. Each object triggers a different audio sample, which begins slowly and then steadily increases to a more 'comfortable' speed as they continue to look at the object. This is designed to encourage the viewer to look from one object to the other as fast as they can, and 'reward' them for shifting their attention rapidly through the saccadic movements that are unique to our visual sense. The sounds act as an audio translation of this very visual characteristic. Furthermore, projected behind the user are the video clips that correspond to the audio, speeding-up, slowing-down, and shifting in synchronisation with the user's attention. While those using the device cannot see this themselves, it acts as a visualisation tool for the audience of the very subjective experience being simulated. In this way, the interaction of the user with the environment, and their body itself, becomes a conduit not only for their own experience, but also for the experience of the audience.

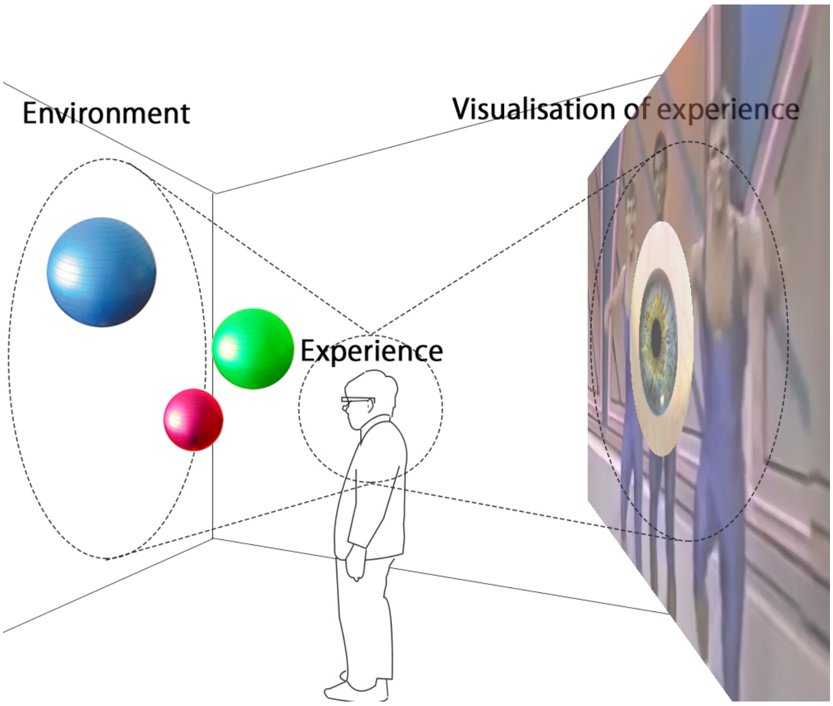

Fig. 30: *FOVear* v3

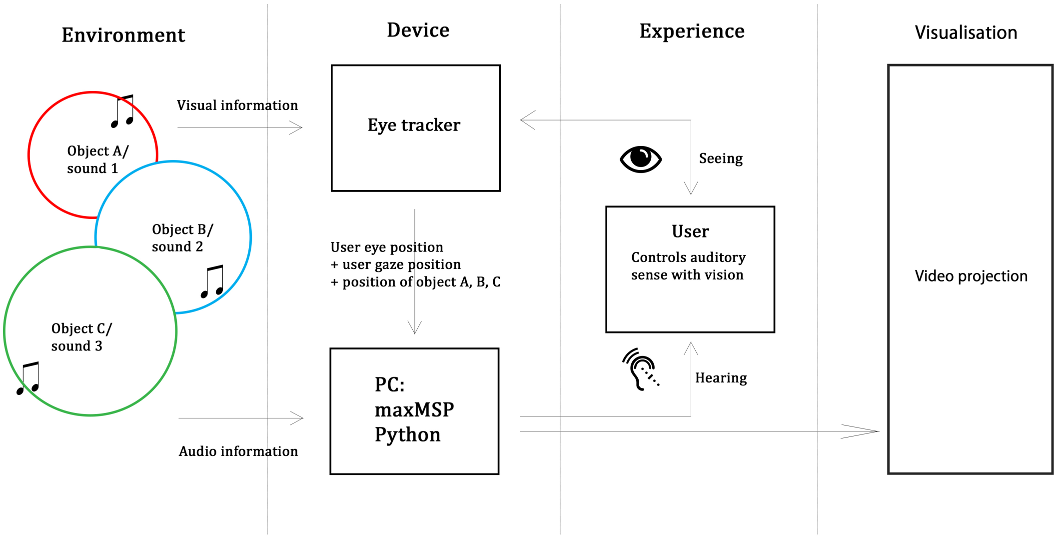

Fig. 31: Schematic diagram of *FOVear* v3 Audio-visual sensory integration project

4.3.2 Evaluation

The work has been exhibited in a number of different formats: using both mannequins and live performers. The audience response to these two formats has been quite different from one another, so it is best to clarify by looking at both individually.

Audience responses to the early (not live) designs of the FOVear system were generally very positive and provided encouragement for me to pursue this mode of experiential presentation into the next step. The work was shown in a solo exhibition at Antenna Media Gallery in Kyoto, Japan, for the duration of one week in April 2014. The gallery is small, independent and used to showing experimental sculptural and painting works. However, few interactive exhibitions of this interdisciplinary art-science nature had been shown and so audiences were perhaps unfamiliar with how to interact with the work. This was not necessarily a problem, but it did raise issues about the importance of location when exhibiting my work, suggesting that venues that are not purely artistic in nature may be more successful.

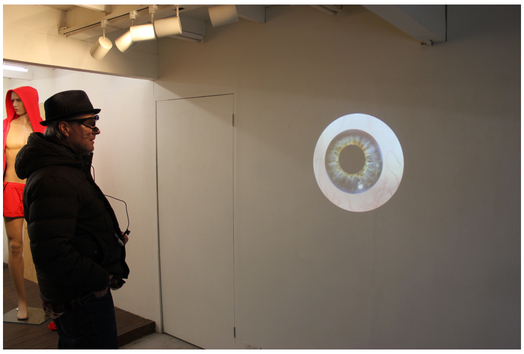

Fig. 32 Looking at the figures triggers the sounds Fig. 33 Graphically rendered eyeball

After the initial explanation of the work and calibration of the eye tracker users seemed to react very enthusiastically to the eyeball visualization (see fig. 31) that moved in real-time with their own eye movements. Of particular interest was the pupil that would constrict and dilate as the user looks at, or away from, the light. While this element was not necessarily the intended focus of the work, it added an extra level of accessibility to those unfamiliar with theories of sensory-integration (which formed the majority of the audience). The system worked very well in almost all cases, the only real problems stemming from unsuccessful calibration of the eye tracker (which could easily be corrected), and users adapted to the system surprisingly quickly. However, the initial response was one of confusion. Due to the complex scientific nature of the explanation of the work, the majority of the users were experimenting with no real understanding of what they might expect to happen. For this reason, it took between 30 and 45 seconds for them to understand that their eye movements were triggering the audio. Once they had come to understand this, they very quickly warmed up and could begin experimenting with making sounds, moving around the space, and testing the parameters of the system. One aspect that became apparent through this exhibition was that the experience was far more interesting for the one person using the device, than for the bystanders. Although this was the intention (the work was designed to examine first-hand perceptual experience), it did make me consider options to make the experience more involving for the audience while they wait to test the system for themselves.

