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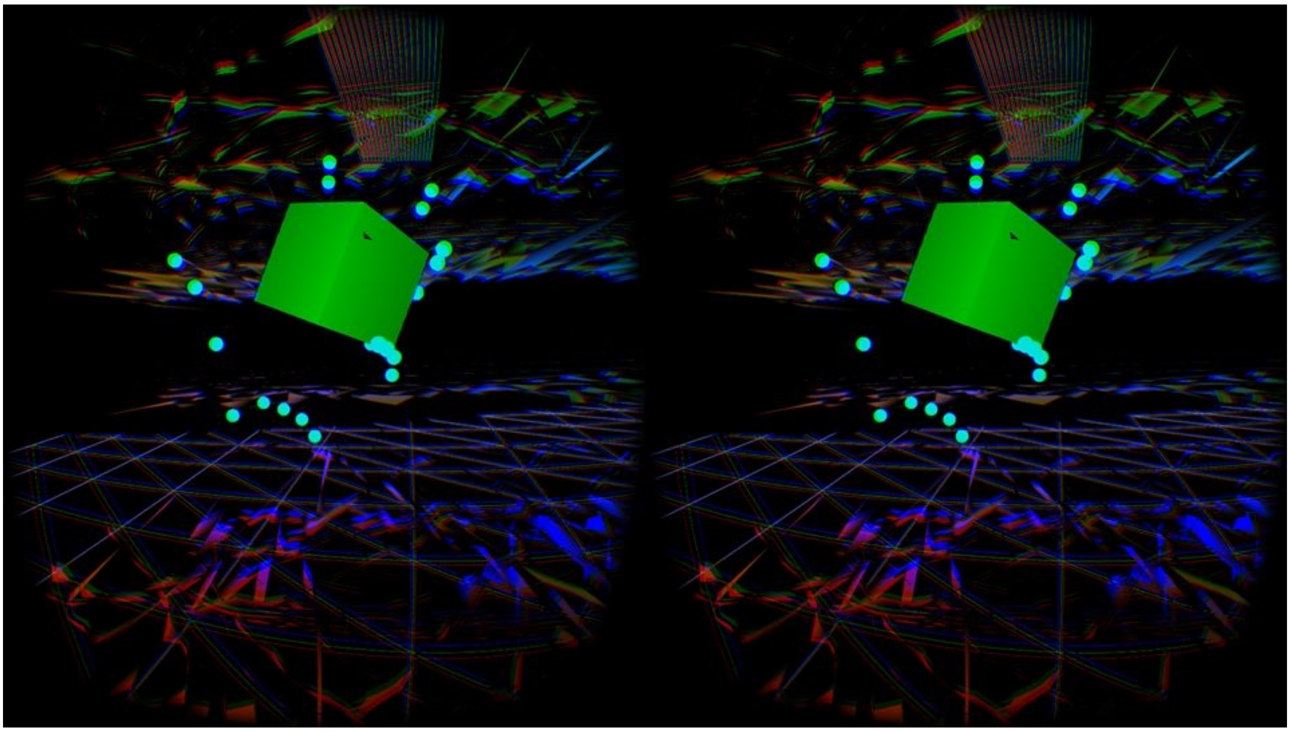
Facilitating user interaction in an immersive environment:
How do we relate to the gestural control of sound objects in an immersive 3D environment?



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Abstract

This paper aims to gather both theoretical and practical knowledge of the aspects involved in the development of VR audio-visual experiences. By developing a prototype in which user's can be immersed in a 3D-computer generated, interactive environment, it aims to investigate how we relate to the gestural control of sound objects in immersive 3D environments, and provide a primary source of research to understand the technology, its limitations, and how it might be used within different fields of the audio industry. At the same time, by observing user's behaviour during a practical test, the research aims to establish how a multidisciplinary approach –with the consideration of computer science, art, audio and design– can optimise the development and implementation of VR experiences.

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1. Introduction

This reacher paper aims to shed new light on how people relate to the gestural control of sound objects when immersed in a computer generated, Virtual Reality environment. It further aims to find out if the implementation of 3D audio in computer generated environments could provide a multi-sensory experience that feels real and heightens users' sense of immersion.

In the past five years Virtual Reality (VR) technology has attracted the attention of numerous investors, who strongly believe that this platform will transform entertainment media-content with new forms of interactive, immersive, multi-sensory experiences (Zuckerberg in Vanity Fair, 2015). In regards to music and the audio industry, VR has been quoted to have the potential to change the way music is created and experienced, presenting a 360-degree blank canvas in which spatial audio techniques and cutting edge visual art could transform the way audiences connect with their favourite artists (Wilson, 2015). To address how we relate to the gestural control of sound objects in such virtual 3D environments, this paper will begin by offering analytical research of the historical, cultural and technical aspects surrounding VR technology. Having contextualised VR technology and its significance, the paper will explore the role of sound and music in VR, human-computer interaction and the more recent developments in VR experiences. Alongside this descriptive and analytical investigation the results of a question-based survey presented to thirty-three audio production students and a practical observation will serve as primary references to evaluate the audio industry's current awareness and interest in the technology.

In order to facilitate the latter, a Virtual Reality experience prototype has been created to support this paper's research. The prototype uses an Oculus Rift head-mounted-display, Leap Motion and Max/MSP/Jitter, and is explained more fully in chapter four. By conducting a user test of the prototype, qualitative and quantitative data will be collected and used as a primary source of reference to answer the research question. By observing user's behaviour during the test, key aspects of the prototype such as technological limitations, system usability, state of immersion and ultimately, how people relate to the gestural control of sound objects when immersed in a VR environment, will be identified and used as a valuable source of reference to help further developments of VR audio-visual experiences.

2. Introduction to a virtual world

2.1 The human definition of reality

The concept of perceived reality can be traced back to ancient Greek philosophical theories and allegories (Sonoma, 1997). Plato's *Allegory of the Cave* (380 BC) describes a group of prisoners confined to a cave from birth, chained to a wall and unable to move or turn their heads. The prisoners were constantly exposed to shadows cast on a wall, produced by a fire and the passing by of people along the cave's roadway. The projection of such images created an illusion of reality for the prisoners who, unable to move or turn their heads, remained ignorant of the natural causes of the shadows. The prisoners would mistake appearances (shadows) for reality. This belief remained unchanged until one of the prisoners was set free and witnessed the *real*[*] causes of the projections (Plato and Bloom, 1991, p. 195). Plato used this analogy to explain the importance of questioning the nature. He explains how education, and the pursuit of knowledge, helps to develop human intellect, and plays a vital role in understanding the difference between appearance and reality.

What humans consider to be real has continued to be questioned since Plato's *Cave*. In *Meditations on First Philosophy,* first published in 1641, philosopher Rene Descartes resolves to doubt anything he previously believed to be true, rejecting all knowledge acquired from human senses.

> *' Whatever I have accepted until now as most true has come to me through my senses. But occasionally I have found that they have deceived me, and it is unwise to trust completely those who have deceived us even once'.*
>
> (Descartes, 2010, p. 2)

Descartes dedicated his life to question what mankind considered to be real, a topic that puzzled many philosophers in the seventeenth century. In his *Meditations* he doubts and contemplates every material thing, including himself, and the existence of a God or higher creator. Significantly, Descartes concludes that his ability to think, his intellect, stands as the essential proof of his being, and the one thing he could be certain to be real

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[*] 'Real': *Actually existing as a thing or occurring in fact; not imagined or supposed*, Oxford English Dictionary, 2015

(Descartes, 2010, p. 14). Plato and Descartes' theories have evolved over the centuries as the definition of reality has remained a focus for many philosophers, sociologists and artists. The expansion of education and rapid technological changes from 1870 further enabled humans to develop new ways to challenge and expand their understanding of the world (Rodrigues and Garratt, 2010). The advancements of electricity, aeroplanes, radio and cinema transformed common notions of time and space (Kern, 2003, pp.1-9).

Reflecting on changing perceptions of reality in *Simulacra and Simulation* (1981), Jean Baudrillard, argues that such developments created nothing but confusion:

> *'… the era of simulacra and of simulation, in which there is no longer a God to recognize his own, no longer a Last Judgment to separate the false from the true, the real from its artificial resurrection, as everything is already dead and resurrected in advance.'* (Baudrillard, 1981, p. 6)

Baudrillard paints an image of a society that has lost the ability to distinguish the real from the fiction. However, it could be argued that what Baudrillard describes as a 'simulation' of the real world is actually mankind's attempt to investigate the power and potential of imagination, offering new questions and interpretations of reality.

2.2 From science fiction to virtual reality (VR) and the Oculus Rift

As previously mentioned, new social, cultural and technological developments have contributed to take the argument of the real vs. non-real much further. David Seed's *Science Fiction, A Very Short Introduction* (2011), provides an extensive catalogue of Science Fiction, which he describes as '… a genre based on an imagined alternative to the reader's environment …' (Seed, 2011, p.1). Seed charts sci-fi back to the second century AD and identifies Lucian of Samosata's tale of space travel and interplanetary war, *A True Story,* as one of the earliest examples of the genre.

Science and technology play a key role in these narratives: writers describe distant futures where humans interact with advanced technologies in quests to discover new worlds. William Gibson's novel *Neuromancer* (1984), still considered one of the most influential texts within science fiction's sub-genre Cyberpunk (Seed, 2011, p. 78), narrates the life of freelance hacker and gamer Henry Case: a 'console cowboy' (Gibson, 1984, p. 18) hired by an enigmatic benefactor to transform the future of their digital environment. As Gibson defined it,

> *' Cyberspace [is] A consensual hallucination experienced daily by billions of legitimate operators, in every nation, by children being taught mathematical concepts . . . A graphic representation of data abstracted from the banks of every computer in the human system."* (Gibson, 1984, p. 74)

Neuromancer introduced readers to virtual realities: computer generated environments, cyber culture and coding heroes like Case, who used advanced computer technologies to protect the future from a cyber collapse. Gibson's fiction also inspired director-duo, the Wachowskis' cult film*The Matrix* (1999). Addressing similar themes, in *The Matrix* a cyber hero is called on to save humanity from an artificial, computer generated environment coded by a supreme architect to deceive humanity from reality (BBC, 2003). Discussing the film's inspiration in a recent interview, Lana Wachowski explained:

> *' [before we made the movie] … we were talking about the problem with virtual reality … and books like Neuromancer … that lead us to the discussion of how you interrogate reality, and what reality is … that led us to the entire philosophical spectrum on what The Matrix ended up being …'*
> (L. Wachowski, in DePaul, 2014)

It is clear that the Wachowskis were interested in the same philosophical questions that puzzled Plato, Descartes and Baudrillard: the human definition of reality. *The Matrix* combines a diverse range of topics such as science, politics, computer technology, art and fiction to create their own representation of reality (L. Wachowski, in DePaul, 2014).

The connection between science fiction and the realization of virtual realities has been highlighted by several scientific and computer researchers. In the mid-1960s computer scientist and virtual reality pioneer Ivan Sutherland initiated several research projects exploring the creative potential of computer graphics. 'The Ultimate Display' project (1965) emphasized the importance of our sensorimotor skills in our perception and interpretation of the world around us, and produced an innovative prototype to study the effect of immersion in virtual reality. Similarly his experimental 'Sketchpad' (1963) prototype proved that '…in order for a computer generated environment to be effective, it needs to engage as many senses as possible, rather than concentrating only on sight' (Sutherland in Chan, 2014, p. 14). These early experiments in computer graphics inspired further academic research, with institutions such as Harvard and Berkley exploring alternative realities through creative forms, hallucinogenic plants and music rituals that involved dance and performance.

Infamously, the American psychologist and former Harvard professor Timothy Leary, researched the consumption of LSD as mean to access alternative realities, and became a major supporter of virtual reality (Robertson, 2014). Melanie Chan's *Virtual Reality: Representations in Contemporary Media* (2014) quotes Leary highlighting the connections between the introduction of Apple computers, early video games and human interaction with '…moving flashy electronics [and] digital information around the screen…' and the San Francisco area, where many of those technologies' manufacturers lived and tended to use psychedelic drugs (Leary in Chan, 2014, p.16). Consequently Chan has emphasised how the 1980s and 1990s became vital years for media representation of virtual reality as '… an opportunity to transcend the limitations of physical embodiment', and a new form of escape (Chan, 2014, p.1-3).

However, observing this period of cyber culture, Baudrillard noted:

> *'…[the] enquiry into the virtual is made even more delicate and complex today by the extraordinary hype surrounding it. The excess of information, the massive advertising effort, the technological pressure, the media, the infatuation or panic — everything is contributing to a kind of collective hallucination of the virtual and its effect …'*
>
> (Baudrillard and Turner, 2013, p.111)

Baudrillard's words reflect the view of many who lived and experienced this period of experimental research and fictional narrative, which not always delivered what the advertisement campaigns promised. An example of this statement is Nintendo's 'Virtual Boy' (1994): a stereoscopic, 3D gaming platform, consisting of a head mounted display (HMD) and computer generated environments. Presented as a gaming platform capable of delivering virtual reality to the masses, it failed to achieve its goal due to an uninterested public, rushed marketing and general misunderstanding of the product (Kohler, 2010).

Despite this, it could be argued that even though the 'Virtual Boy' did not reach every home as Nintendo had intended, it did encourage further research and development in fields such as computer graphic technology, virtual reality and user experience (Boyer, 2009, pp. 23–33). Founded in 1991, Nintendo's 'Virtual Boy' and it's wider R&D1 research department was backed by years' of academic and scientific research in computer graphic technologies, and contributed to its future advances. Examples include Sutherland's 'The Ultimate Display' (1965), NASA Ames's virtual reality research VIEWlab (1989), the invention of the Internet (1960): a global network that linked multiple computers, and Tim Berners-Lee's invention of the World Wide Web (1989): a system that facilitated the sharing of documents via the internet (Abbate, 2000). These inventions were the result of years of experimental research that inspired a vast range of content creation, such as Atari's arcade game Pong (1977), AOL instant messenger (1990), the first Web Cam prototype (1991) and Google's search engine (1996). Such developments helped us understand the possibilities and limitations of computer technologies, and raised more questions about the role of technology in people's lives, helping to shape our present reality (Penn, 2014).

If Descartes concluded that his ability to think was the primary proof of his being (Descartes, 2010, p. 14), the constant questioning of reality throughout human history can be considered as the tangible proof of the human's intellect potential. Technology is a creation of mankind's intellect, used to expand the argument of reality versus the virtual. Baudrillard may argue that technology, virtual worlds and digital art can only produce 'useless perfection' (Baudrillard in Zurbrugg, 1998), and only create a culture of confusion. Yet projects like Palmer Luckey's 'Oculus Rift' (2012): a virtual reality (VR) head-mounted display (HMD), funded by 2.5 million dollars of public donations via a KickStarter campaign, have arguably shown to unite a significant part of modern society rather then confuse them. Consisting of two 1080x1200 HD (high definition quality) displays, the Oculus Rift has a 90 Hz refresh rate (1/second, 90Hz meaning it can draw 90 images per second), producing a fast, smooth rendering of computer generated images and real time head tracking (rotation and position). Michael Abrash, Chief scientist at Oculus, summaries VR potential:

> *'…VR can drive the human perceptual system in the way its built to be driven, as a result VR can producer experiences that feel deeply real and that will result in fundamental changes in the way we interact with technology… '*
>
> (Abrash in Oculus, 2015).

The Oculus Rift is tangible proof that years of research into computer technologies, such as Sutherland's 'Ultimate Display', NASA and Nintendo's 'Virtual Boy', contributed to scientific, cultural and social developments that shaped the state of modern society. Moreover, VR is not only beneficial for the computer game and film industries, as it can also help to raise humanitarian issues around the world. *Clouds Over Sidra* (2015) an interactive VR film designed to support the United Nation's campaign to highlight the reality of the Za'Atari refugee camp in Jordan, won the interactive prize at Sheffield Doc/Fest 2015 (Feltham, 2015). Created by United Nation adviser Gabo Arora, filmmaker Chris Milk and producer Socrates Kakoulides, the film is a virtual representation of the reality through the eyes of Sidra, a twelve-year-old refugee girl living in Za'Atari (Feltham, 2015). As Catherine Allen, one of the judges who awarded the prize to the VR film explained:

> *'Its creators delivered a compelling, informative and emotional experience, bursting with potential for real world change. It [is] advanced the medium, offering storytelling language to this emerging space… Clouds Over Sidra took us into the Za'Atari refugee camp and achieved a level of empathy that went beyond what [is] possible in traditional film. It managed to make the technology disappear from view, and instead guided by powerful voice…'*
>
> (Allen in Feltham, 2015).