The second exhibition of the system was for a more specialized audience at Kyoto City University of Art as part of my PhD assessment in July 2014. The work was shown to a mixture of faculty and students after my presentation outlining the current state of my research. For this reason, the general understanding of the nature of the work, my intention in exhibiting it, and what participants might expect in experiencing it, was higher than at the previous exhibition open to the general public. I decided to make the experience more involving for the audience by including a performance element to the exhibition. Instead of using mannequins, which I had decided were both distracting to the work and visually displeasing, I invited 3 performers to take the place of the coloured objects. In this case I used two Kansai based opera singers and one sound artist. Microphones were attached to the singers and the sound artist was using a midi device, all were connected to maxMSP via computer. The singers and musician all performed simultaneously, but not in harmony, producing a confusing cacophony of sound. The user, by looking at one of the performers was able to isolate that one sound by hearing it through the speakers at a relatively higher volume than the other two. This provided a much more interesting environment for both the audience and the current user of the device.

Fig. 34 *FOVear*, live version, July 2014.

4.3.3 Feedback

I was very keen to receive as much feedback as possible in regards to this project, and I was especially grateful to Dr. Shinsuke Shimojo of California Institute of Technology for his comments. I was particularly interested to hear his opinion about the nature of the work in terms of sensory substitution and sensory integration. Dr. Shimojo commented that while the *FOVear* does not produce sensory substitution in the strictest sense (for example by giving blind users a visual experience via training with a device), it is likely to produce a "synesthesia-like experience" or cross modal correspondence. He suggested that through over-experiencing the system repeatedly, some degree of merging of sensory experience could be expected.

I was satisfied that the work had accomplished my goals of elucidating one aspect of our perceptual experience, that of sensory integration. I feel that through this device and installation, participants were able to experience what it might feel like to have a greater merging of our senses and it had given me great motivation for exploring the idea of an integrated perceptual system further.

Chapter 5 - Interoceptive Awareness

In the previous two chapters, I detailed two methods that I have found to be successful in using interactive multimedia art to elucidate the nature of perceptual experience. Until this point, the work has been based on a fairly literal interpretation of perception; taking it to mean the physical sensory experience of interacting with our environment. In one respect, the focus of the *Diplopiascope* and *FOVear* bodies of work was narrow, looking at very specific sensory phenomena (binocular rivalry and sensory integration) as a means of better understanding our perceptual experience. However, through these projects, and especially in the *FOVear* work, I began to think of the way we interpret our physical environments into a conscious experience as an integrated process. Findings in sensory substitution research had made it clear to me that our senses are not as compartmentalised as is often assumed. While our vision and hearing are undoubtedly very specialised, it became apparent to me that the nature by which this information is processed and interpreted is, in fact, very adaptable in its nature. What has become clear through the development and experimentation with these multimedia systems is that through the integration of this different sensory information, we produce a sense of being ourselves. In other words, our experience of body ownership is derived from our awareness of our sensory processes. This more holistic approach to thinking about perception and consciousness leads me onto the final section of research: interoceptive awareness.

5.1 Internal Perception

Interoception, or internal sense, is any sense that is stimulated from within the body. The brain receives information from many sensory receptors that exist in our internal organs such as stretch receptors that monitor and control the lungs and heart, and chemoreceptors that monitor changes in chemical concentrations in the body. Interoceptive awareness refers to how conscious we are of these internal senses, a classic example being the ability to focus your attention on your heartbeat (something that is relatively common amongst young, lean athletes, yet unfamiliar to the vast majority of people). Recent research suggests that this physiological awareness of the internal state of one's own body is related to the conscious experience of feeling[32]. What researchers have found is that the area of the brain that is activated when participants try to judge whether their heartbeats are beating in time with a series of tones, is the same region that correlates with our ability to correctly identify certain emotions[33]. Using fMRI techniques, they found that the size and activity of the right anterior insular cortex was related to participants' accuracy in judging the timing of their own heartbeat.

5.1.1 The Role of The Right Anterior Insula Cortex

The insular cortex has been linked to a number of 'higher' functions that exist only in humans and great apes, specifically cognitive-emotional processes like empathy and emotional awareness. Furthermore, the size of the right anterior insular cortex has been found to correlate directly with the ability to time one's own heartbeat and accuracy in judging internal body states and negative emotions. One of the main proponents for this theory, Antonio Damasio of the University of Southern California, has argued that this area of the brain is responsible for mapping visceral states associated with emotional experience[34]; in other words, it provides the basis for emotional awareness.

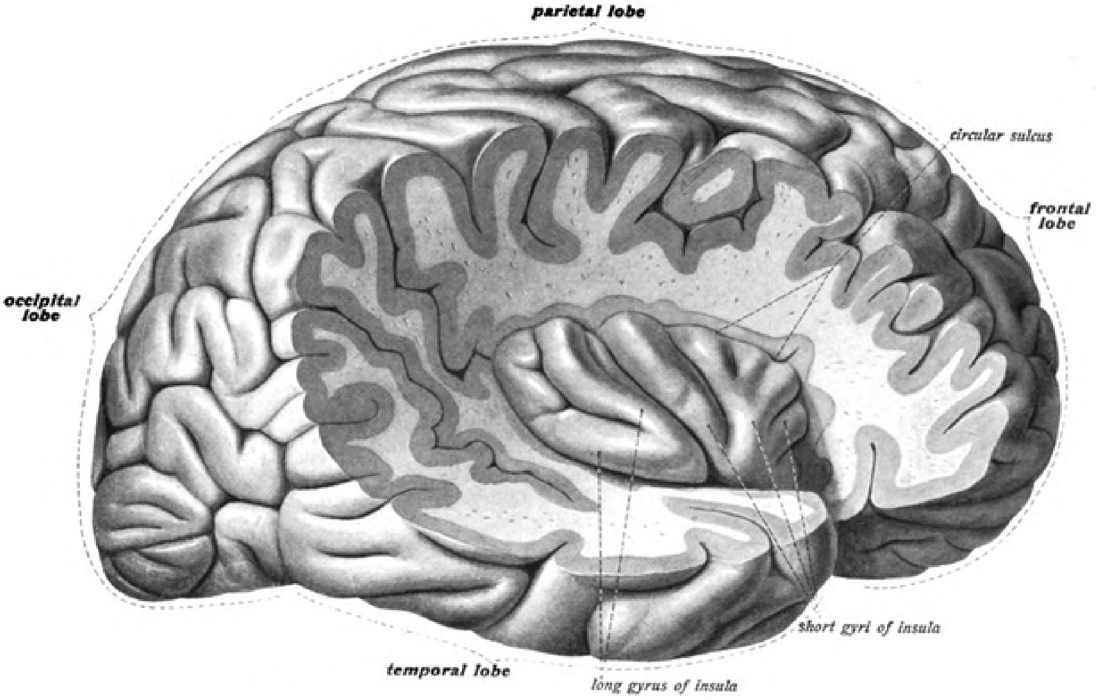

Fig. 35 Right insula cortex, exposed by removing the opercula

However, while evidence in the form of fMRI data has given empirical evidence of activity in cortical areas, the connection between interoception and emotion is not necessarily a new concept. In actual fact, earlier social psychology experiments, philosophical theories, and even ancient Buddhist meditation practices have all made explicit the connection between an awareness of internal bodily states and the conscious experience of emotion.