Oculus Rift is leading the VR industry, and their aim is to make VR the future of immersive, interactive entertainment. Mark Zuckerberg, founder of Facebook, shares Oculus' vision:

> *'…there is always a more immersive and richer way that you want to experience things… every 10 or 15 years there is a major platform that comes along I do think that virtual reality is going to be that [platform]…'*
>
> (Zuckerberg in Vanity Fair, 2015).

As an internet entrepreneur, Zuckerberg's 2 billion dollar acquisition of Oculus VR in 2015 is testament to the belief that Oculus and VR are the platforms that will open the gate to the content creation of the future. Whilst sci-fi narratives fantasize about the unknown, contemporary experimental research is seeking to realize it. These forms of self-embodiment and alternative realities use narrative and technologies to push the boundaries of human's definition of real. In light of this and Sutherland's research, the question that guides this research further is: what role will audio and user interaction play in making virtual reality experiences more credible, therefore real?

2.3 A brief history of immersive audio

From Descartes' first contemplation of reality to the realization of computer generated worlds, humans have been searching for new forms of self immersion, capable of providing a heightened sense of presence, of being in a moment. As this paper has already highlighted, research in the field of science and technology: questioning how humans perceive the surrounding world via the brain's sensory systems such as touch, taste, smell, sight, and sound, have proven vital to achieve this immersive goal (Abrash in Oculus, 2015). Hearing, like sight, has been a predominant aspect that has challenged writers, inventors and music composers to experiment in their working methods. With Alexander G. Bell's patent of the telephone in 1876 and Siemens' patent of the first loudspeaker in 1877 (AES, 2015), the late nineteenth century was a crucial period for music and audio development, and created a shift in music composition and listening methods (Cox and Warner, 2004, p.5). Many composers of this period relied upon classical instruments such as the piano and wood instruments to create elaborate compositions. Yet reflecting on the rapid pace of change in this period, some began to question the limitations and relevance of these instruments, preferring to consider the role of noise in music. Futurist composer Luigi Russolo (1885-1947), author of *The Art Of Noise: Futurist Manifesto* (1913) explained:

> *'… Ancient life was all silence. In the 19th Century, with the invention of machines Noise was born. Today Noise is triumphant and reigns sovereign over the sensibility of men…'* (Russolo in Cox and Warner, 2004, p.10).

Russolo's 'noise' referred to the sounds produced by mechanical and technological innovations that occurred during this period. Like many other composers and innovators who came after, he urged the need for new musical instruments and a radical change in composition.

American composer Charles Ives is another composer who shared Russolo's ambitions. His *Universal Symphony* (1911-1928), an unfinished composition written to be performed simultaneously by multiple orchestras, challenged the static form of music tempos and rhythms. Significantly, Ives' inspiration for this ambitious project came from his philosophical interest in 'Earth, evolution in nature and humanity' and the universal balance of life (Ives in Burkholder, 1996, p. 188). In a letter sent to composer Henry Cowell, Ives explains the spatial elements of the score for Universal Symphony, and how his regular holidays in the American countryside influenced his composition:

> *'In the same way that an eye views the countryside, focuses on the sky, the clouds and the distant outlines and simultaneously perceives the shape and [colour] of the objects in the foreground as well as those in the distance, the listener also has the possibility to order the rhythmical, harmonic and other components, placing them in relationship to one another in his mind. In other words, in music, the ear has the same capacity as an eye observing the countryside'* (Ives in Reinhard, 2005).

Like Russolo, Ives's innovative approach was inspired by life's surroundings. He envisioned the potential of spatiality in music and how this could create a multi-sensory experience for the audience. In his letter to Cowell, Ives invites future generations of musicians to further develop his concept: '…somebody might try to work out the idea…' (Hall and Sallis, 2012, p. 212), acknowledging that he may not be able accomplish such challenging project. As loudspeakers developed with advances such as Bell Labs two-way loudspeaker (1931) and Blumlein's patent of stereo binaural sound (1931), spatiality and the mode of listening to music became aspects that sparked the interest of composers, academics, audiences and record labels.

In the late 1940s the *Musique Concrète* movement founded by experimental composers Pierre Schaeffer and Pierre Henry challenged the state of recording technologies and listening methods. As Schaeffer explained:

> '*…We are not trying to restore preexisting depth, as in ordinary stereoscopic, but to provide the sound objects of concrete music with a spatial development in keeping with their forms'* (Schaeffer, 2013).

Using magnetic tape recorders, record players and early electrical instruments such as synthesizers, Schaeffer became fascinated by the results of his research into sound manipulation and listening modes. The concept of *Musique Concrète* attracted other composers who were interested in electronic compositions and sound manipulation. In 1957-58 Edgar Varèse created *Poemè Electronic*, an eight-minute electronic composition written in Schaeffer's studio for the Philips Pavilion at the 1958 Brussels World's Fair. The *Poemè Electronic* installation consisted of 350 loudspeakers and visual projections spread across the structure of the Pavilion to create an immersive audio-visual experience for the audience. In a series of essays and lectures from 1936 to 1962 Varèse observed:

> *‘We have actually three dimensions in music: horizontal, vertical and dynamic swelling or decreasing. I shall add a fourth, sound projection—that feeling that sounds is leaving us…for the ear as for the eye…a journey into space.’*
> (Varèse in Cox and Warner, 2004, p.18)

Varèse’s *Poemè Electronic* installation became a reference for later works such as Karlheinz Stockhausen’s design of the Spherical Concert Hall, build for the 1970 World Expo in Osaka. This featured groups of fifty loudspeakers spread along its structure to reproduce three-dimensional music experiences, ranging from pre-commissioned compositions to live concerts of Stockhausen’s nineteen-musician ensemble (Net, 2015). In 1976 François Bayleme utilized a similar method called ‘Acousmonium’: an orchestra of loudspeakers led by a conductor who played a sound or musical piece using a mixing console.

Bayleme presented his work as a sound utopia (Bayle, 1996), but such experimental approaches remained unpopular for the mainstream consumer market. The high costs involved in multi-speaker projects made the idea of domestic spatial audio reproduction unpopular, leaving the consumer’s market to rely mainly on two-channel audio feeding two loudspeakers (Rumsey, 2001, p.3). However, further developments in computer technology helped academic research in spatial audio and cinema sound to evolve in both professional, commercial and increasingly consumer markets. Today, multi-channel and object-based formats such as Ambisonics, Dolby Atmos and Binaural technologies are being used frequently, all aiming to create the illusion of sound sources located in the surrounding space (Rozenn, 2010, p.10).

Binaural audio technology has come a long way since the developments of the late nineteenth and twentieth centuries such as Clement Ader’s Theatrophone (1881), Oscar: the first dummy head by the AT&T Bell Laboratories (1933) and Neumann KU-80 (1973). Struggling to appeal to an uninterested consumer market, for many years it remained a field for academic research, but the increasing affordability and accuracy in recreating a real sense of 3D sound immersion, have revived interest in the past ten years (Rumsey, 2001, p.14). Professional and consumer products for gaming and virtual reality experiences have widely embraced Binaural Audio, resulting in an inspiring new wave of researcher focused to develop and optimise both recording and reproduction aspects of Binaural technology (Abrash in Oculus, 2015).

This chapter has highlighted the significance of experimental research in fields such as computer graphics, virtual reality, music, audio and art, all of which have contributed massively to the development of humans' intellect within modern society. At the same time those arguments have raised more questions in terms of how people adapt to such developments, and how new musical instruments, audio reproduction mediums and computer technology can benefit people creative spark, rather then suppress it.

3. Music computing and human interaction

3.1 The development of gesture in musical composition

Human intellect expands through life experiences, including their perceived observations of the surrounding environment. Human perceptual and motor systems are self-learning mechanisms that begin to develop during the early stages of infant life, with attempts to interact and communicate with a care taker (Hatten in Gritten and King, 2006, p.3). The same natural observations apply to music, which relies on a deep understanding of meaningful body motions. At the Sixth International Congress of the International Association for Semiotic Studies, researcher Fernando Iazzetta presented an insightful paper on the meaning of musical gesture:

> *'Music gesture is not only movement, but a movement which is able to mean something, a movement which carries a special signification. It is more than a spatial change, or a body action, or a mechanic alteration: music gesture is a sign that becomes actual through movements'* (Ianzetta, 1997)

Musical gesture may be described as practical and theoretical musical concepts learned through active demonstration, and many factors have contributed to the development of expressive musical gesture. A prime example are the gestures used by the maestro, classical music conductor, to guide the orchestra throughout the execution of a written musical piece. The maestro '…makes music's meaning clear through body motion…' (Wakin, 2014) while the musicians respond to the observed gestures, engaging in an interactive and expressive communication. Professional musicians undertake years of disciplined study to read and write music as well as practical exercises in physical gesture (time) and force (dynamic), to play instruments such as the piano, violin or drums. While these mechanical instruments share the same principle of sound production: 'the mechanic vibration of an elastic body' (Iazzetta, 1997), gestural practice allows musicians to develop a personal performing style essential to translate human feelings into characteristic sounds.

The twentieth century saw the advent of The Theramin (1912), the first electronic instrument played by the movement of a performer's hands, and the public release of other electronic based instruments such as tape recorders (1940s) and synthesizers (1956), which all generated sounds via electronic and mathematical means that were beyond human perception. This led composers to a period of experimental music made of new sounds and timbres, where performance, composition and mode of listening became the subjects of much discussion. Composer and musicologist Marc Battier reflects:

> *'Traditionally, to attend a music performance is to apprehend through the sight the intention which is loaded in the instrumentalist's gesture. In the mediation of the technological work, this prediction does not work all the time.'*
>
> (Battier in Iazzetta, 2000, p.263)

Live performance was replaced by a new listening experience of recorded music, computer technologies and play back devices like record players, tape recorders and mobile devices such as the Sony 'Walkman'. Composers such as Battier were very critical of this perceiving it as a limitation to self-expression. However, a large number of classical musicians shared the view of many electrical engineers, researchers and software developers who considered the invention of electronic instruments to be a valuable contribution to composition and live performance (Subotnick in Clarity Films, 2014). Computer science and technological development not only intended to expand the range of musical gesture, but further question how to make new musical instruments to facilitate human interaction. In the 1970s, musician and five-time Grammy nominee Suzanne Ciani devoted her classical background to experimental electronic music using the Buchla: the first modular synthesizer. In a recent interview she stated some of the reasons for her decision:

> ‘…*people would ask me what it was, and nobody understood it. So I wanted to develop a technique for it the same way people have a technique for playing the violin. You know, Don Buchla viewed it as a performance instrument, and I believed him…’* (Ciani in Self-Titled, 2014)

Many shared Ciani’s philosophy and these ideas allowed new methods and philosophies to become a relevant cultural movement in music composition. This encouraged the evaluation of the limited range of musical gestures available through instruments like the violin or the piano, and further became an opportunity to explore new concepts for musical instruments. One such example is the first keyboard-based synthesizer, the Mini Moog, invented by Robert Moog and released in 1967. The Theramin remains an important reference for other research projects that aimed to translate human movement into expressive musical gesture (Smirnov, no date). Modern computer technologies facilitate the development of new instruments, maximizing human interaction to create new sounds and timbres via expressive gestures. Roli’s ‘Seaboard’ is a very recent example as a silicon keyboard that has a heightened response to human touch. Former Seaboard engineer Jack Armitage explains:

> *‘The Seaboard GRAND exhibits an emphasis on maximizing creative control during performance, which I think is extremely important for a musical instrument. It concentrates your attention towards the richness of human touch, and in doing so empowers players to explore complex sounds in an immediate and intuitive way.’* (Armitage, 2014)

It is clear that the past visions and beliefs of engineers, musicians and philosophers like Leon Theramin, Robert Moog and Pierre Schaeffer has influenced the state of modern music. Yet while music and audio technology has found acceptance within modern society, research and engagement with human-computer interaction (HCI) remains a fairly new and uncharted topic amongst the wider public. In order to facilitate interaction with new technologies a deeper understanding of how to engage with them is required. This will help instruments’ manufacturers, artists and society to develop new, meaningful forms of expressive interaction, to bridge the gap between human and machines.

> *‘We envision a world where technology feels like a natural and intuitive extension of the body’* (Roli, 2015).

3.2 Human-Computer Interaction (HCI)

Studies on the interaction between humans and machines can be traced to the beginning of the last century when factory owners began to study effective human performance to optimize production (Beale et al., 2003, p. 2). The Second World War further advanced such research in light of the need to develop and build more efficient weapons. Inspired by such research, in 1949 a new generation of academics and researches founded the Ergonomics Research Society a professional circle of researchers dedicated to studying the physical properties of machines, systems and user performance (Factors and Society, 2004). With the advent of new computer technology in the 1980s and its widespread use among society, an increased number of specialized researchers investigated physical, psychological and theoretical aspects involved in the interaction between humans and computers.

Originally called ‘man-machine’ interaction, the field of research was termed Human-Computer Interaction (HCI) in the early 1980s, a period that also saw the rise of experimental research groups such as Xerox Park lead by scientist Mark Weiser (Beale et al., 2003, p. 181). In 1988 Weiser coined the term ‘ubiquitous computing’ to represent the radical new ideas on computing, design and user interaction that were emerging in the period. In 1991 he expressed in his paper, *The Computer for the 21st Century*:

> *‘The most profound technologies are those that disappear. They weave themselves into the fabric of everyday life until they are indistinguishable from it.’* (Waiser in Ubiq, 1991)

Weiser envisioned the reality of modern life. Wearable computer technologies such as Apple iWatch and the mobile app market represent some ideas stated in *The Computer for the 21st Century*. His vision of computing called for a radical rethink of philosophy, science, technology, design and interaction, fields of study that define the multi-disciplinary aspects of HCI (Beale et al., 2003, p. 4). It is important to consider all of these characteristics when designing a system or platform that requires a user (or users) to interact with any kind of computer technology. HCI is no longer a field in which only science and mathematic knowledge prevail, instead designers and engineers must combine multiple fields of knowledge in order to optimize the user experience (UX).

While HCI focuses on the process of technology creation, UX aims to research and understand the end users’ experience with the product. In this way UX is also responsible for establishing the relationship between the company and the user. Research from both fields contributes to the creation of new and useful technological products, and can reduce the risk of product failure (Sears, 2009, p.4). Accordingly, UX and HCI draw on cognitive psychology, industrial design, computer science, customer relations and marketing practices. Projects like the global crowd funding platform ‘Kickstarter’ are testaments to the success of the combination of HCI and UX. As the team behind Kickstarter described themselves:

> ‘*We [are] developers, designers, support specialists, writers, musicians, painters, poets, gamers and robot-builders — you name it. Between us, we [have] backed more than 34, 000 projects (and launched plenty of our own).’* (Kickstarter, 2015)

Kickstarter’s web-based platform is designed to enable millions of users to easily interact with a fundamentally complex computer system. This creates a chain reaction of valuable resources in terms of direct marketing, product feedback and social interest. The people, the computer and the task to be performed are the key aspects of a successful system that exhibits a high level of usability. Yet this can only be achieved by creating a comfortable, intuitive user environment. With their multi-disciplinary knowledge, the Kickstarter team has managed to create a unique system that exhibits efficient HCI, empowering users to directly finance products, inspiring them to create, and providing valuable UX feedback. More technological products should encourage dialogue between users and systems, and one would argue that HCI and UX are essential references to achieve this goal.

3.3 Expressive gesture interaction

3D interactive graphics researchers Kurtenback and Hulter identified gesture as a universal language that allows people to communicate and express their feelings (Kurtenback and Hulter in Laurel, 1990, p.310). The hand waving during the departure of a loved one at a station carries emotive meaning. Imagine a world without expressive body gestures, where you cannot wave to a loved one or simply point to indicate a direction. What comes to mind are scenarios in which self expression become intricate verbal puzzles. In some cases the scenarios reflect the experience of the majority of people who use desktop computers to send emails, browse the internet and, in the interest of this paper, compose music (Krantz, 2010, p. 146). With the advent of hard disk recording and other electronic based instruments, technology opened the door to new possibilities of sound creation. Such developments captured the attention of researchers and musicologists who questioned the role of the musician and ‘the importance of the body's presence in musical production’ (Iazzetta, 1997). Computers and Electronic instruments are not always designed to capture expressive body motions, but it is arguable that they could be designed in this way and that this could enable the creation of more expressive musical compositions, drawings and other art forms. *The Glove,* an innovative instrument created by electronic musician Imogen Heap and her team is one example of an effort to create such an instrument. She describes it as:

> *‘… a unique motion data capture system which can be used as an instrument or a controller… [it allows] artists and other users… to use their motions to guide computer-based digital creations…[it’s] like painting music rather than typing it into a spread sheet.’* (Heap, 2012)

It is clear that modern technology is allowing the implementation of expressive gesture interaction within computer systems, using sensors and other inexpensive parts that are widely available (Carmack in Oculus, 2015). However, to date Heap’s ambitious project has required a team of eight people ranging from computer programmers and designers to stylists and musicians, all of which have contribute to both HCI and UX aspects of *The Glove* (Heap, 2012). Furthermore, as Computer Music and Sound Technology researcher Joe C. Schacher explained, a unified language that would enable all computer users to accomplish multi-tasking transformations –like the hand gestures of a conductor that communicate both tempo and dynamic cues to the orchestra– is yet to be defined (Schacher, 2007). The notion that computers will replace self-expression with meaningless, algorithmic music also contribute to existing limitations. As writer William Hochberg claimed, *‘computerized composition raises questions about the nature of music, art, emotion and, well, humanity.’* (Hochberg, 2014). Yet computers require the creative wisdom of people, responsible for the ideas and concepts beyond the code. Jazz guitarist Pat Metheny provides an optimistic view in opposition to Hochberg’s argument:

> *‘I tend to think more along the lines of computer assisted [music], since whoever writes the code or whichever user sets the parameters is already going to be making many of the decisions about what the result might be like.’*
> (Metheny in Hochberg, 2014)

Accepting that technology can assist rather then replace intellect and creative spark, one can envision a world were cognitive computing (self learning computer algorithms) can be designed to work alongside humans and not against them (Swantee, 2014).