5.2 Precedents in Interoceptive Research

The two-factor theory of emotion, which states that emotion is based partly on physiological arousal and partly on cognitive labeling, was the primary research of Stanley Schachter and Jerome E. Singer in the early 1960s. They performed a study to test how people respond to environmental cues when they are under various states of physiological arousal. Participants in three groups were injected with epinephrine, a drug that causes respiration and increased heart rate. The informed group was accurately told the physiological changes they would feel, while the other two groups were either inaccurately told they might experience headaches, itching or numbness in their feet (misinformed group), or told nothing about what they might experience (ignorant group). There was also a control group that was injected with a placebo. All the groups were then observed as they interacted with an assistant, who would act either euphorically or angrily, to see how much of an impact it has on the emotions of the participants. As expected, the misinformed and ignorant groups were more euphoric or angry, depending on the emotional state of the assistant, than the informed and control groups. This suggests that the less aware of your physiological state you are, the more likely you are to label your feelings in terms of suggestions in the immediate environment.

Going back further, the James-Lange theory refers to the hypothesis of 19th century psychologists William James and Carl Lange. They suggested, without any experimental evidence, that all emotion comes from stimuli that provokes a physiological response[35]. Their theory puts it that emotion is a secondary feeling, brought about by this physiological response to a stimulus, which is the primary feeling. To clarify, stimulus from the outside world, the image of an aggressive dog for instance, is relayed through the eyes to the cerebral cortex. The brain then sends this information to the bodily organs (heart, lungs, etc.) and muscles; causing them to respond appropriately: increased rate of heartbeat, faster breathing, tensed muscles, etc. Finally, the information of this physical response is sent back to the brain, which can now interpret the dog as an “object-emotionally-felt”[36].

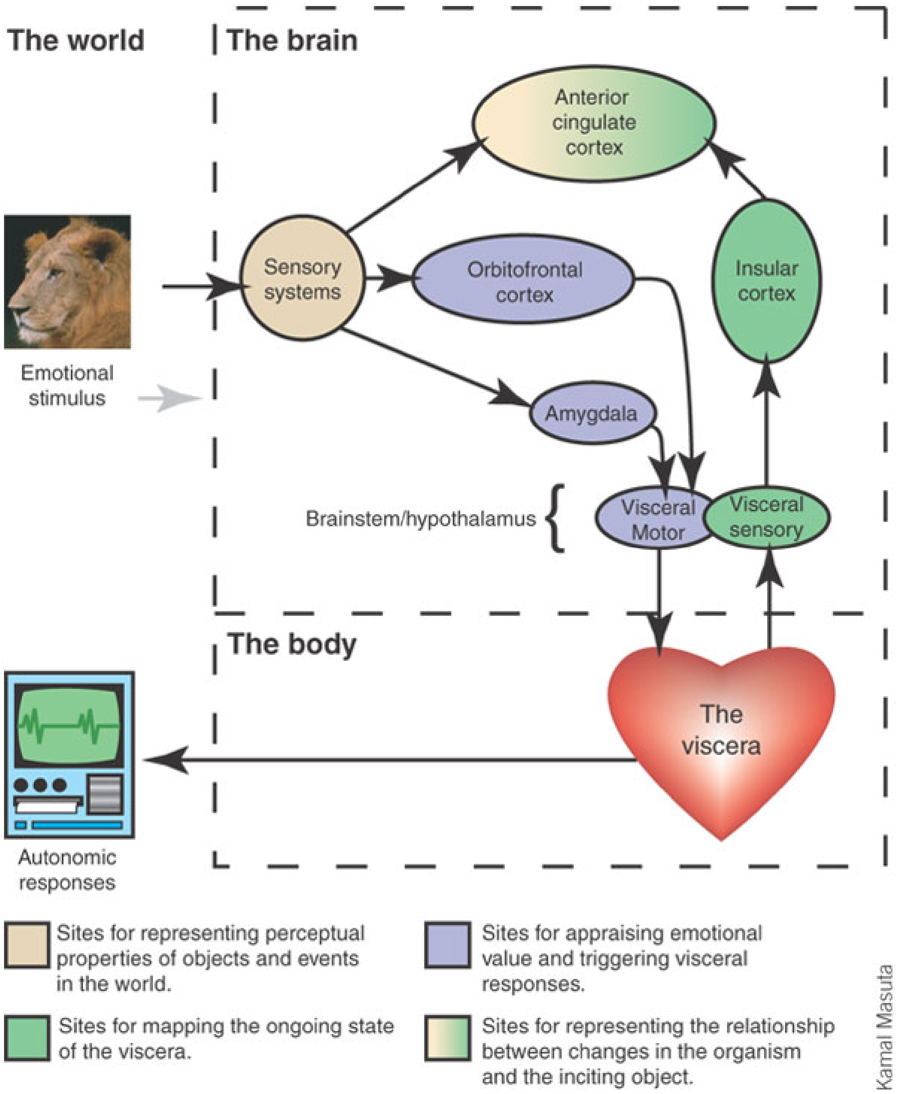

Fig. 36 Relationship between stimulus, physical response, and emotion according to the James-Lange Theory.

There has been considerable criticism of these ideas since the theory's inception. Most notably from psychologists Walter Cannon in the 1920s who proved that the viscera could be separated from the central nervous system without having any impact on perceived emotions. Further studies showed that stimulating the viscera through adrenalin injections was ineffective in producing an emotional response, and only caused physiological changes[37]. Despite this criticism, the ideas of James and Lange remain as one of the several competing theories of the body as a substrate for emotion.

However, we should be careful not to think of these ideas connecting the physiological with the emotional as purely discoveries of western science. Anapanasati breathing techniques, as practiced in Buddhist meditation, have been used for thousands of years as a mode of mindfulness training. The technique, which involves paying attention to the sensations caused by the movement of the breath in the body, is taught in several Buddhist traditions in both ancient and modern times as a way of achieving tranquility and one pointedness of mind. The route of the word gives an obvious indication of what it hopes to achieve: *Ana* meaning to inhale, *apana* to exhale, and *sati* to be mindful. Anapanasati trains the meditator to be sensitive their body's physiological state, and through this aims to focus and steady the mind. There are several variations on how the meditation can be practiced, but the essential element of concentrating on the breath remains the same. These methods are becoming increasingly popular outside of the Buddhist tradition and are used widely in secular mindfulness training. What is fascinating is that, while these techniques have been used since ancient times, long before any brain imaging technology existed, recent studies using magnetic resonance imaging have shown that the right anterior insula is significantly thicker in those that regularly practice these types of mediation[38]. The implications of this discovery are two-fold. Firstly, it strengthens the argument linking the size of the right anterior insula with physiological awareness. More significantly, it suggests that this is something that can be trained.