Examples where both cognitive computing and expressive gesture interaction have been implemented are evident in software applications like the iPhone's 'Siri' app, iTunes' 'Genius' feature (Jobs in The Eyes Of Apple, 2013) and the innovative 'Leap Motion Controller'. Leap Motion, an invention of American software developers Michael Buckwald and David Holz, has grown a community of more then 200,000 developers who implement the device to create immersive, interactive VR experiences focused on expressive gesture interactions. The Leap Motion website describes the technology as:

> *'…Technology [that] senses how you naturally move your hands, so you can reach into the world beyond the screen – in virtual reality, augmented reality, Mac or PC…Truly immersive VR begins with your hands. Interact with virtual objects like you do in the real world – or bend the rules of reality.'*
>
> (Leap Motion, 2015)

The Leap Motion website presents a wide range of interactive applications, concepts that inspire people to think of new ways to merge the fields of computer science, interactive design and art to create new concepts to serve multi-disciplinary purposes such as: education, architecture, design, medical and humanitarian research, art and music.
In a recent speech given at the University of Texas, Oculus' Chief Technology Officer (CTO) John Carmack remarked, 'there is so much more that could be done with audio' (Carmack in Oculus, 2015), encouraging audio engineers, music composers and sound designers to explore VR platforms to create interactive audio-visual experiences. Expressive interactive designs are becoming more popular among users thanks to UX designer Bret Victor, responsible for the initial user interface concepts for Apple's iPad and iPod Nano (Victor, 2013). Victor's UX concepts are in use in many iOS applications and have also been implemented into the professional audio market. Similarly, Steven Slate's 'Raven', a multi-touch audio production console, lets users interact with their favourite digital audio workstation via touch-screen computer technology (Slate, 2015). Asserting the value of gesture in music, last year IRCAM researcher Marcelo M. Wanderley presented an insightful paper in which he described such new gestural instruments as:

> *'…Alternate instruments…[that] allow the use of other gesture vocabularies than those of acoustic instrument manipulation, these being restricted only by the technology choice in the controller design, thus allowing non-expert performers the use of these devices. Even so, performers still have to develop specific skills for mastering these new gestural vocabularies.'* (Wanderley, no date)

Like any instrument, the Glove, Leap Motion and other electronic instruments still require user's practice to learn or familiarise themselves with the technology or instrument, and studies on VR interaction with 3D objects have shown promising results, proving that the human mind can adapt and become proficient in using these systems (Beale et al., 2003, p. 6).

3.4 The role of the human in an immersive environment

Immersion, or 'the extent to which the senses are engaged by the mediated environment' (Schuemie, van der Straaten, and Krijn, 2001), can refer to a broad range of fields including education and gaming, but also everyday experiences such as art exhibitions or listening to music, (Jennett et al., no date). In the interest of this paper, focus has been given to VR audio-visual immersion, where computer generated environments, user interaction and optimised audio could improve the sense of being immersed in a moment.

For the purpose of this research and to optimize both HCI and UX aspects of an immersive audio-visual VR experience (created in support of this paper), I posed the following question to thirty-three audio students: When you listen to music do you feel you are on the outside looking in, or are you fully immersed in the sound environment? The results show (fig. 1, p. 20) that the majority reach a state of immersion when exposed to music, predominantly where two audio channels (stereo) are used for positioning sounds in a 2D space (e.g. X for left or right and Y for depth). However the surrounding environment could contribute to a multi-sensory experience, which could lead to a heightened sense of immersion. By designing a multi-sensory system that could control the surrounding environment, and even facilitate body gestures to interact with 3D virtual objects, the conventional role of the user as listener could be redefined. Creating new possibilities for engaging and interacting with music. During a public lecture, John Carmack stated his view on HCI aspects of VR, providing a few ideas that could improve the user's role in VR experiences. In regard to HCI he noted:

> *'…I do not think we have seen the winning combination yet for how [VR is] going to improve HCI, but I have no doubt [that it] is going to be out there..'* (Carmack in Oculus, 2015).

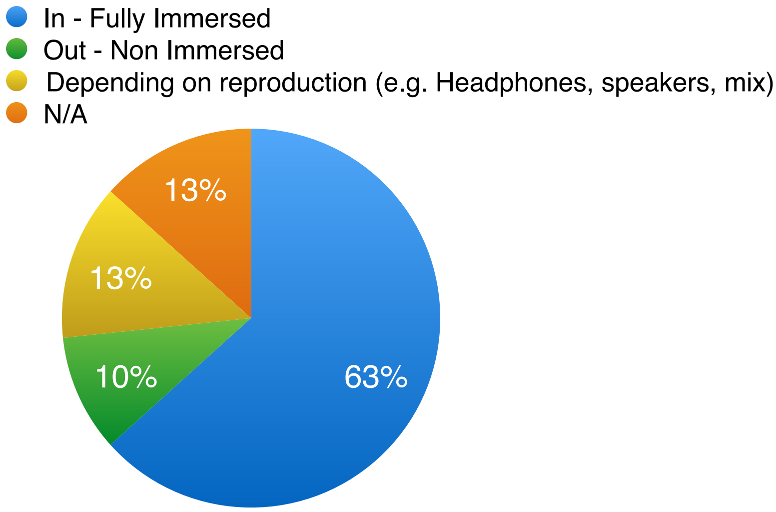
In regards to the user's role in VR, Carmack suggested two known game design methods for creating VR experiences: narrative and interactive. Narrative-based experiences rely on a storyline similar to a film or novel, in which the user does not interact, but is entertained by a story. Interactive experiences are designed to let users explore and interact with virtual surroundings, focusing on tactile implementation that enables the user to change their surroundings by grabbing and moving 3D objects (Carmack in Oculus, 2015). In regard to user interaction I asked the survey group: Are you attracted by the idea of users interacting with or restructuring your finished composition, or do you prefer to deliver a 'static' piece of art? The results (fig. 2, p. 20) reflect Carmack's statement on the role of interaction when creating a VR experience. As he claimed *'…*interactivity is great but you [do not] need it everywhere, statics show that people do not always want to interact with content…' (Carmack in Oculus, 2015). Yet the results also confirm that the author of an artwork does not always want the user to interact with its creation. These findings bring to mind Dr. Ernest W. Adams' quote regarding the role of the author or designer in game design. In an online article titled *The Designer's Notebook: Postmodernism and the Three Types of Immersion,* Adams argued that the role of the author or designer of gaming experiences at time can interfere with the user's role, resulting in breaking the state of immersion for the user. As he explained:

> *'One of the worst annoyances of video gaming is the designers who want to show off how clever they are. Interrupting the players' immersion in order to remind them "Don't forget, it's only a game!" may be the designers being playful, but the game is supposed to provide gameplay for the players, not for the designers. Such cute gimmicks don't improve the players' experience; they harm it. It's a direct slap in the face.'*
> (Adams, 2014)

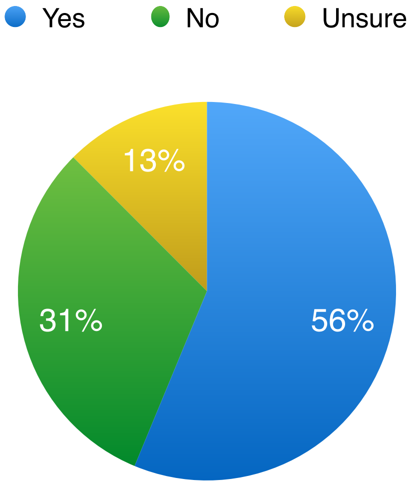
Both Carmack's and Adams' arguments provide valuable insight into the roles of the user and designer, which could improve both HCI and UX aspects of VR experiences. While it is clear that there is not yet a winning formula that can define the exact role of humans in an immersive environment, the research suggests that user experience should be the central focus for designers and authors of VR experiences. The forthcoming game *No*

Man's Sky created by Hello Games (UK) is one example in which both interaction and narrative concepts have featured in order to empower users' roles. Not only can the user interact with the environment, but by collecting objects and resources during the game, their interaction can create 'an infinite procedurally generated galaxy', a never-ending storyline (Hello Games, 2016).

This method allows users to interact with the surroundings but at the same time, empowers them to contribute to the game's story line, increasing a state of self embodiment and immersion. This procedurally generated method could be also applied when developing VR experiences in order to empower user's role and to do not interrupt a state of immersion. However it is to early to draw a conclusion on such an argument, as Carmack suggested. While scientific studies have shown that a full state of immersion is achieved when multiple brain motor sensors are stimulated simultaneously, modern technology is not yet capable of doing so and further research on both user roles and immersion are required to accomplish such goals (Abrash in Oculus, 2014).



(Figure 1 - Survey data - When you listen to music do you feel you are on the outside looking in, or are you fully immersed in the sound environment?)



(Figure 2 - Survey data - Are you attracted by the idea of users interacting with or restructuring your finished composition, or do you prefer to deliver a 'static' piece of art?)

4. Designing an immersive 3D audio experience

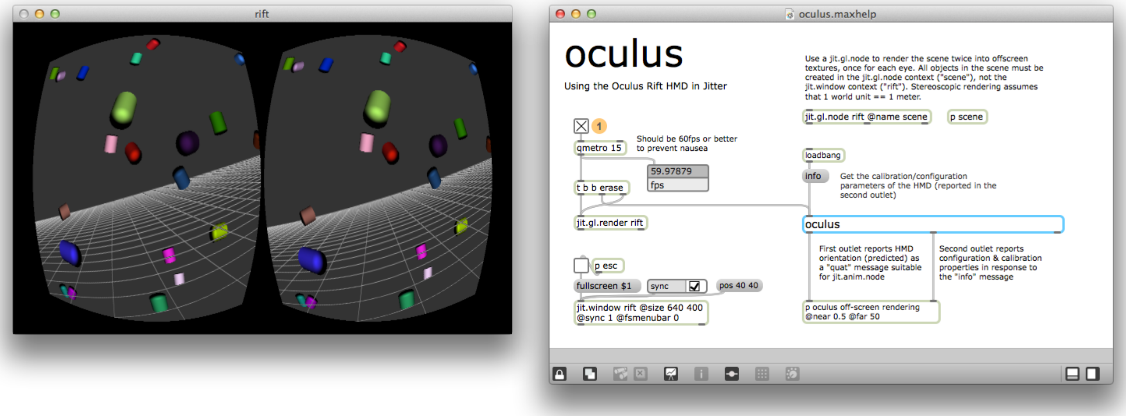
4.1 OpenGL and Max/MSP/Jitter

Since Sanderaland's Sketchpad project (1963), computer graphic technology has evolved dramatically, enabling programmers to display complex 2D and 3D images on computer screens (OpenGLBook.com, no date). While computer generated images once required numerous lines of code, today such images are easily accomplished using the Open Graphic Library (OpenGL): an open source, application programming language (API) for operation commands to the computer's graphics hardware (Shreiner et al., 2013).

Cycling 74's Max/Msp/Jitter is a visual programming language that enables users to implement audio signal processing (Msp) and OpenGL commands (Jitter), using visual programmes called 'patches' and building blocks called 'objects' (Cycling 74, 2015). Research on the creation of Oculus Rift patches using Max/MSP/Jitter identifies developer Graham Wakefield as responsible for creating the first Oculus Jitter patch (fig. 3, p. 22) which consisted of stereoscopic video processing and head tracking data implementation (Wakefield in Cycling 74, 2015). The Cycling 74 forum and technical guide proved to be an invaluable resource for creating the VR user's experience that supports this research paper. Documentations and practical examples, such as developer Rob Ramirez's *Patch-along* video tutorials (Ramirez in Cycling 74, 2015), further clarified the theory and implementation requirements of the Jitter physics system and objects that form the architectural structure of a 3D virtual environment in Max's Jitter. This initial research on OpenGL and Max/MSP/Jitter provided the technical understanding required to design the practical support to this paper. This was complemented by the consideration of three '*use'* words in regard to HCI and UX aspects of the patch, quoted by the authors of *Human-Computer Interaction*:

> *' Useful: Accomplish what is required… Usable: Do it easy and naturally without the danger of error…Used: Make people want to use it.'*
>
> (Beale et al., 2003, p. 5)

The initial design of the VR audio-visual experience that supports this paper consisted of implementing the following open source Max/MSP/Jitter patches, all of which required modification in order to accomplish the final 'main' patch (fig. 4, p. 22).



oculus

Using the Oculus Rift HMD in Jitter

Use a jit.gl.node to render the scene twice into offscreen textures, once for each eye. All objects in the scene must be created in the jit.gl.node context ("scene"), not the jit.window context ("rift"). Stereoscopic rendering assumes that 1 world unit == 1 meter.

Should be 60fps or better to prevent nausea

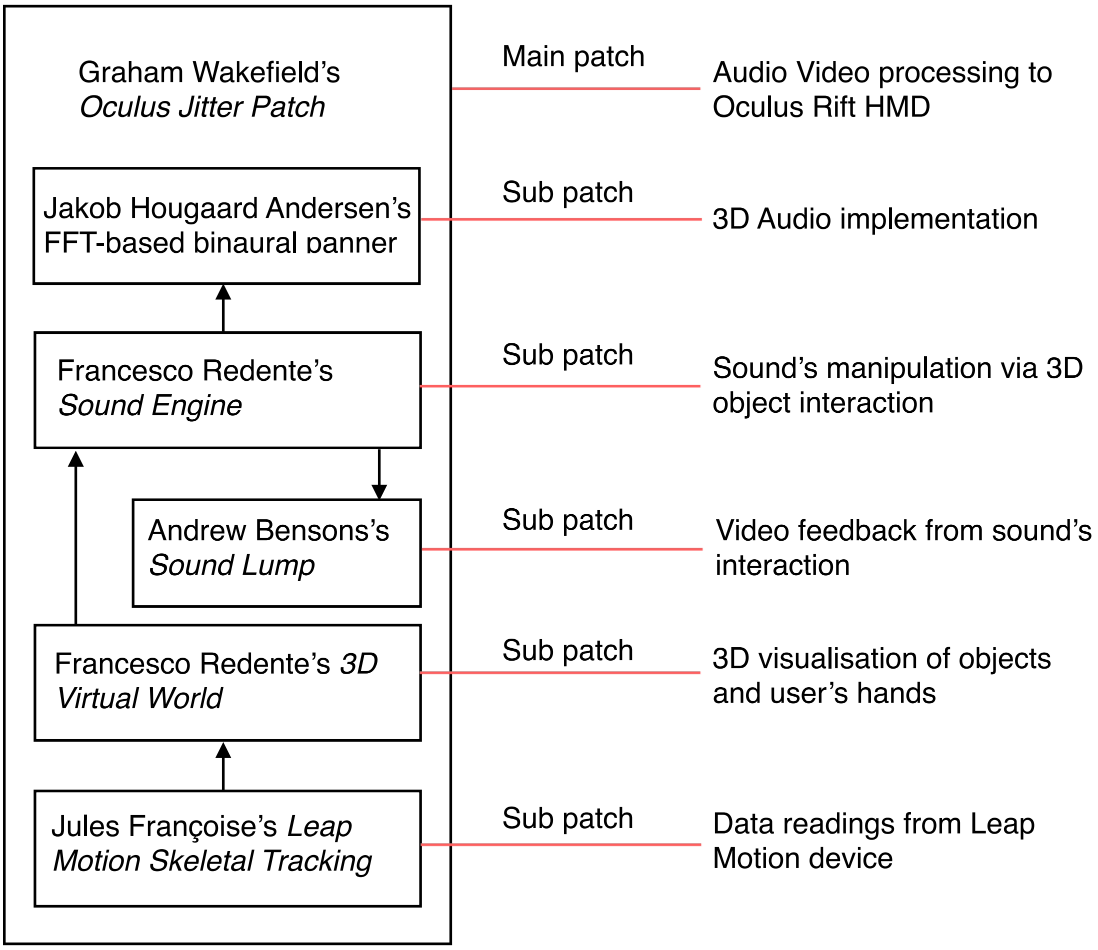
Get the calibration/configuration parameters of the HMD (reported in the second outlet)