5.3 Interoceptive Awareness and Health

These findings indicate a number of interesting things. Primarily they show that our perceptual experience is much more deeply integrated that we generally assume it to be. The idea of connections between the 'body and mind' is something often discussed to the point of cliché, yet it is arguable whether or not the concept is truly understood. Vague notions of physical health having an effect on mental health, and vice-versa, are widely assumed to be correct, but the extent to which this relationship exists, and the nature of the mechanism, is still a very cloudy area of knowledge. Secondly, they imply that people that have a clearer sense of their physiological selves are less likely to suffer from various negative disorders like panic attacks, eating disorders, and depression. Importantly, this could mean that interoceptive awareness training might be effective in the treatment of these disorders[39].

The relationship between interoceptive awareness and alexithymia (a lack of emotional awareness) has been the research focus of Olga Pollatos, the head of the health department at the University of Ulm in Germany. Pollatos found that the more accurately participants were able to detect their own heartbeats, the less likely they were to suffer from alexithymic characteristics such as substance abuse disorders, posttraumatic stress disorder, depression, and eating disorders[40]. Another line of research, being carried out at Anglia Ruskin University by psychologist Jane Aspell, has involved more complex heartbeat visualisation techniques. Using cameras and virtual-reality glasses, Aspell was able to capture the image of the participants from behind and then show this virtual image with the real-time heartbeat projected on top. The findings were that this heartbeat visualisation led to an increased self-identification with the virtual body, implying that interoceptive training is certainly possible[41].

Taking these findings into account, I decided to investigate the way in which interactive systems could be used to highlight the nature of our interoceptive perceptual experience. I have two main aims through the creation of this body of work. Firstly, I hope to enable a greater understanding of this emotional-physiological dynamic through the first-hand, direct experience of these multimedia systems. By doing this, my intention is draw our attention to another aspect of our sensory lives that we seem to be naturally disposed to overlook: the connection between our internal bodies and our emotional states. I believe that this casual overlooking of something so inherent to our direct experience is further proof of the transparency of experience. Secondly, I am interested in discovering possibilities for using such devices in the treatment of dissociative bodily disorders as mentioned in the research of Aspell and Pollatos.

5.4 *Heartvise*

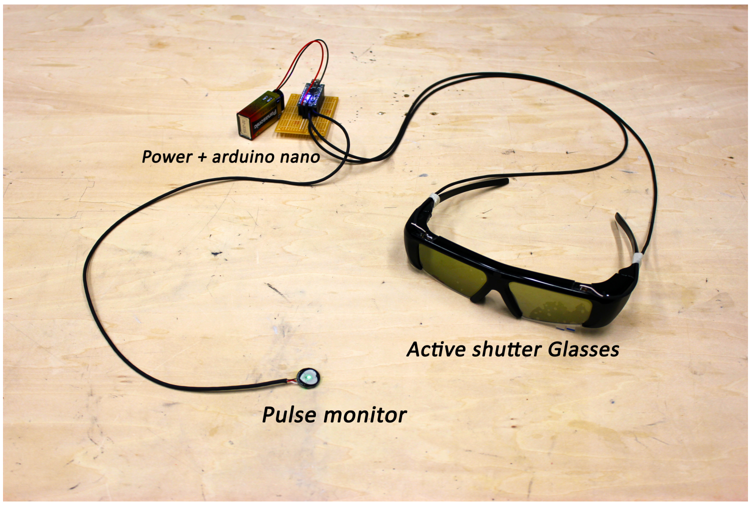

Fig. 37 Heartbeat visualisation in early stages with the *Heartvise*

The intention behind my ongoing *Heartvise* project is to develop an artistic system that can be used in the training of interoceptive awareness. Although the work is still in the developmental stage, I feel that it offers great potential in both artistic endeavor and in the role of assistive technology for improving our sense of bodily awareness. In its most basic format, the system consists of a low-cost heartbeat monitor[4] connected to an Arduino running a custom code that sends the heartbeat signal to a visualisation device, in the case of fig. 35 this device is a pair of active shutter glasses, used for watching 3-D films, that have been hacked to allow the display to be controlled by the heartbeat signal.

At this stage I think it is important to define exactly what the *Heartvise* is and what it is not. Previous research into interoceptive awareness has focused on the relationship between the ability in participants to identify their own heart rate, brain activity (especially in the right anterior insula cortex), and identification of emotional states (especially negative). This relationship has been shown to be strong and a considerable amount of empirical evidence has been produced through extensive experimentation done by Damasio, Critchley, Craig, Bechara, Naqvi, Herbert, and Pollatos[42]. Furthermore, the work of Herbert and Pollatos has found a clear inverse relationship between alexithymia (the difficulty in identifying negative emotions) and interoceptive awareness[43]. What this implies is that the more skilled a subject is at recognising their internal physiological state, the less likely they are to suffer from negative somatic and psychiatric disorders. The *Heartvise* project does not offer any attempts to further clarify or investigate this relationship. I feel it is important to acknowledge the position of the work as firmly resting in the field of art. What I am developing is not a device to be used in rigorous scientific experiments. However, what it does attempt to do is to provide a platform from which we can investigate the themes that have resulted from these previous academic studies in a direct, first-hand sense.

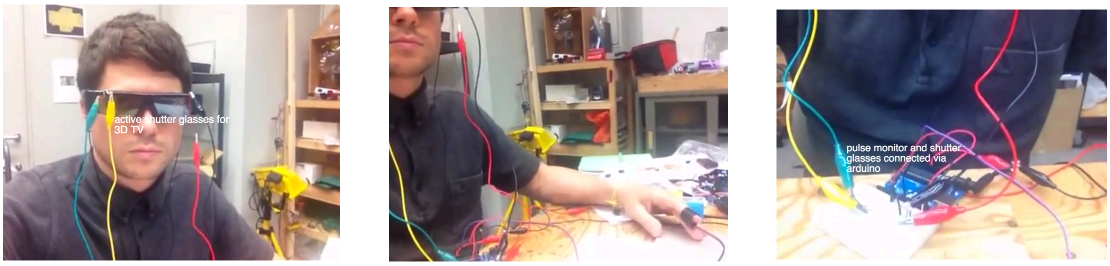

Fig. 38 *Heartvise* prototype, heartbeat visualisation via Arduino and active shutter glasses.

In the early stages of development, I designed the device to be wearable technology. My aim was to create a lightweight, mobile unit that can be worn throughout the day as a means of training the user's interoceptive awareness. Previous scientific research into the emotional-physiological relationship has produced a number of heartbeat visualisation systems, but they have all been static, non-mobile systems, that, while suitable for testing under laboratory conditions, cannot be worn outside of the testing environment. I want to

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[4] Details of the open source heartbeat monitor *PulseSensor* can be found at https://www.sparkfun.com/products/11574

investigate the effects of this kind of device if worn over a prolonged length of time. The inspiration for this approach came from the advice of Dr. Shimojo who advised that "over-experiencing" my *FOVear* work would present more satisfactory results. In the same way I hope that through over-experiencing the *Heartvise* system, users might be able to develop a more acute sense of interoception. Another source of inspiration for the system comes from the perceptual adaptation experiments of G.M. Stratton and Ivor Kohler, who found that, after extended periods of wearing inverted lenses, their vision would re-invert itself.

In the next stage of development, I wanted to see if these ideas of heightening our bodily awareness could somehow be applied simultaneously to more than one body. For some time I had been interested in the notion of a mutual or common sensory system and I felt that this offered a great opportunity to pursue this. My idea, while very simple, was to combine the heart rates of two people and visualise this new averaged pulse. The idea is most simply expressed in the illustration below of two people simultaneously taking each other's pulse (fig. 37).

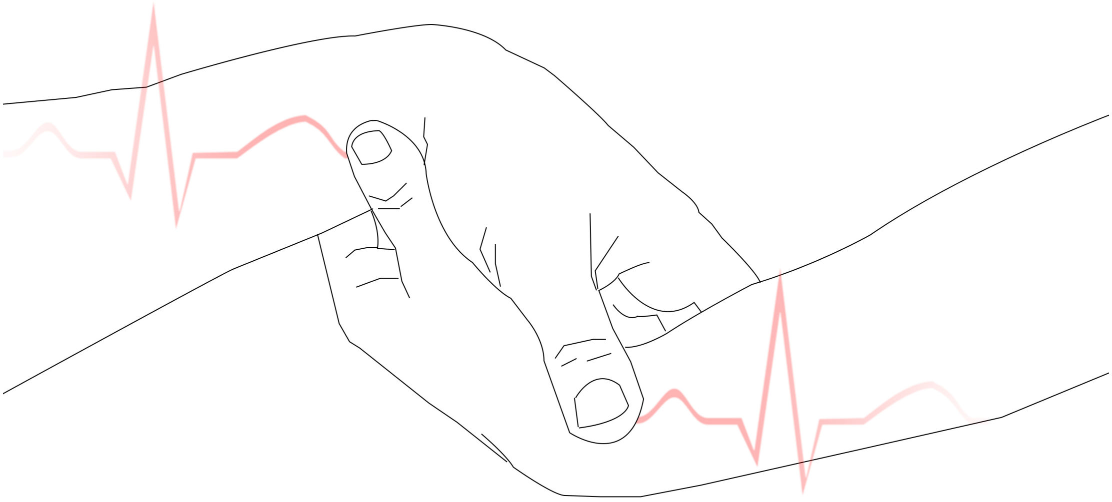

Fig. 39 Simultaneous pulse taking

The mechanism I developed to investigate this idea is very simple. It involves a two-way mirror, on either side of which stands a participant. The two participants' pulses are read by placing their hands onto a box to their side with a pulse monitor embedded in its surface. These pulses are streamed to a computer where the data is averaged, producing a pulse rate of a frequency exactly between that of the two. This rate is then used to control two lights positioned above the participants' heads, on either side of the two-way mirror; the lights will blink on/off in time with the averaged pulse rate. The participants are presented with a changing image standing before them of their own reflection and the image of the other participant, blinking back-and forth in time with the average pulse rate.

Fig. 40 and 41 Changing body image in time with the users' average pulse rate

Through this work I attempted to investigate two things. Firstly, I was interested to see whether the pulse rate of each participant would gradually change over time by using this system, speeding up or slowing down so that they both became the same. Should this be the case, it would clearly show that an increased awareness of the body's internal state (as illustrated by the pulse visualisation) has an explicit effect on physiological rhythms such as pulse rate. Secondly, through the visualisation of a changing body image in rhythm with the mutual pulse rate of the users, I wanted to see what kind of impact this might have in terms of a sense of dissociation or bodily awareness. What is especially fascinating for me is that, through this system, the idea of bodily awareness is no longer limited to the singular body that we inhabit, but it instead takes on a more interconnected notion in which separate bodies can somehow be recognised as one.

My previous *Diplopiascope* and *FOVear* bodies of work successfully enabled the user to gain a better understanding of their perceptual experience, and in doing this helped elucidate what is known as the transparency of experience. The *Heartvise* system is an extension of this method. However, while the previous two projects had investigated quite specific and well-researched perceptual phenomena, the *Heartvise* project is a more holistic approach to our conscious experience. What it presents is a method of experiential inquiry into the idea of a physiological-psychological relationship, and, in this respect, is not under the same constraints of the previous two projects.

Chapter 6 - Aesthetic Decisions

This chapter is designed to tackle an issue that regularly appeared thought the course of developing and exhibiting my artwork: the problem of aesthetic decisions. The nature of my research and artwork, being heavily reliant on scientific findings and based on empirical evidence, has meant that the visual quality of the work has been of particular concern. One of the keys to worthy scientific research is its objective and unbiased nature, both in practice and publication. The books and papers that have become the backbone of my research into perceptual mechanisms are filled with illustrations and diagrams that are unified by their detachment from any emotional or subjective charge. In this simple quality lies the effectiveness of a good scientific illustration; they are easy to understand, do not include any gratuitous detail, and do not distract from what they are trying to clarify.

This is not to say, however, that there are no aesthetic decisions in scientific publication. On the contrary, the challenge of creating an image that is at the same time explanatory yet non-distracting is a complex and difficult challenge. It can be argued that aesthetic decisions are of even higher importance in these cases. Furthermore, it is surely the case that the pared down aesthetic of scientific imagery is a style in itself. The minimal, non-distracting, quality is in fact a very stylized method of illustration.

Fig. 42 Stereoscopic image demonstrating rules of vision in Donald D. Hoffman's *Visual Intelligence*

Examples of this utilitarian diagrammatic beauty can be found in most visual science books and academic papers, but is particularly well represented in Donald D. Hoffman's *Visual Intelligence* (see fig. 37). The above illustration is designed to show how the brain is able to construct three-dimensional coloured surfaces out of limited information (the images should be fused by cross-eyed or straight-view stereopsis). The image is at once highly functional, and aesthetically pleasing. Of course, whether or not any visual success in this diagram is the author's intention would be very difficult to discover. Yet the success itself surely cannot be argued and simplicity and functionality of illustrations such as this are qualities that have influenced my own work greatly.

One further example of interesting aesthetic qualities in scientific practice can be found in the sensory substitution work of Paul Bach-y-Rita. A good example of this is the tactile-vestibular sensory substitution helmet (fig. 38). The device itself consists of a hard hat mounted with x/y accelerometers, the signals from which are fed into an array of electrodes to be worn on the tongue; allowing the user to detect horizontal head displacement. In this way the helmet can be used in the rehabilitation of people with bilateral vestibular loss. For display purposes, accessibility, or possibly to reduce weight, the helmet has been cut away, revealing the inner workings of the system. This immediately adds an interesting aesthetic element to the device and it becomes less about pure function as we are drawn in by the strange looking headwear. Whether this decision was made for artistic purposes, or simply to make the mechanics of the device more easily understood, is, like the illustration above, uncertain. All we can conclude with certainty is that is visually successful.

Fig. 43 Vestibular substitution helmet, Paul Bach-y-Rita

In research into perceptual phenomena, the point at which the role of aesthetics diverges between art and science is in the intention of the creator. In dealing with perceptual experience, artists are generally more interested in the representational content and emotional impact of visual perception, yet are less inclined to pay attention to the scientific merit, while scientists are more concerned with investigating the neural mechanisms and mental processes[44]. In this respect, visual elements of the work become far more important to the artist (in trying to intensify the experience) while the scientist may view this as a distraction.