First outlet reports HMD orientation (predicted) as a "quat" message suitable for jit.anim.node

Second outlet reports configuration & calibration properties in response to the "info" message

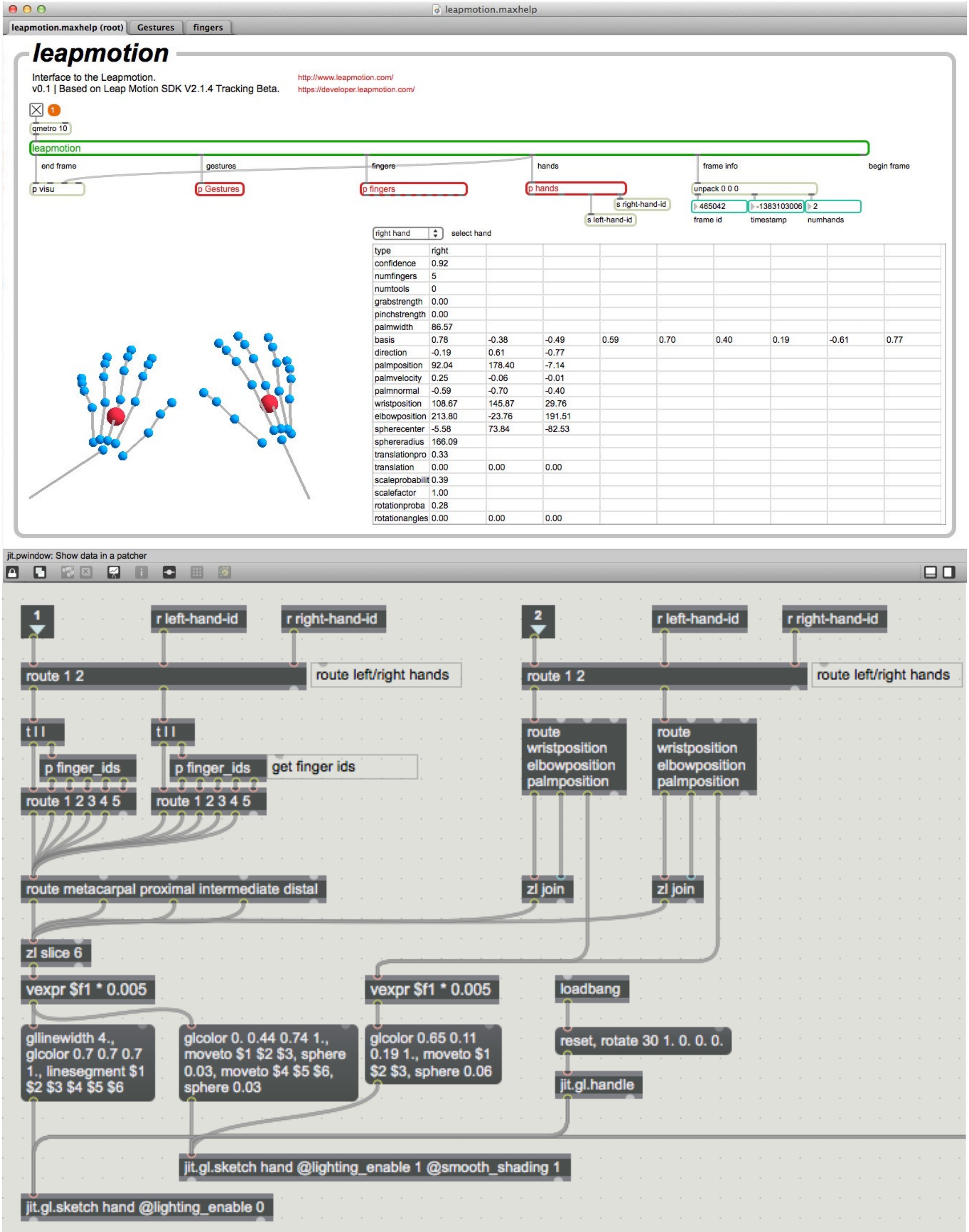
(Figure 3 - Example of Graham Wakefield's Oculus Jitter patch - C74 forums, 2014)

The Max modular system allows one to easily implement open source patches and external objects, such as Wakefield and Jules Françoise, the latter covered in the next section of this chapter. Using patch cords and attributes (responsible for the specific behaviour of Jitter objects), it is possible to create a main patch similar to the example show below in figure 4.



(Figure 4 - Example of Francesco Redente's initial design concept, consisting of Max/MSP/Jitter sub patches contained in Graham Wakefield's Oculus main patch)

Initial tests of both the Oculus's HMD and Max patches were successful, in terms of compatibility between the Oculus' hardware an Max's software, but they revealed some problems in regards to the user's abilities to interact with 3D objects within the virtual environments. Ramirez's examples of interaction and physics within the 3D Jitter world, used conventional computer input devices, such as a mouse and keyboard, to interact with the virtual environment by grabbing or moving 3D objects. Wakefield's patch was also limited as it only provided an initial framework for the Oculus Rift HMD video specifications, required for the stereoscopic processing of any Jitter sub patches. However, further research on the Cycling74 forum revealed a motion capture patch called 'Leap Motion Skeletal Tracking' (IRCAM, 2014) by IRCAM (Institute for Research and Coordination Acoustic / Music)'s researcher Jules Françoise. Françoise's patch reads incoming data from user's hand movements via the Leap Motion device. This data is then sent to Max, compiled into a list and used to create visual representations of the user's hands using Jitter objects such us jit.gl.sketch. An example of Jules Françoise's method used in his Leap Motion Skeletal Tracking patch can be seen in figure 5, page 24.



Interface to the Leapmotion.
v0.1 | Based on Leap Motion SDK V2.1.4 Tracking Beta.

http://www.leapmotion.com/
https://developer.leapmotion.com/

type	right								
confidence	0.92								
numfingers	5								
numtools	0								
grabstrength	0.00								
pinchstrength	0.00								
palmwidth	86.57								
basis	0.78	-0.38	-0.49	0.59	0.70	0.40	0.19	-0.61	0.77
direction	-0.19	0.61	-0.77						
palmposition	92.04	178.40	-7.14						
palmvelocity	0.25	-0.06	-0.01						
palmnormal	-0.59	-0.70	-0.40						
wristposition	108.67	145.87	29.76						
elbowposition	213.80	-23.76	191.51						
spherecenter	-5.58	73.84	-82.53						
sphereradius	166.09								
translationpro	0.33								
translation	0.00	0.00	0.00						
scaleprobabilit	0.39								
scalefactor	1.00								
rotationproba	0.28								
rotationangles	0.00	0.00	0.00						

jit.pwindow: Show data in a patcher

(Figure 5 - Example of Jules Françoise's Leap Motion Skeletal patch, showing the data list compiler and jit.gl.sketch objects)

4.2 Creation of a virtual environment

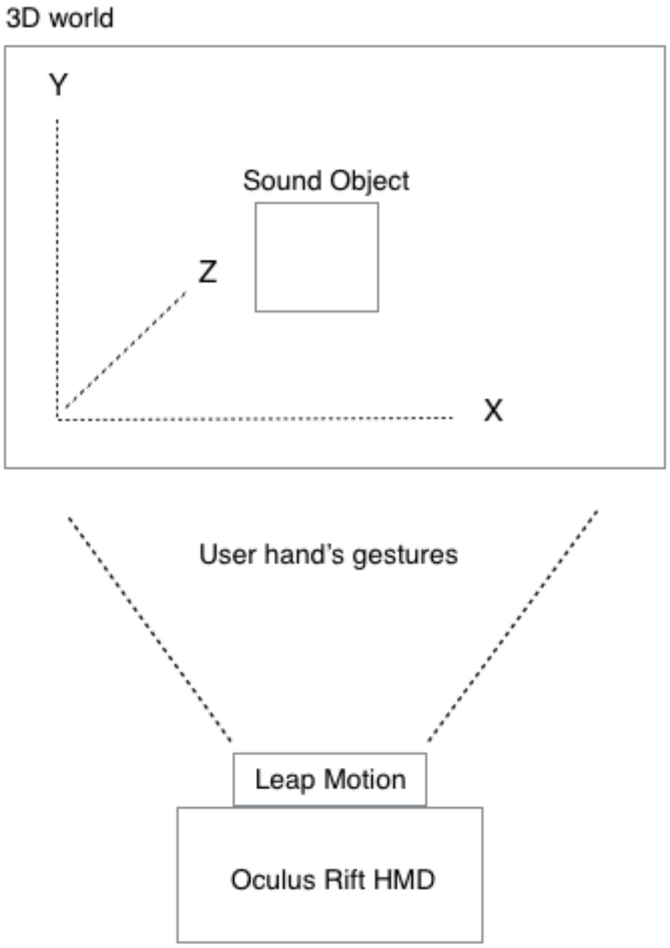
The example below (fig. 6) provides the architectural guide to building an interactive, immersive 3D visual experience. Max’s Jitter objects will be used for the visual (OpenGL) processing of 3D objects and environments, while the Leap Motion device will be used to capture the hand gestures used to implement interaction within the 3D world. The Oculus Rift HMD will be used to visualise the 3D virtual world, and by implementing head tracking data readings from the Oculus external camera, the user will be able to move and rotate their head within the virtual environment, heightening the sense of immersion and embodiment within the virtual world.

jit.phys.world

This building block or ‘object’ allows the replication of physical characteristics such as gravity and collisions in the virtual environment. jit.phys.word is also the container of any rigid bodies: virtual 3D objects. By setting the scale attribute the user specifies the world’s confines and dimensions.

jit.phys.body

This object allows the creation of a rigid body within the virtual world environment. By setting the position attribute in the form of X (left-right), Y (height) and Z (depth), the user is able to move the rigid body within the virtual space. The values of the X, Y and Z axis will then be used to manipulate the sound engine of the patch.



(Figure 6 - Example of an architectural guide to building an interactive, immersive 3D visual experience)

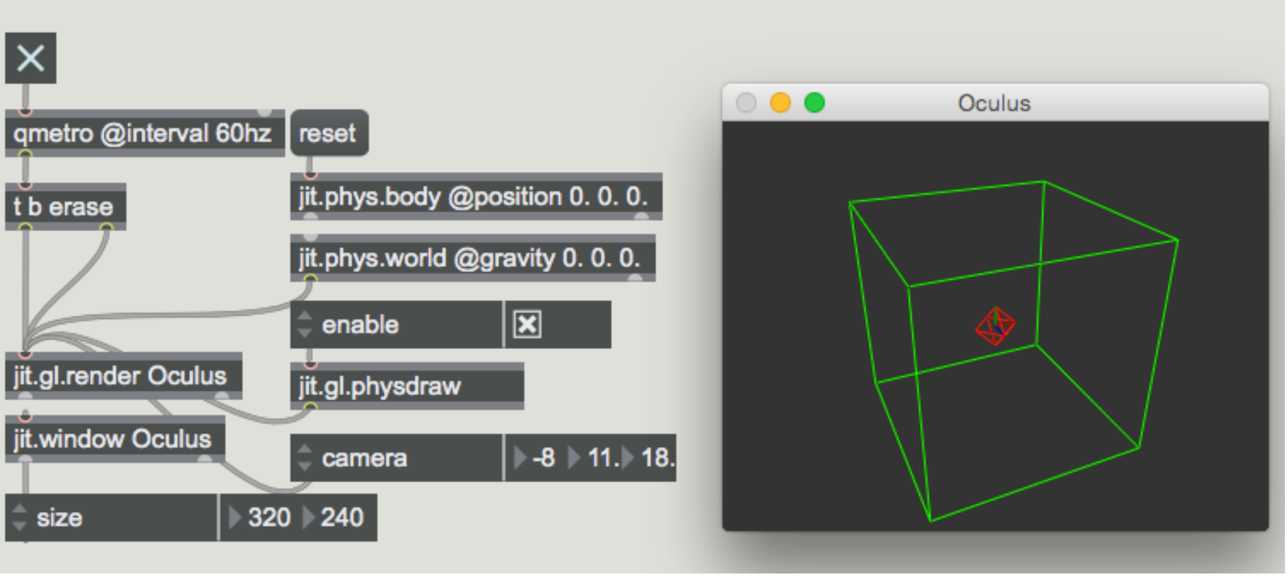
jit.gl.render

This object allows the rendering of OpenGL graphic commands, while the attribute Oculus (fig. 7) determines the destination of the rendering, in this case jit.window as discussed below. The camera attribute allows the user to change the camera position in the form of X, Y and Z values.

jit.window

This object allows the drawing of pixels (or OpenGL graphics data) to a preview window on the computer screen. By setting the attribute Oculus, jit.window receives rendering data from [jit.gl.render], while the size attribute allows to scale the preview window.

The example in the picture below (fig.7) shows all the objects required to render a basic simulation of a 3D virtual environment. The [qmetro @60hz] provides a frame rate for the animation of objects and determines the frames per second (fps) at which the rending will occur. The trigger object [t b erase] deletes each frame and renders the next. The Oculus Rift HMD requires a minimum of 60 fps in order to obtain a smooth rendering and pleasant experience.



(Figure 7 - Example of physics world - Max/MSP/Jitter)

The difficulty with this method of rendering for a small preview window is that it underlines a process of computation, separating the user form the virtual world instead of facilitating an immersive experience. Writer Slavoj Žižek describes this aspect of looking at another reality from beyond a screen in his book *An Introduction to Jacques Lacan Through Popular Culture,* he notes:

> *'…Behind the closed [screen]…the external objects are, so to speak, transposed into another mode …They appear to be fundamentally unreal, as if reality has been suspended… a kind of cinematic reality projected onto the screen…we have been confronted with the…emptiness of the screen…the disproportion can be abolished only by demolishing the barrier, by letting the outside swallow the inside.'* (Žižek, 1991, p.15-16)

This phenomenon of looking at another reality can be overcome by implementing Wakefield's patch, which provides the stereoscopic framework to be able to render this paper Jitter 3D patch on the Oculus Rift HMD (fig. 3, p. 22). This will eliminate the effect of looking at the virtual representation of something on a computer screen, and instead provide a real sense of immersion for the user by 'stepping through the glass' (Slater and Wilbur, 1997, p. 604).

5. Personalising gestural control of sound objects

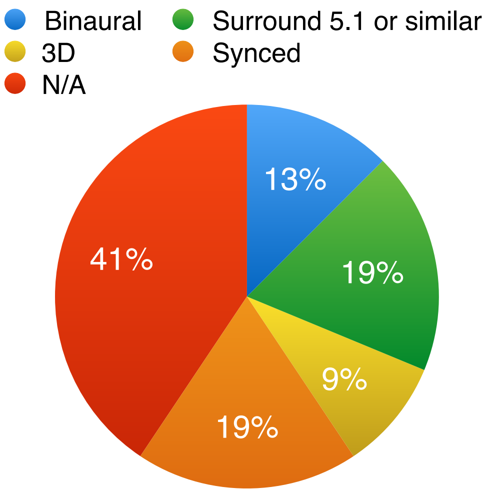
5.1 What is sound for virtual reality?