My early *Diplopiascope* body of work was my first attempt at combining aesthetically pleasing or amusing elements with the more austere research I had investigated in visual perceptual science. Acknowledging that the work would ultimately be exhibited in gallery spaces, and not under scientific experimental conditions, I was able to play with certain aspects of the presentation. By using large round mirrors for the viewing device, it was transformed into a pair of bug-eyes when seen head-on, accentuating the focus on *vision*. Added to this was the decision to use a hard-hat, much like in the work of Bach-y-Rita, which gave a comical aspect to the installation through the contrast between the mundane and the peculiar.

Fig. 44 *Diplopiascope,* 2012, with head mounted cameras, @KCUA Gallery

It was at this point that I became more confident in my mode of expression. The work is experiential, and is designed to expose the fuzzy-edges of sensory experience. Taking this into account, I began to have more fun with the aesthetics of the work. In the next installation of the *Diplopiascope* work I decided to play on this idea further by combining videos of very subjective subjects with the same principles of binocular rivalry and stereopsis. I decided to film a double shrine gate tunnel (Fushimi Inari, Kyoto, Japan) because it possessed both the technical aspects that I required for the exhibition, and was a very suggestive image. The video was filmed and shown stereoscopically with two cameras; one camera was walked down the left and one camera down the right tunnel. When the footage was watched, it gave the impression that your eyes were travelling down different passageways. I felt that the colour of the shrine gate paint and the repeated structure of the tunnels was very suggestive of biological forms, specifically, I was referencing the visual pathways of the human eyes. It goes without saying that references such as this would be both distracting and counterproductive had the work been designed for laboratory condition experiments.

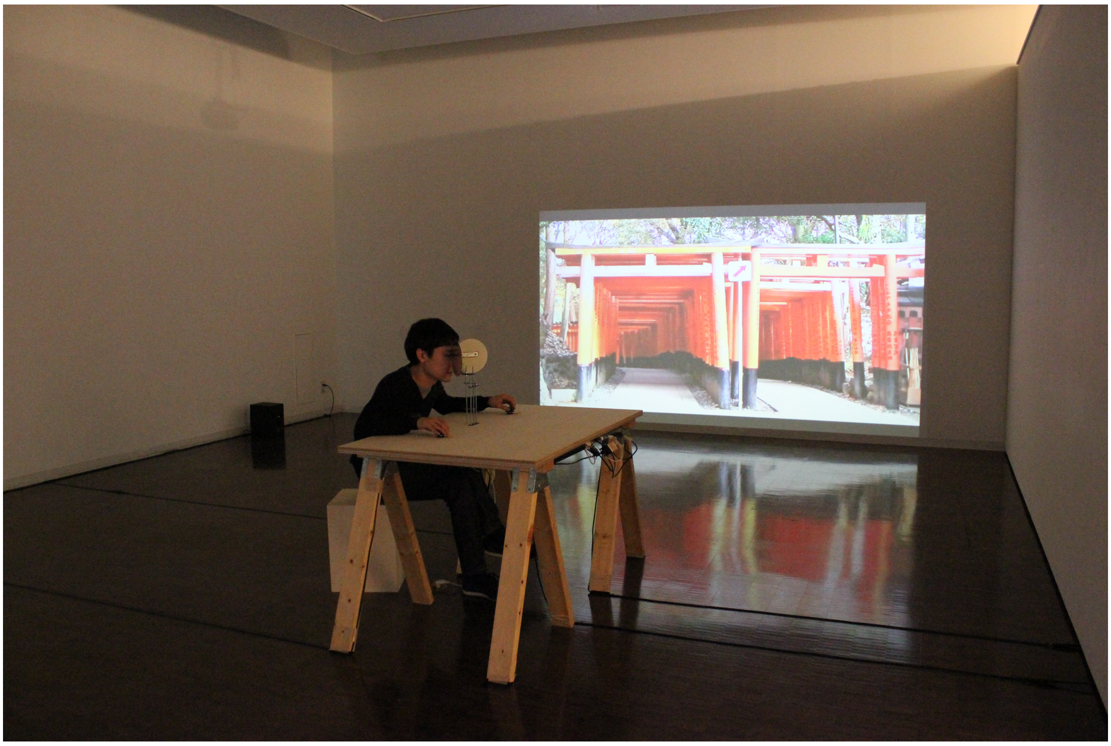

Fig. 45 *Diplopiascope,* 2013, with shrine gate video, @KCUA Gallery

After realising that it was possible to combine the principles of vision research with artistic aesthetic qualities, I decided at take this further by adding more comical elements to the work. I used stereoscopic footage I had filmed of a kick boxer in training for the next development of the installation. A pair of boxing gloves was fitted with accelerometers that enabled the user to control the speed of the video. In this way they were able to interact with the work on a much deeper level than had previously been possible. The decision to use a kick boxer was two-fold. On one level, the use of a very physical element such as a martial artist helped to illustrate the sensorimotor theory of perception that I had been researching (as discussed in the earlier Contextual Framework chapter). At the same time, the striking visuality and thunderous sound of the kick boxer combined with the somber presentation of the rest of rest of the installation produced a very exciting aesthetic contrast. The boxing glove controller element made the work more accessible to those with little or no knowledge of vision science and was designed to make the installation less intimidating and more visually entertaining.

Fig. 46 *Diplopiascope,* 2013, with kick boxer and boxing gloves controller, Kyoto City University of Arts

The *FOVear* installation posed an additional constraint on what was possible in terms of aesthetic decisions. This was due the fact that a major element of the system was a colour-tracking maxMSP patch that I had made in order to calculate the position of designated coloured objects in the scene. This meant that any additional bright colours would confuse the system and stop it from functioning correctly, so the walls and surrounding area had to be kept monochrome. In actual fact, this additional technical constraint was useful in guiding how I visually designed the installation, and gave the work a very clean and almost scientific quality. Perhaps the most immediately noticeable aspect of the *FOVear* installation was the graphically rendered floating eyeballs that darted around on the peripheral wall of the space, controlled by the user's eye movements. Arguably, this element was separate from the purpose of the work (to provide a platform for sensory integration); however, I do not feel that it was a distraction. My decision to include this visualisation was not solely based on aesthetics; I also felt that, on a more practical level, it provided an interesting point of focus for the audience who were not able to experience the system directly.

Fig. 47 Aesthetic decisions towards the FOVear installation were subject to constraints due to colour tracking elements of the system, Kyoto City University of Arts, 2014

Fig. 48 Graphically rendered eyeball visualisations, Kyoto City University of Arts, 2014

I found, through this series of exhibitions, that the role of aesthetic decisions when exhibiting artwork that intersects both scientific and artistic disciplines is a complex task. In one respect the visual elements of the work must be exciting enough to interest the kind of audiences that frequent art gallery spaces, and who may have little interest in findings in perceptual science. At the same time, by making the installations too visually active there is a risk that it will distract from the experiential purpose of the research itself. Ultimately, I decided that aesthetic decisions must be made by conscientiously deliberating on the true purpose of the work. If the exhibition is designed to produce empirical evidence for ongoing scientific research, then visual elements must surely be kept under control as to not disturb the objectivity of the research. However, my work does not fall into this category, and I felt that the defining purpose of the installations was to produce a heightened emotional response. While the artwork may be based upon academic scientific evidence, it does not mean that the work itself is scientific. In this respect, I feel that a great deal of subjectivity is not only welcome in my future exhibitions, it is also something that is necessary to their success.