What really inspired this research was the desire to find out what a VR experience would sound like, especially if one imagined a 360-degree environment without the physical restrictions of the real world. Research in Audio Engineering and Acoustics fields provide audio engineers, producers and sound designers with the knowledge to address recording and mixing problems encountered in real world environments (Rumsey, 2001, p.2). Sound's reflection and absorption from reflective walls (concrete or wood) and porous material (carpet or foam) are only a few of the problems that engineers face while trying to reproduce or create the illusion of a three-dimensional aural experience. The challenge is even greater when the audio reproduction medium relies on only two audio channels to carry all of the sounds' directional information to the audience's ears, a format known as *stereo* invented in 1933 by EMI audio engineer Alan Blumlein (Toole, 2004), (emiarchivetrust, 2014). On the other hand VR experiences are essentially a blank canvas for audio-visual possibilities. The developer's skills are the only limitation on what is possible to achieve in terms of design and interaction, but by *complementing* the computer generated visual cues with optimised audio, the user could experience a three-dimensional, audio-video environment that feels real (Abrash, 2014). In support of the argument posed by Oculus's chief engineer Michael Abrash, Dr Francis Rumsey's book *Spatial Audio* provides an insight into how humans perceive everyday life through sound and vision, both senses are crucial to our understanding of the surrounding environment as well as our interaction with it. As he explains:

> *'Typically natural sound environments contain cues in all three dimensions (width, height, depth) and one is used to experience sounds coming from all around…Because listeners do [not] have eyes in the backs or tops of their heads, they tend to rely on vision more to perceive the scene in front of them and on sound more to deal with things behind and above them.'*
>
> (Rumsey, 2001, p.1)

It is clear from Rumsey's statement that people naturally rely on both visual and audio cues in order to make sense of their natural environment. VR experiences are capable of providing both of these cues to recreate a real, or natural, experience, while allowing developers to challenge real world restrictions by creating virtual environments. On the other hand VR technologies could lead to unrealistic audio scenarios, or as Rumsey states *'…acoustic fiction…spatial experiences that challenge or contradict natural experiences…'* (Rumsey, 2001, p.8), which could cause discomfort and disorientation for the user. It is important to remind the reader that even if VR and spatial audio technologies have been known of for over 50 years (Fisher in Laurel, 1990, p.424), only in past five years have they attracted the attention of the consumer market, leading audio professionals to further research and optimise the technology.

Significantly the argument that audio for VR is a fairly new topic also for audio students, is supported by the findings of the survey of thirty-three audio production students. The question asked: What do you imagine audio for VR would involve? (Survey result are shown below in figure 8)



(Figure 8 - Survey Data - What do you imagine audio for VR would involve?)

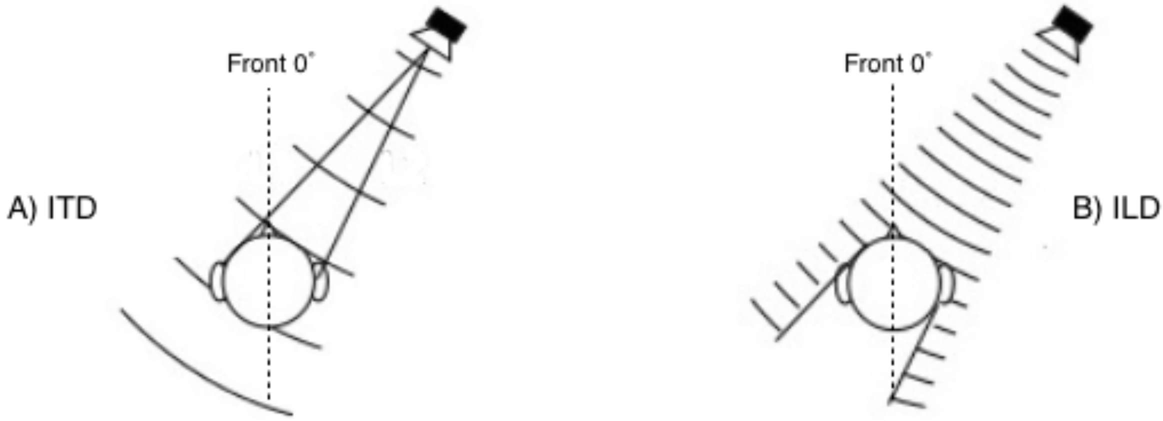
The 41% of students who do not know exactly what audio for VR would involve, represent the reason why Oculus chief engineer Michael Abrash gave a talk at the last Audio Engineering Society conference, which took place last October 2015 in New York (AES, 2015). While Binaural audio has become the standard audio format for VR (thanks to its low cost and efficiency in reproducing the way humans localize sound sources in the real wold), Abrash describes VR as revolutionary, encouraging audio researchers and developers to play a key role in the future of this platform (Abrash in Oculus, 2015).

5.2 Advanced sound spatialisation: Head-related transfer function (HRTF)

There are a few known audio engineering methods for recreating an accurate three-dimensional picture of the sound field, these are Wave Field Synthesis, Ambisonics and Binaural Audio (Choueiri in AES New York, 2015). However, for the interest of this research, Binaural Audio (recording and reproduction) will be the standard discussed in this section. First of all, a question that needs to be addressed is: How do we hear in 3D? The human psychoacoustic characteristics of sound perception and cognition of the natural three-dimensional sound relies on an audio signal and the difference of arrival at the listeners left and right ears. This theory is also know as the Duplex Theory, pioneered by spatial audio researcher John Strutt at the turn of the twentieth century (CIPIC, 2011). The difference in these audio signals can be described as:

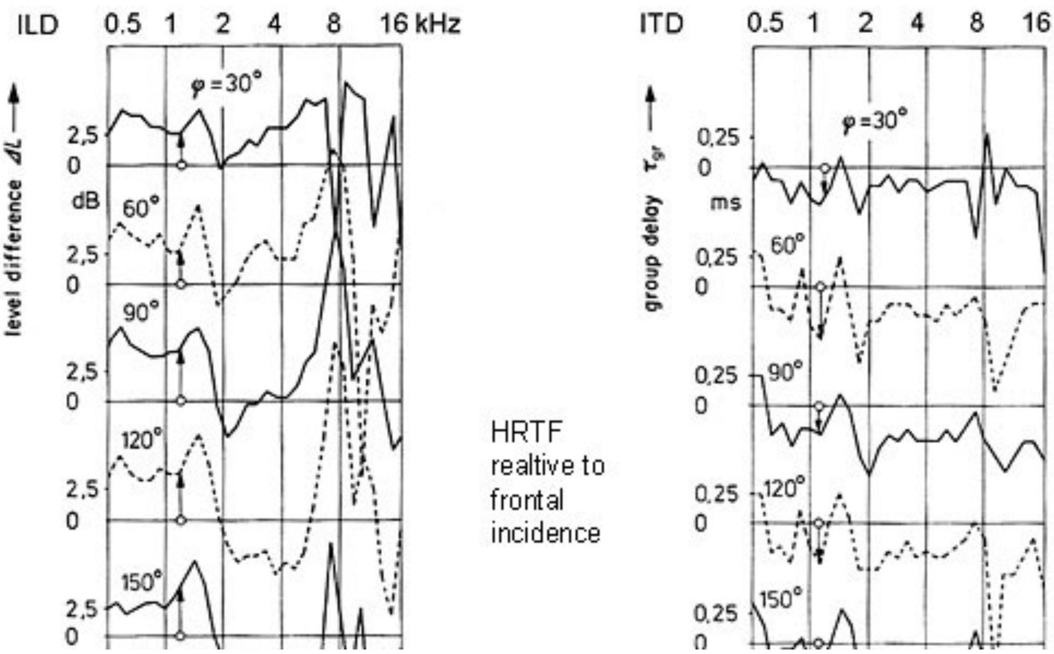
A) Inter-aural Time Difference (ITD): Time cues information (or phase difference) of a sound source located off the 0˚ axis (centre front) arriving at the ears.
B) Inter-aural Level Difference (ILD): Amplitude cues information (or spectral difference). Spectral cues consists of tonal coloration of the sound, highly dependent on the shape of the ears (pinna) and body size.

The example shown below in Figure 11 is a visual representation of both ITD and ILD



(Figure 9 - Example of ITD and ILD audio signal differences - NAVER 2D, 2015)

The sum of these two differences, phase and spectral, make up a subject based head-related-transfer-function (HRTF) which varies depending on the different position and angle of the sound source, including elevations and front-back positions (Rumsey, 2001, p. 24). An example of HRTFs data readings are shown below in figure 12.



(Figure 10 - example of HRTFs data readings, depending on the different angle of the sound source - Linkwitz Lab, no date)

Modern recording technology allows audio engineers to record high quality 3D audio that takes into account the above cues using a technique called Binaural recording, and reproduces them using Binaural audio. Binaural recording can be achieved using Neumann KU 100 dummy head's binaural stereo microphone, 3Dio's Omni-Binaural microphone and Sounman OKM headphones binaural microphones, all of which consist of in-ear condenser microphones. Examples of Neumann KU 100 dummy head, 3Dio's Omni-Binaural microphone and Soundman OKM headphones can be found on page 33, fig.11, 12 and 13.

While the reproduction of Binaural audio can be easily achieved using standard headphones, the research on Binaural recordings and reproduction has shown to be accurate on only thirty subjects out of a hundred (Choueiri in AES New York, 2015). Those problems are related to a mismatch of HRTFs between the heads of dummies and humans, especially since every subject's ear changes in shape and size, and also exhibit other problems related to head rotation. In order to minimise such problems every subject is required to take a personalised HRTF (fig.14, p. 33), using a measurement know as head-related impulse-response (HRIR), a process that requires trained audio specialists, time and high quality equipment to achieve successfully.

Oculus Rift released their own spatial audio software development kit (SDK) last year (fig.16, p. 33), a technology based on a dummy head HRTF measurement (fig. 15, p. 33), a choice made to avoid the problems mentioned in regard to personalised HRTFs (Abrash in Oculus, 2015).

However, for the interest of keeping this research paper open source and for compatibility reasons, the Binaural audio method used for this project patch will be based on Jakob Hougaard Andersen's FFT-based binaural panner: an open source Max/MSP patch that uses forty-three subject-based HRTFs from the University of California's CIPIC (Center for Image Processing and Integrated Computing) database, featuring real time sound position, and listener position and head tracking (Andersen in Cycling 74, 2014). Andersen also developed a HRTF's Subject Matcher sub-patch, which is included in is FFT-based binaural panner patch. The [p HRTFSubjectMatcher] allows the user to enter their own ear and body measurements in order to identify the best match out of forty-three HRTFs files provided by the CIPIC HRTF database. It also provides a description of the mathematics involved in the development of a personalised HRTF file. Examples of the [p HRTFSubjectMatcher] and its content is shown in figure 19 and 20, page ?

It is important to mention Andersen's remarks with regards to this prototype, he notes:

> *'…it must be mentioned that this matcher is a very basic prototype and that it by no means is scientifically valid, but might serve at a rudimentary tool for selecting an appropriate HRTF file set.'* (Andersen in Cycling 74, 2012)

(Figure 11 - Example Neumann KU 100 dummy head - GmbH, no date)

(Figure 12 - Example 3Dio Omni-Binaural - 3Dio, 2016)

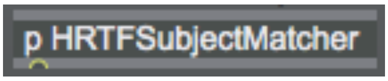
(Figure 13 - Example Soundman OKM headphones - KmrAudio, no date)

(Figure 14 - Example of a personalised HRTF measurement - Microsoft, 2016)

(Figure 15 - Example of HRTF measurement based on a dummy head - Zhong and Xie, 2014)

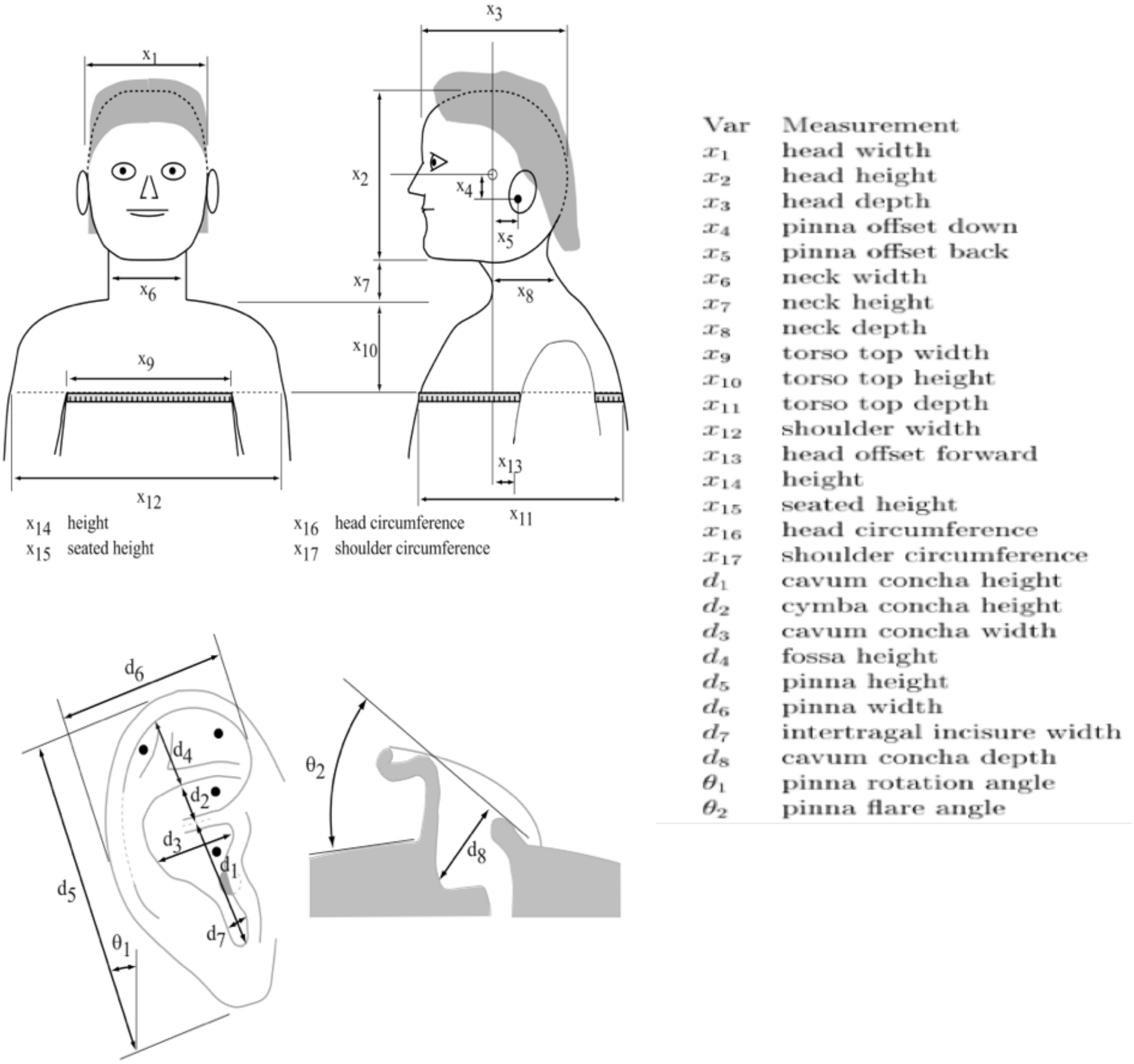
GAIN (dB) 0.00
NEAR (m) 32.81
FAR (m) 57.00
X POS (m) -0.32
Y POS (m) 0.00
Z POS (m) -33.92
X SIZE (m) 3.00
Y SIZE (m) 4.00
Z SIZE (m) 5.00
LEFT 0.80
UP 0.80
RIGHT 0.80
FRONT 0.80
BOTTOM 0.80
BACK 0.80
158.98 SCALE (m)

(Figure 16 - Example of Oculus' spatial audio SDK - Oculus, 2015)



p HRTFSubjectMatcher

(Figure 17 - Example of Jakob Hougaard Andersen's HRTFSubjectMatcher sub patch)



Var	Measurement
x_1	head width
x_2	head height
x_3	head depth
x_4	pinna offset down
x_5	pinna offset back
x_6	neck width
x_7	neck height
x_8	neck depth
x_9	torso top width
x_{10}	torso top height
x_{11}	torso top depth
x_{12}	shoulder width
x_{13}	head offset forward
x_{14}	height
x_{15}	seated height
x_{16}	head circumference
x_{17}	shoulder circumference
d_1	cavum concha height
d_2	cymba concha height
d_3	cavum concha width
d_4	fossa height
d_5	pinna height
d_6	pinna width
d_7	intertragal incisure width
d_8	cavum concha depth
θ_1	pinna rotation angle
θ_2	pinna flare angle

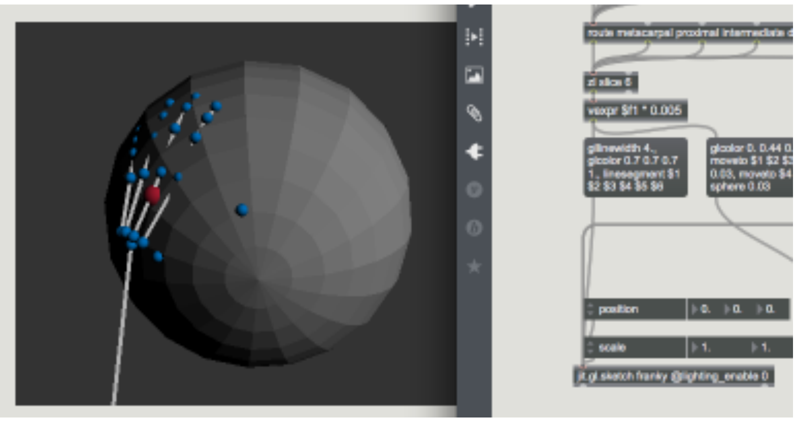
(Figure 18 - Example of HRTFSubjectMatcher sub patch's content - Andersen, 2011)

5.3 Facilitating user interaction in an immersive environment: A personalised implementation

The research on interactive sound design via gestural control identified few methods that could be used in personalising a system to facilitate user interaction in an immersive environment. The inspiration for the design and implementation of the practical aspect of this paper came primarily from two computer music researchers: Jan C. Schacher and Youichi Horry. Schacher's paper: *Gestural Control of Sound in 3D Space,* provided a theoretical understanding of HCI aspects and the challenges involved in the design and implementation of user's gestural control aimed for sound design purposes (Schacher, 2007). Horry's paper: *MIDI Signal Generation and Sound Synthesis,* suggested a practical method of implementing user's interaction with computer generated 3D objects (mainly X, Y and Z position in 3D space), to control or modify sound parameters such as timbre, volume and timing (Horry, 1994). The papers provided a valuable source of reference for both the practical and theoretical aspects required to facilitate user interaction with 3D sound objects. But they also highlighted the need to design and implement a personalised method that took into account the main aspect of this research: an immersive 3D virtual environment.

In regard to this last point, VR researchers Mel Slater and Sylvia Wilbur's paper: *A Framework for Immersive Virtual Environments* helped to emphasise the importance of high quality equipment, in this case the Oculus Rift HMD, optimised audio, head tracking and real-time hand rendering, in delivering '… inclusive, extensive, surroundings and a vivid illusion of virtual environments to a participant.' (Slater and Wilbur, 1997, p.1-7). Once the theory and practical components were gathered (the patches mentioned in the previous chapter, Oculus Rift HMD and Leap Motion device), the initial design consisted of creating a system that could be used as a test patch.

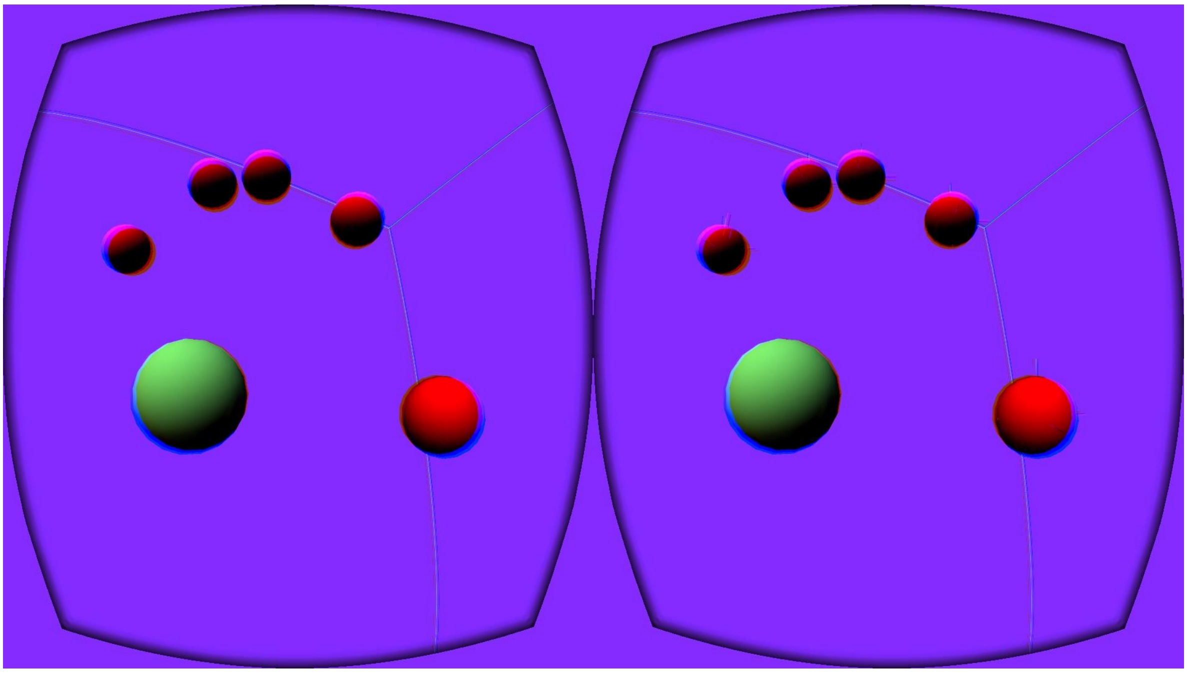
Some of the problems encountered during the implementation of the *Leap Motion Skeletal Tracking* (IRCAM, 2014) by IRCAM's researcher Jules Françoise, consisted of the absence of real physical characteristic from the hands rendering method used by Françoise. Also Françoise's patch was not designed for VR, therefore did not take into account head-tracking data from the Oculus Rift HMD. Such technical problems led to an inability to interact with rigid bodies contained within the 3D virtual world (e.g. grabbing or moving 3D virtual objects), and without head-tracking the hands' rendering would not follow the changes in the user's position (e.g. head position and rotation). The example shown below in figure 19 represent the first patch created to test user interaction, head-tracking and the computer's graphic rendering power.



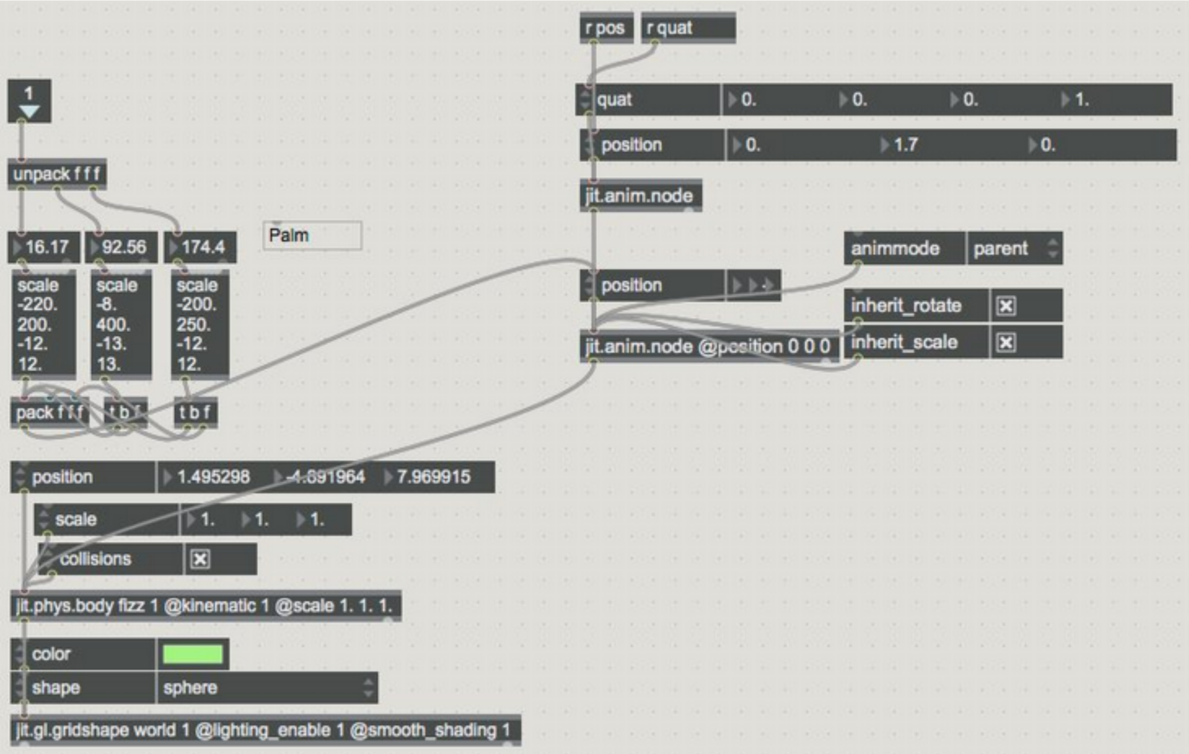
(Figure 19 - Example of first test patch, which also shown the absence of real physical characteristic from the hands rendering method used in Jules Françoise's patch)

As a result of this first test, new research into possible solutions led to a series of posts exchanges with other Max/MSP/Jitter developers on the Cycling 74 forum, including Graham Wakefield and Rob Ramirez (see appendix 2.2, p. 65). Their contribution led to the understanding that the implementation of physical interaction within the 3D virtual environment could be achieved via rigid bodies (jit.phys.body) instead of only OpenGL drawings (jit.gl.sketch).

The examples shown in figure 20 and figure 21 on page 37 , show the rendering of the left hand's fingertips and palm, using rigid bodies and head-tracking implementation, the latter achieved using Jitter's animation object [jit.anim.drive] which receives real-time position and rotation values from the external Oculus camera. While these early experimental tests resolved user interaction and head tracking implementation problems, they also revealed a severe computer graphic challenge which was affecting the frame per second (fps) required by Oculus Rift HMD (60 fps). Rendering both hands involved fifty rigid bodies to be drawn on the computer screen (in real time) and a very high computer graphic processing power (not available on an 2011 Apple iMac computer). The results of such technical problems consisted of a drop of twenty frames every second, making it impossible to achieve a working, usable VR experience for the user.



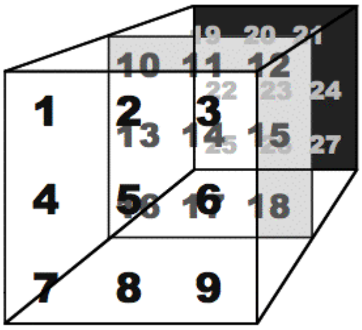
(Figure 20 - Example of rendering of the left hand's fingertips and palms, using rigid bodies)



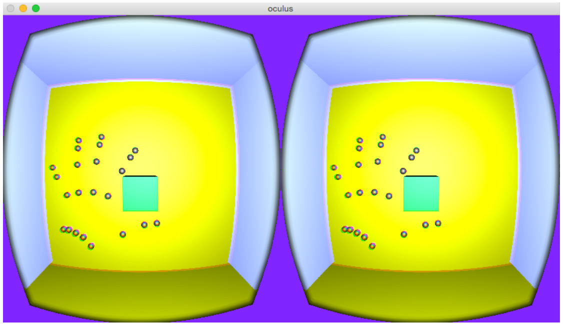
(Figure 21 - Example of head-tracking implementation to a rigid body, using Jitter's animation object [jit.anim.drive])

However this initial test served as a learning step for both Oculus' HMD and Leap Motion implementation, which helped in researching a better solution to achieve a usable patch. The aim was to use a single jitter object to draw multiple rigid bodies, at the same time being able to implement head-tracking data from the Oculus' HDM to update the user's hand positions in real time. A similar method was implemented by developer Sam Tarakajian in his patch *Tutorial 26:The Floor is Lava,* discovered during early research on Max/MSP/Jittter. Tarakajian's patch used a single Jitter object [jit.phys.multiple] to render multiple rigid bodies using a data-grid object called [jit.matrix]. However this method required further research on both Jitter objects [jit.phys.multiple] and [jit.matrix], and further consultations with Cycling 74's developer Rob Ramirez in order to implement real time head-tracking. Solving this technical problem led Ramirez to write a new section on Max/MSP/Jitter online documentation (see appendix, section 2.2, p.65), which explains how to solve some of the problems found during the making of this paper's prototype and will hopefully help other developers to make VR experiences using Max/MSP/Jitter.

The examples show below in figure 22 and figure 23 represents the method implemented for the drawing of the user's left hand, using the Leap Motion device and data readings from Jules Françoise's *Leap Motion Skeletal Tracking* (IRCAM, 2014) sent to a single [jit.phys.multiple]. Solving all the above technical problems in regards to user interaction, Oculus's head-tracking and computer graphic powers led to the successful implementation of all the patches which took into consideration the required frame per seconds (60 fps) in order to achieve a ' …Useful…Usable…Used..' (Beale et al., 2003, p. 5) VR experience.



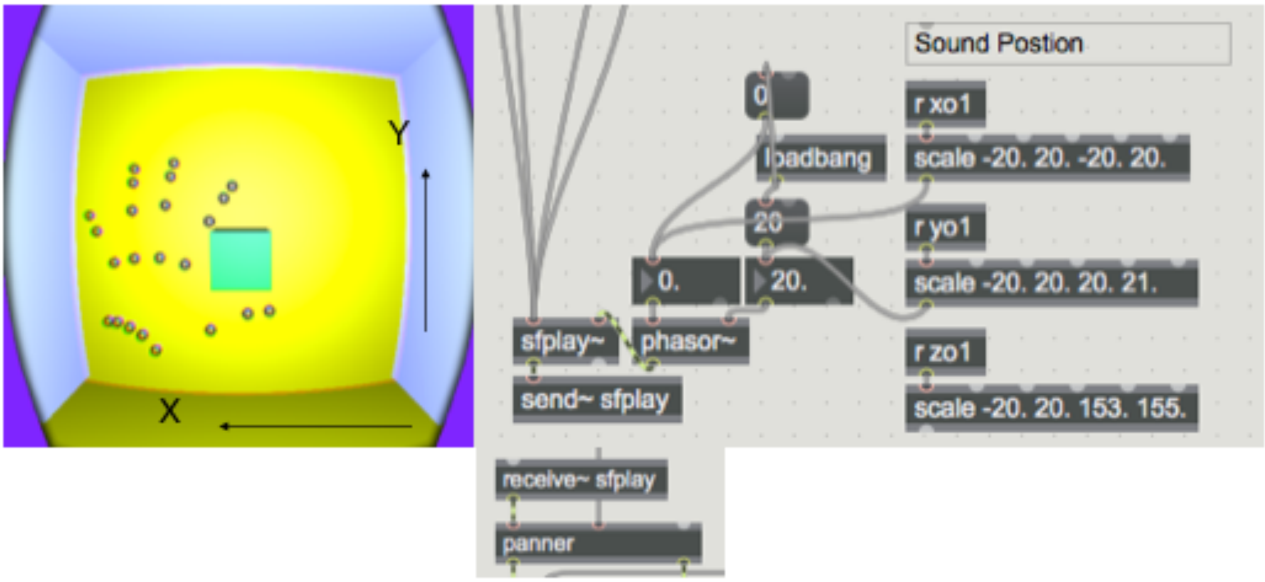
(Figure 22 - Example of jit.matrix, consisting of 3x3x3 data grid = 27 possible drawing cells - C74, 2008)



(Figure 23 - Example of jit.matrix and jit.phys.multiple for rendering/drawing 22 rigid bodies to 22 cells, using one jit.phys.multiple object to render the user left hand)

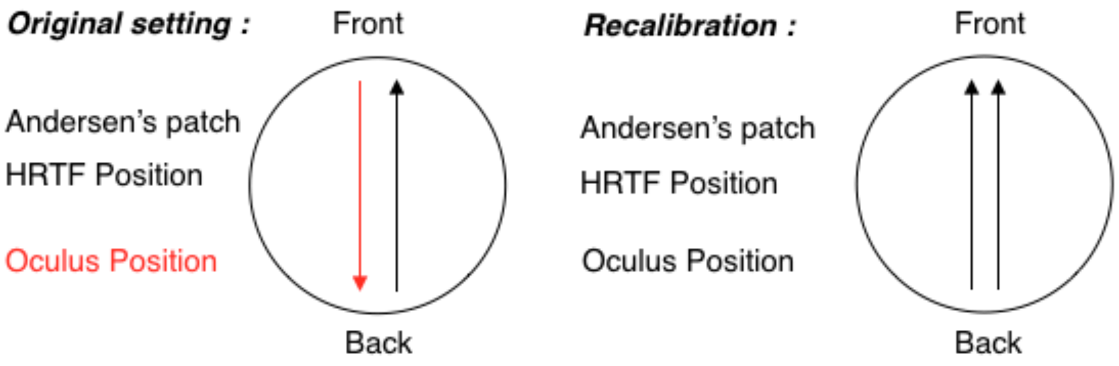
5.4 Personalising gestural control of sound objects

The design and implementation of the interactive sound engine within the patch consisted of two methods: an audio sample being played by Max/MSP's object [sfplay~] and Jakob Hougaard Andersen's patch: FFT-based binaural [panner] responsible for the 3D audio implementation. The 3D virtual object position coordinates (X and Y) would manipulate pitch and speed of the audio sample, sending its out-put signal to Andersen's patch for the Binaural audio decoding. The user would be able interact with the 3D object (cube) and by doing so modify the sound's pitch and speed, while updating the FFT-based binaural [panner], as shown in the example in figure 26 below.