Chapter 7 – Conclusion

This thesis aimed to detail ways in which multimedia art systems can be used as a platform to deliberate on the nature of our sensory experience. It did this by investigating three connected perceptual phenomena (perceptual ambiguity, perceptual integration, and interoceptive awareness) and by describing my own bodies of artwork developed as a result of this research (*Diplopiascope, FOVear, Heartvise*). The connecting theme throughout all of these artworks was to shine light on what is known as the transparency of experience, the way by which we find it difficult to consciously and accurately consider our own perceptual experience. The thesis began by introducing clear examples from modern perceptual science and philosophy that illustrate how unaware of the true nature of our sensory lives we really are; using the recent grand illusion theory of perception to expand and clarify these ideas. The notion of the changing dynamic in the observer-object-image relationship became central to the thesis. This was first outlined with reference to the Wheatstone stereoscope and other *philosophical toys* of the 19th century and was extended into all three of the bodies of artwork. This connection was made explicit in the *Diplopiascope* installation series that described the ubiquitous internal synthesising that occurs as we interpret visual information into a rich three-dimensional perceptual experience. By allowing participant to experiment with the parameters of this mechanism, testing the limits of our brain's ability to integrate disparate images, a new mode of perceptual exploration was successfully created. These themes of disparity and integration, rivalry and synthesis, were pursued further in the following chapter, Perceptual Integration. It was at this stage that the scope of the thesis expanded to incorporate not only visual perception but also hearing; introducing precedents in perceptual adaptation and sensory substitution research before detailing my own *FOVear* project that enabled participants to experience a heightened sense of sensory integration. My hope, through this work, was to allow for a greater appreciation of the prevalence of sensory integration in our normal perceptual experience. By providing a multimedia device that was able to heighten this phenomenal merging of the senses, I believe that viewers could better understand a more true nature of their experience. I pursued this notion of an integrated and combined perceptual system in the final of the three central chapters to the thesis, Interoceptive Awareness. Incorporating both recent scientific findings in interoceptive awareness, as well as ideas outside of western medicine in the practices of Anapanasati meditation, I explored how interactive art can be used to explore this idea as the body as a substrate for emotion. This is a concept that I feel has huge potential for exploration and is the direction in which my work is going to follow in the future.

Through these three main areas of research, this thesis introduced solutions to the idea of transparency of experience through multimedia interactive systems.

7.1 Discoveries

Some important discoveries that I made throughout the research and production of the bodies of work can be identified as follows:

1. Primarily, I discovered that this kind of research, intersecting both artistic and scientific fields, holds huge potential as a mode of inquiry. The work was largely informed by recent discoveries and empirical evidence at the forefront of perceptual science. Through the dissemination of academic papers and information, it is now possible for those at the periphery of these disciplines to incorporate such concepts into their own research. At the same time, artists are not limited by the same constraints that exist in the scientific fields such as objectivity of practice.

2. Aesthetic decisions, while problematic, are essential to the success of the artwork. In the early stages of developing the projects, I often found that I struggled to resolve the level of subjective visuality that should be included in the artworks. Being based in scientific research, I sometimes felt a need to maintain a sense of aesthetic impartiality that would not distract from the theory behind the artwork. However, throughout the course of developing the three systems and exhibiting on a number of occasions, I became more comfortable with including elements that were either visually pleasing or amusing. The realisation that this did not distract from the principles behind the work, and in fact added to their success as exhibitions, came from audience feedback.

3. The nature of the exhibition and venue for showing the work were also of great importance to how the work was evaluated. The work has, until this point, only been exhibited in art galleries, although I have introduced the work in presentations at scientific institutions. It became apparent through these exhibitions that the prior knowledge of the target audience was vital to how the work was interpreted and is a factor that must be considered when showing the artwork. In a gallery setting, when the audience is generally unaware of the more complicated perceptual concepts that the work deals with, it is very important not to exclude the visitors through the inclusion of weighty scientific information. The work should remain primarily visual and accessible in order to maintain the interest of such audiences.

7.2 Future Research

I feel that there is great potential for developing these interactive multimedia systems further. I am interested in incorporating more advanced virtual reality hardware into the *Diplopiascope* work as a way of creating a more convincing experience for the user. Although this work has, until now, been designed to expose the mechanisms behind our visual perception, and in this way the open design of the system was a success, I feel that it is now ready to develop as a more refined experience. The *FOVear* work has several possibilities for further investigation. I hope to adapt the system so that it can be used in the dark, creating an environment in which the user can work out spatial relationships by looking around and hopefully developing a new mode of seeing akin to echolocation. I aim to do this by using infrared beacons instead of colour tracking. My intention for the *Heartvise* project is to further develop a more refined wearable system and subject it to rigorous testing in the field. One line of inquiry that I am particularly keen to pursue is the possible effect of prolonged use of the system and the implications of this, both from an artistic standpoint, and in terms of its use in the treatment of various bodily disorders.

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Appendix

The following Interviews were conducted via Email between May and October 2014

Non-bold text: interviewer (William Hall, PhD candidate, Media Art Department, Kyoto City University of Japan)
Bold text: interviewees

Email Interview with Dr. Shinsuke Shimojo, Shimojo Psychophysics Laboratory, California Institute of Technology, USA, May 2014

In relation to the audio-visual project:
The first project (project title: FOVear) uses an eye tracker to work out where the user is looking in a scene. This is combined with object tracking software so that sound files can be triggered when the user looks at certain objects. In the case of my recent exhibition, it was set up like a concert so that when the user looked at the object representing the guitarist they would hear the guitar, if they looked at the vocalist then they would hear singing, and when they looked at the keyboard player they would hear the keyboard section. In this way, the user is able to experience a much more selective and active hearing modality, in the same way that is already enjoyed with vision.

OK, I think I do understand what you are doing, but what is the calibration accuracy of the eye tracker, realistically? And what is the temporal delay of gaze shift to the sound onset? Also, are those delays fixed, or varying? Anyways, I do like the basic principle here (though in the technical side) - it's straightforward, and making sense.

Please refer to the files attached below “FOVear description.pdf” and “FOVear diagram.pdf” for more detailed descriptions. The 2 videos found by clicking here show the system in use in a recent exhibition:

My questions related to this work are as follows:

1. My initial interest was in relation to sensory substitution. However, in this project, seeing is still done with the eyes, and hearing with the ears. Do you think that there is, in fact, any actual sensory substitution occurring here at all?

Not in the strict sense (where it means for instance "to give blind users visual experience via a device and training"), but either "synesthesia-like" experiences, or "crossmodal correspondence." (Charles Spence' terminology - he has books & multiple papers.) As for side notes, 1) True synesthesia(perceptual) and synesthesia-like experience(imagery) are different though overlapping, 2) crossmodal correspondence means intrinsic (nearly innate) mapping, whereas your case, the associations (V-A) are mostly experiences with the musical instruments in the past.

2. To what degree do you think the idea of "transferring the sensory qualities of vision to hearing" is successfully achieved in this work?