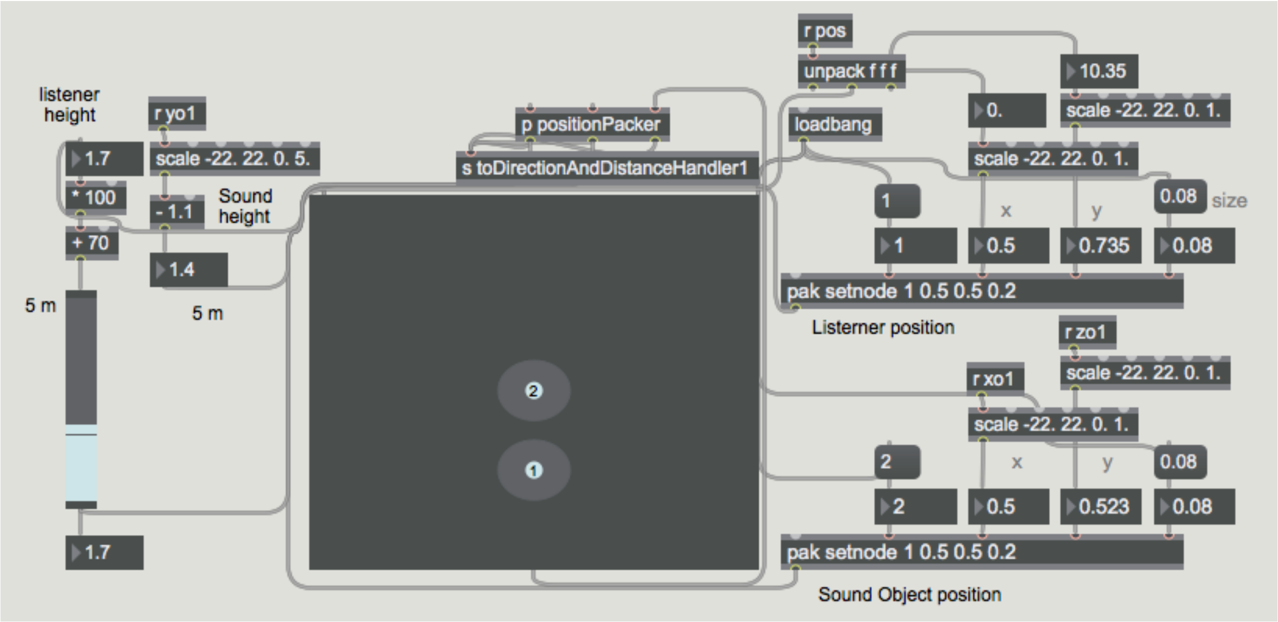


(Figure 24 - Example of using the 3D object position coordinate to control [sfplay~] parameters and panner)

The Binaural panner's implementation proved challenging, mainly because Andersen's patch was not designed for VR, did not include head rotation and its HRTF file was not matched with the Oculus HMD position. Therefore it required a recalibration of 180-degrees in order to provide the correct setting for the HRTF file, responsible for the Binaural audio decoding. The examples shown in figures 25 and figure 26 (p.40) show the recalibration applied and Andersen's patch, the latter provided visual cues of listener and sound object position once recalibrate.



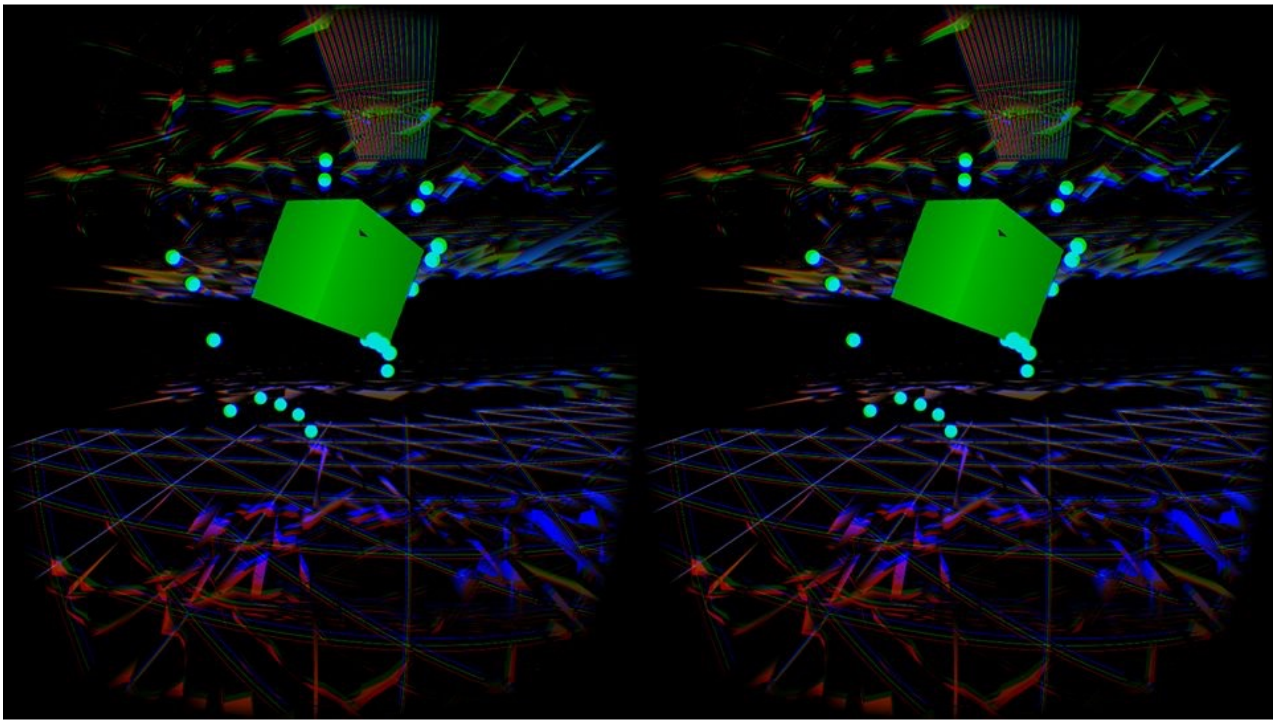
(Figure 25 - Example of Oculus' recalibration)



(Figure 26 - Example of Andersen's patch providing visual cues of listener (1) and sound object (2) position)

While both sound manipulation and 3D audio panner worked well, the user interaction implementation proved to be very difficult to perfect owing to an inability to implement a gestural language that would enable the user to easily interact with the 3D object. A workable solution required removing physical characteristics, such as weight and gravity, from the 3D virtual object (cube) to facilitate user interaction and object movement around the 3D space. This decision was made in light of the time available to complete the project, the available technical resources, the coding knowledge learned during the research and the feedback gathered from other developers.

The example below in figure 27 shows the final prototype patch used to carry out a user test with twenty-five participants from various fields in the audio industry including musicians, engineers, sound designers and audio-software developers. The technology involved in the test consisted of an Apple iMac computer, Max/MSP/Jitter patch, Oculus Rift HMD, Leap Motion and headphones. A video tutorial which demonstrate how to load and use the Max/MSP/Jitter patch, can be found in the appendix (see appendix, digital 2.1, p. 65).



(Figure 27 - Example of the final prototype patch used to carry out the user test)

6. How do we relate to the gestural control of sound objects in an immersive 3D environment ?

6.1 Testing our immersive 3D environment: The user experience

The aim of this test was to observe user behaviour within an immersive, VR environment and gather qualitative and quantitative data in regards to the optimisation of further VR audio-visual experiences. The test was also aimed to create awareness within the audio industry, in terms of considering VR technology as a possible platform for new ways of creating interactive music compositions, sound design, audio engineering techniques and audio software development. This experimental research could also provide insight into alternatives to the static experience of listening to music on streaming platforms such as youtube, Soundcloud and Spotify, none of which support user interaction.

This argument is supported by designer-musician Roey Tsemah creator of Whitestone.io: the first web-based platform for interactive music content, a concept he created in 2012 based on his graduation research project which focused on the way people listen to music on the web. As he explained:

> *'…I found it quite frustrating that while technology evolves around us exponentially, music publishing is still influenced by physical mediums such as CDs and Vinyls…think about it.. why is the album artwork still a square? By now I would expect to be full screen-interactive or even 3D…Why can [not] web-based albums be more then a track-list?…'* (Tsemah in Whitestone, 2015)

Even though Tsemah's platform was not designed for VR, it supports the ideas and concepts that inspired this paper and its aims to research new ways to experience music by creating interactive musical content that exhibit user interaction. The Binaural Audio feature of the prototype's patch aims to gather qualitative data to evaluate the importance of 3D audio in support of interactive 3D environments, which could improve the user's state of immersion and a sense of audio spatialisation when compared to the common 2D stereo experience.

In regards to planning an objective test, interaction designer Kathleen M. Gomoll's paper: *Techniques for Observing Users,* provided valuable instruction in advising on the presentation of the project to all users and execution of an online multiple choice survey. Gomoll's instructions included: a short demonstration on how to use the prototype, finding the right people, explaining that you will not provide help, that users can quit the test at anytime, that users can talk while practicing, choosing a comfortable environment to conduct the test and explaining the reason of the research and practical test (Gomoll in Laurel, 1990, p.86-87). These instructions served to ensure that the data gathered from the online multiple choice survey, presented to users at the end of the test, would be reliable. The five questions presented to the users were: How did the experience make you feel ? How would you rate the immersive experience compared to 2D stereo listening? How likely are you to use Virtual Reality to implement new sound design techniques? How likely are you to use this method to implement user interaction within your compositions? The results of all of the users answers can be found in the appendix of this paper (see appendix 1.1, p.58)

6.2 Evaluating user feedback

Twenty-six people attended the user test, all of whom had different audio-related backgrounds ranging from education and composition to sound design, business and software development. It has been a valuable experience to observe users experience and interact with the prototype, providing significant information in terms of technical difficulties encountered, the errors exhibited by the technologies in use and the different reactions of users when immersed in the virtual environment. The results of the users' feedback from the online survey (see appendix 1.1, p.58) have shown that VR experiences, together with Binaural Audio implementation, provide an higher state of immersion compared to standard, 2D stereo listening experiences. In regard to user interaction of the 3D sounding objects, fourteen out of twenty-six users found it difficult to interact with the virtual object, suggesting to optimise this aspect by implementing a better gestural language that would facilitate user interaction. This result supports Schacher argument presented in Chapter 3.3: Expressive gesture interaction, in which he highlights the absence of a universal gestural language for computer based musical systems (Schacher, 2007).

Users have also helped to highlight the need of better computer graphic power, providing specific feedback on the latency involved to display the rendering of the user's hands in the virtual world, which also influenced the interaction side of the experience.

Such technical feedback supports a recent article publish by the BBC, in which technology reporter Dave Lee summaries the inefficient power of consumers' computer technology in regards to new VR equipment such as the Oculus Rift. In his article Lee highlights a statement made by Nvidia, one of the leading companies in computers' graphics, which quoted that 'less than 1% of the PCs expected to be in use globally in 2016 will be powerful enough to run the best virtual reality technology…' (Nvidia in BBC, 2016).

However the majority of users involved in the test have shown interest in the technology and were all very keen to use VR platforms for new methods of sound design and to implement user interaction in their own musical compositions. Taking into consideration the challenges found during the design and implementation of the prototype, the technology available, and the resources gathered throughout the limited period of this research, the final evaluation of this user's test can be summarised as positive.

7. Conclusion

7.1 What have we learned

This conclusion aims to evaluate the findings gathered from both primary and secondary research presented in this paper. By underlining key aspects learned through the investigation of the research question, I will further address possible improvements for future research and development.

I managed to design and create a usable VR prototype patch, which I then used for a practical users test. This served as a primary source of research to help me to find more answers to my research question. The feedback gathered from the users revealed that in terms of 3D, Binaural audio and visual implementations, both those aspects successfully helped improve the user's sense of immersion in the VR experience. However this state of immersion was compromised by the user's difficulties in trying to interact with the 3D sound objects. While this finding confirms Wanderley's claim that '*performers still have to develop specific skills for mastering these new gestural vocabularies'* , by observing users' behaviour during the experience, I noticed that users did not know when they were touching the sound objects and vice versa (Wanderley, no date). This problem mainly consisted of not having a tactical perception-feedback system which would have helped users to perceive physical contact between their virtual hands and the 3D sound objects within the virtual world.

In light of the research question, one can conclude that users have expressed a need to establish a physical form of contact with the virtual 3D object, while both the visual and audio aspects of the VR experience were perceived as highly immersive. However, the facilitation of haptic interaction with sound objects within an VR experience requires more research and development. Although consideration of the historical, cultural engagement with VR previously and the growing commercial interest in VR today suggests the field will advance rapidly over the next few years (Abrash in Oculus, 2015). The success of such haptic interaction could lead to increased system usability, contribute to find more answers in regards to how users may relate to it and at the same time reduce the risk of jeopardising the user's sense of immersion in VR environments.

Results gathered from the initial survey in which thirty-three audio students took part, revealed that VR technology is still a fairly new subject in regards to music composition and sound design, especially compared to standard forms currently in use for mixing or creating music. The research I conducted on HCI and UX, helped me to implement a form of interaction with the VR experience, at the same time providing a guide to make it easy to use given the tools I had available (Oculus HMD and Leap Motion sensor). While the Oculus Rift and Leap Motion worked well during my first development test, the design and implement of the Max/MSP/Jitter patch, which followed both HCI and UX points on facilitating usability and interaction, proved challenging. On one hand the iMac's graphic power (graphic card processing power), proved to be insufficient, especially when running the Oculus's HMD, Leap Motion sensor and all the Jitter patches. Then a few weeks after purchasing the Oculus's HMD, the company stopped supporting Apple computers, meaning no further software support is available for any VR developers using an Oculus Rift and an Apple computer (Oculus, 2015).

Such sudden scenario meant that the chances of finding any Apple VR developers who could help to improve this research were significantly reduced (Cycling 74, 2015). Also even when it is possible to create prototypes of immersive VR experiences using an Oculus Rift HMD and an Apple computer, the compatibility between the two devices is yet to be optimised. This means that the majority of people with an audio field background, who have been using Apple computer optimised for audio tasks will be forced to use a different platform in order to develop or load VR experiences. In regard to this last point, and with regards to system usability, the HCI and UX research has clearly revealed that such a scenario needs to be avoided if we want to facilitate the user experience (Beale et al., 2003, p. 5). While VR remains dominant within the gaming industry, the overall feedback I gathered from both observations and user feedback in experiencing the technology arguably inspires confidence to continue to research and develop multi-sensory experiences aimed to different fields of the audio industry.

7.2 Going forward

The following sections will propose possible improvements in further developments of VR audio-visual experiences.

Implementing a tactile perception system within VR could help to facilitate user interaction with sound objects, and by learning a script-based coding language, such as Javascript or C++, one could develop a workable prototype and gestural language that could facilitate a more intuitive method of interaction. However, optimised compatibility between all computer hardware and VR technology is yet to come, although it will hopefully be addressed in the following year by hardware manufactures.

The users' feedback has shown that people are willing to experience audio content in more interactive and dynamic forms if a system with an accessible method of interaction was developed. Such positive results inspire me to transform static, text-based content into more interactive 3D content which can be easily accessed by users over the internet. New platforms like Nightly: Mozzilla's first VR enabled internet browser, hosts immersive interactive content that may lead the future of interactive VR content, easily accessed by a wide and varied audience (MOZVR, no date). Interactive audio within 3D VR experiences could also be used to deliver a new form of teaching, that could not only help the learning process to become more interactive and engaging, but at the same time help future developments in facilitating user interaction within an VR immersive 3D audio-visual experience.