Probably not, but again, it is continuous. If one over-experience your system repeatedly, then there might some "merging" experience occurring, due to "prediction" "expectation" and "imagery."

3. The next stage of this project is to configure the system to be used in the dark by using an infrared beacon system for object recognition. The viewer would not be able to see anything in the dark but would hear sounds originating from objects as they look at them and thus they would built up a mental representation of the room. Several beacons would be placed around an area to identify basic spatial features and alert the viewer of walls and objects.

This is a good way of eliminating the knowledge-based expectation that I mentioned above. What will be left are: associations from the experiences on site, and more intrinsic correspondence.

a. Do you think that through this "visual" exploration of a black space they will be able to begin to "see"?

No in the strict sense, because memory association is different from real perceptual experience. However, if you expect is just quick visual imagery triggered by repeated gaze-sound experiences, then may be yes (the visual cortex is known to be activated by visual imagery of a natural scene triggered by natural sounds, for instance).

b. My idea was to try to bypass completely the visual stimulus involved in seeing. Do you think this is a realistic possibility by using this method?

Only in the late blind patients, or in the sighted case, you would need enormous experiences with some twists, I would imagine.

c. Assuming that V1 receives no stimulus, where might this "seeing" occur?

As I wrote above, V1 may be activated by vivid visual imagery. Otherwise, higher level visual cortices, MT if movement is involved, STS and surrounding parietal areas, etc.

- Interview End -

Email Interview with Dr. Jane Aspell, Senior Lecturer in Psychology, Anglia Ruskin University, UK, June 2014

1. How important do you think it is for the delay between heart beat and feedback to be negligible to the user? I imagine in EEG biofeedback it might be important to have a very low latency (<100ms). But seeing as the heart beat feedback is a regular rhythm, is it so important?

Well it depends - important for what? In my Psychological Science paper… participants couldn't tell the difference between the synchronous and asynchronous conditions. Here there was a delay between the R-wave and flash in the synch condition of about 100ms. The asynch condition was created by displaying either a faster or slower flash rate than the P's HR. Our interest was obviously in altering bodily self-consciousness but yours may be different. Even though Ps seem to not be consciously aware of the difference between my flash conditions, it's possible they could still discriminate between the two at a non-conscious level (if you forced them to guess many times and computed if they are better than chance level). Ps who do interoceptive sensitivity tasks - e.g. silently count heartbeats can perform above chance while having little confidence that they are correct in their responses.

2. Does the kind of feedback (visual, tactile, other modalities) have a great effect on the kind of emotional response in the participant? Ultimately I hope to make a multimodal feedback device but would like to hear your comments on the types of feedback and the varying emotional responses they might produce.

I have never measured emotional responses to own heartbeat sounds and don't know of any studies but there probably are some (perhaps outside of neuroscience). I would

imagine that hearing your own heartbeat might evoke a greater emotional response. There is a paper by Lenggenhager et al.(2013 or 2014) in Experimental Brain research where i think they presented heartbeat sounds while Ps played some kind of risk taking game i think.

3. Which disorders do you think interoceptive awareness training has the greatest potential for treating? Dissociative disorders of the body such as anorexia are often mentioned, how about in substance addiction treatment or disorders connected with impulse, control, or attention?

Yes, eating disorders. A new paper from Pollatos group just came out which showed reduced interoceptive sensitivity in obese individuals. It's possible that substance abuse patients may also benefit - any disorder i suppose in which the relationship with the body is somehow sub-optimal.

4. To what extent do think that a heightened sense of interoceptive awareness is something that is inherent in an individual? How much does this vary from person to person? I read that a lot of young athletes are constantly aware of their pulse. In this respect, how much depends on physical things like BMI and how much on brain structure?

It seems to be quite a robust trait - which is a bit of a pain re. training as there is not much evidence that training makes a difference - at least not mindfulness type approaches. It varies quite a lot but most people are below- chance level at detecting their hearbeat. About 30% are 'good perceivers'. People with slower heartbeats are better as are slimer people. A classic paper by Hugo Critchley (nature neuroscience, 2004) showed that increased interoceptive sensitivity is related to the activation and size of part of the brain called the insula. Of course all we've discussed is regarding the heart but we also have interoception for other processes e.g. gut movements. The assumption is that greater heartbeat sensitivity is associated with better interoceptive sensitivity in general but this has not been comprehensively tested.

- Interview End -

Email Interview with Vipassana Meditation expert James H. Emery, International Mediation Centre, September 2014

1. What are the key techniques of Anapana meditation that you teach to students?

To observe the touch of the breath wherever it touches somewhere below the nose or on the upper lip as and when one breathes in and as when one breathes out.

2. If possible, could you describe the mental or physical changes that may occur when successfully meditating using this technique?

The mind will become calm and tranquil and concentration and focus can become enhanced. Eventually if the breath becomes soft and more subtle the body may then become more relaxed. When Anapana is practiced and cultivated on a regular basis it can create a cumulative effect of calm and the desire to become calm and to maintain calmness in daily life.

3. What do you think is the overall goal of Anapana meditation?

The Buddha taught it to achieve tranquility and one pointedness of mind and as a prerequisite for Vipassana meditation which otherwise cannot be properly practiced or understood on an experiential level.

4. Do you see Anapana mediation as something inseparable from the greater sphere of Buddhism?

Yes, in the sense that it is a vital component to understanding the teachings of the Buddha on an experiential level.

5. Do you agree with it being taught as a method of 'mindfulness training' in western programs?

The concept of mindfulness of breathing is not unique or limited to Buddhism. Anapana (ana means inhalation and apana means exhalation) as taught by the Buddha is for the purpose as stated above. There may be many types of "mindfulness" training and many different reasons for developing mindfulness. It would be difficult to find someone who didn't agree that mindfulness and more specifically, a truly calm mind was beneficial to all. However it is important to understand that the objective and achievement of the correctly calm and one-pointed mind of a Buddhist meditator differs from that of say, a tiger ready to pounce on a prey or that of a sniper.

6. What do you think about the use of Anapana mediation as a possible treatment for disorders (such as anorexia or addiction)?

Such kinds of disorders and problems have very often been overcome by people practicing Buddhist meditation both through anapana and vipassana. I have seen so many cases of

gradual or radical changes for the better or complete recoveries in meditators and have directly heard about numerous more. However, these cases I know were more or less by-products of following strictly and diligently the practice of the Buddha's teachings and meditation under the guidance of a trained teacher. I can well imagine there are various different trainings giving attention to the mind that produce positive results both for mind and body. But I am not experienced or qualified to seriously comment on them or to compare them. I do believe from my own experience though that something that is pure and tried and tested needn't be confused or easily mixed together with anything else. There may be a useful time and use for each individual treatment and the proper confidence in the doctor or specialist administering it. But careful consideration is always necessary for all.

7. The research i mentioned above is mainly about heartbeat visualisation techniques: a heartbeat sensor would send a signal to a computer which might project a red circle that pumps in time with your heart. What do you think about this in terms of the connection with your own practice?

It would be distractive and counter productive. Anapana meditation is always useful in bringing about a calm and more focused mind both when formally practicing in a relaxed position with the eyes closed and when the practice is cultivated on a regular basis it can create a cumulative effect of calm and the desire to become calm.

- Interview End -