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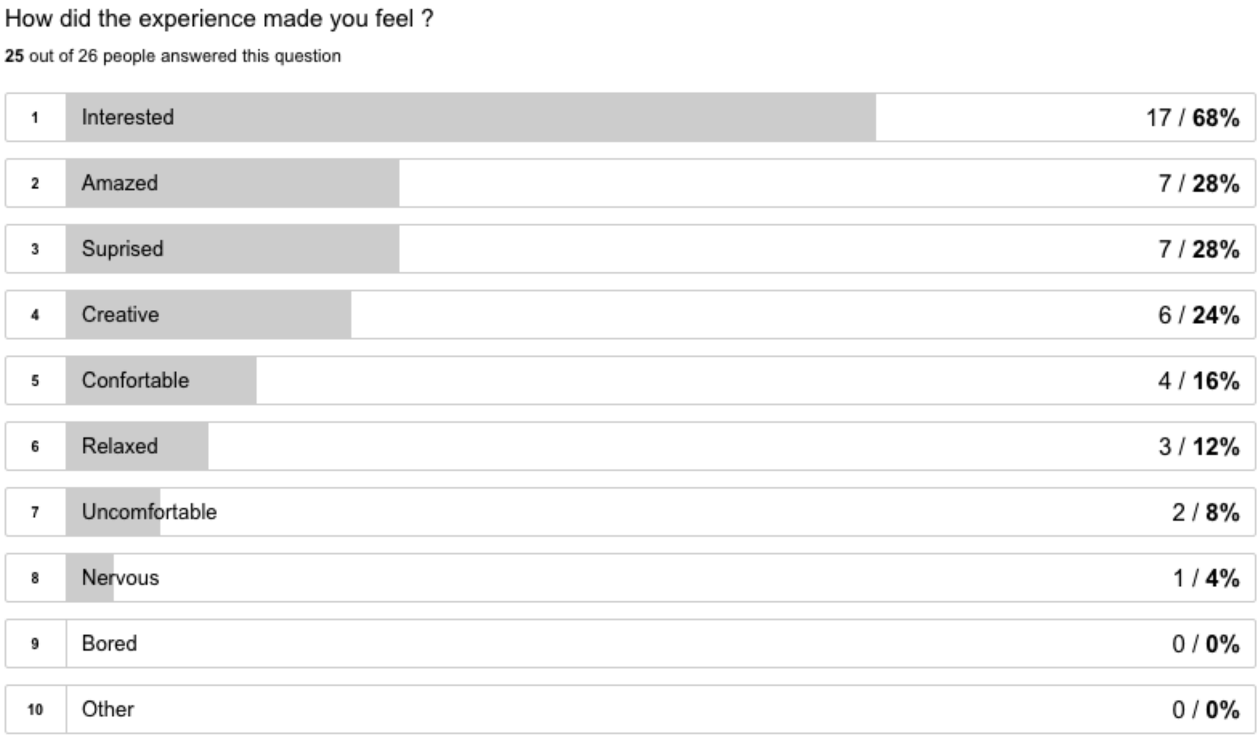
Appendices

1. Appendix

1.1 User’s test and survey data results

1.1.1

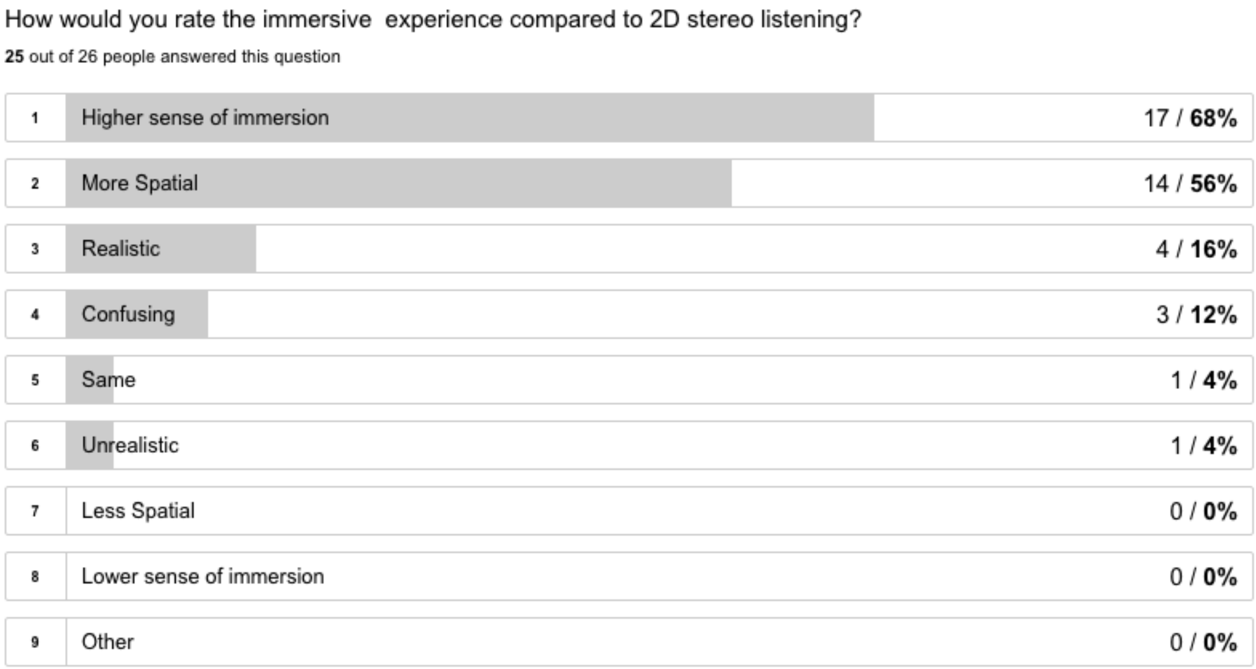


How did the experience made you feel ?

25 out of 26 people answered this question

1	Interested	17 / **68%**
2	Amazed	7 / **28%**
3	Suprised	7 / **28%**
4	Creative	6 / **24%**
5	Confortable	4 / **16%**
6	Relaxed	3 / **12%**
7	Uncomfortable	2 / **8%**
8	Nervous	1 / **4%**
9	Bored	0 / **0%**
10	Other	0 / **0%**

1.1.2

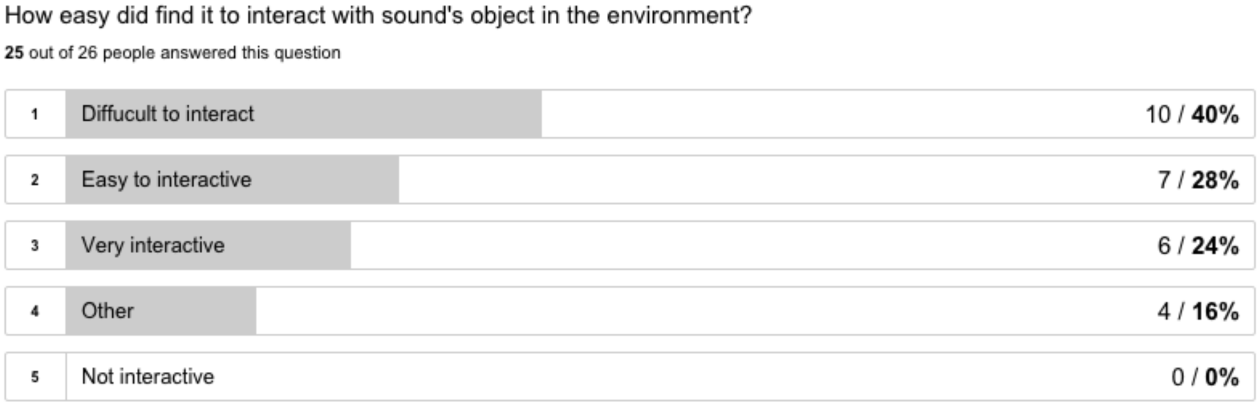


How would you rate the immersive experience compared to 2D stereo listening?

25 out of 26 people answered this question

1	Higher sense of immersion	17 / **68%**
2	More Spatial	14 / **56%**
3	Realistic	4 / **16%**
4	Confusing	3 / **12%**
5	Same	1 / **4%**
6	Unrealistic	1 / **4%**
7	Less Spatial	0 / **0%**
8	Lower sense of immersion	0 / **0%**
9	Other	0 / **0%**

1.1.3

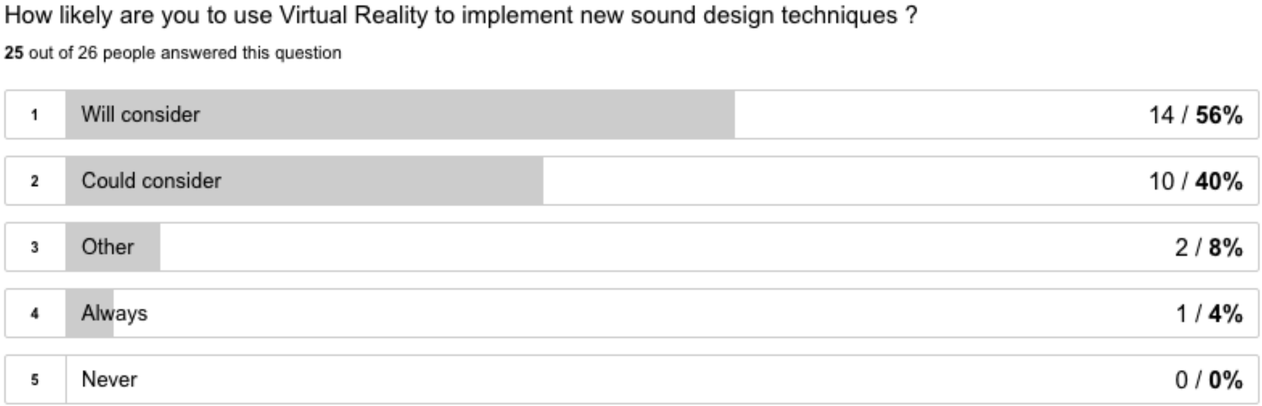


How easy did find it to interact with sound's object in the environment?

25 out of 26 people answered this question

1	Diffucult to interact	10 / **40%**
2	Easy to interactive	7 / **28%**
3	Very interactive	6 / **24%**
4	Other	4 / **16%**
5	Not interactive	0 / **0%**

1.1.4

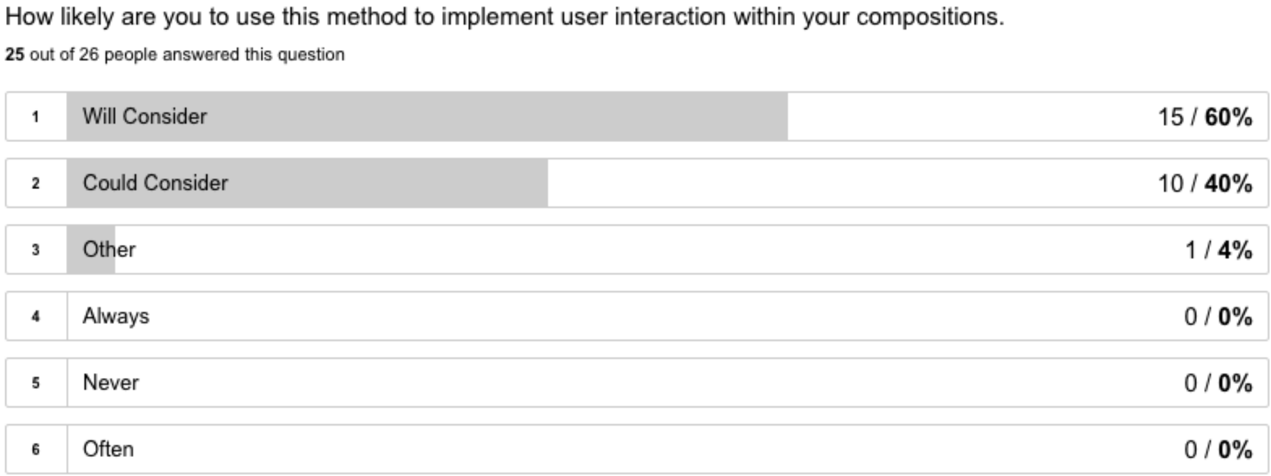


How likely are you to use Virtual Reality to implement new sound design techniques ?

25 out of 26 people answered this question

1	Will consider	14 / **56%**
2	Could consider	10 / **40%**
3	Other	2 / **8%**
4	Always	1 / **4%**
5	Never	0 / **0%**

1.1.5



How likely are you to use this method to implement user interaction within your compositions.

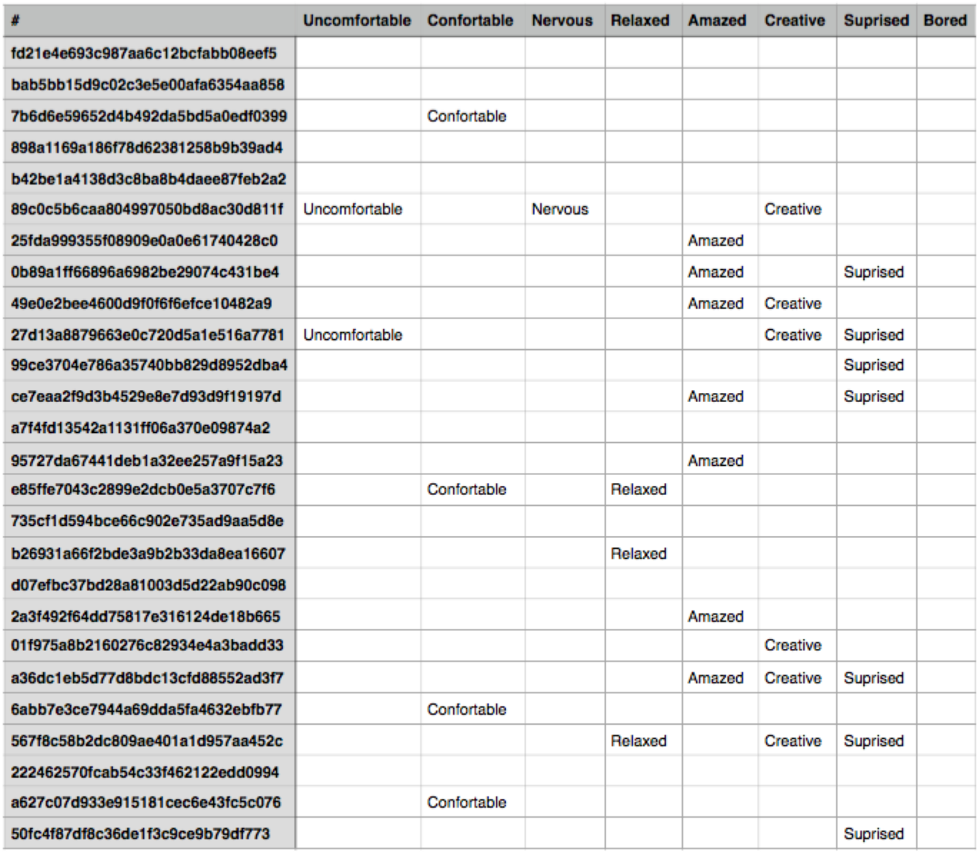
25 out of 26 people answered this question

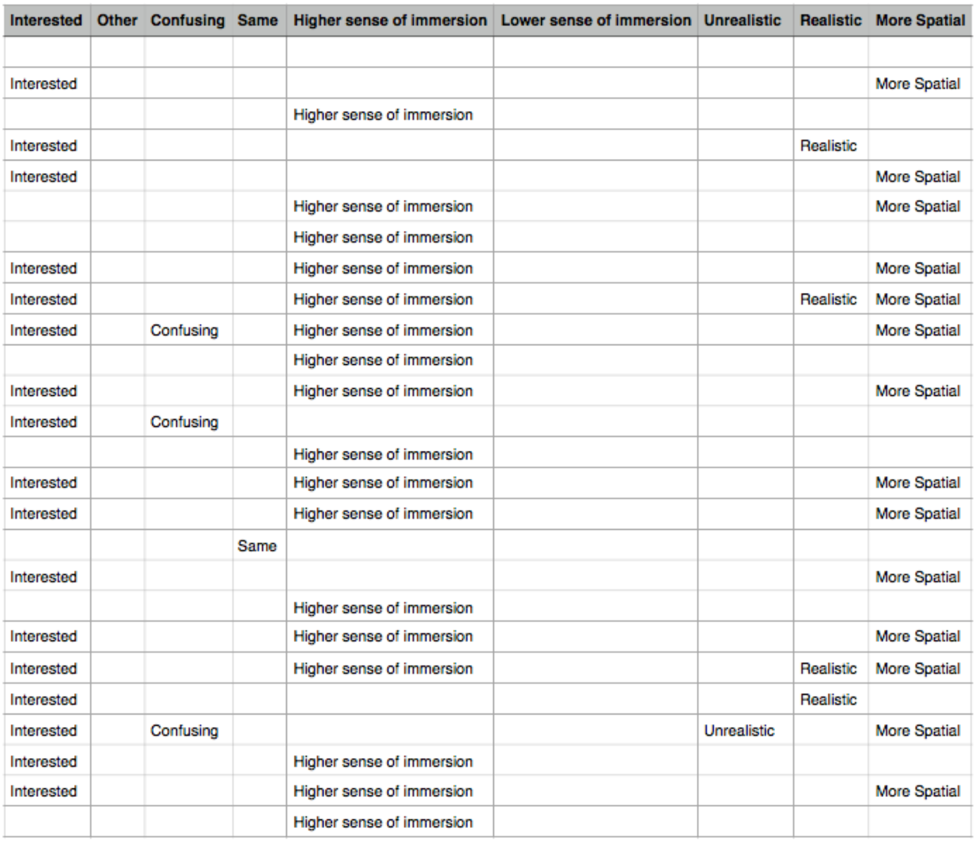
1	Will Consider	15 / **60%**
2	Could Consider	10 / **40%**
3	Other	1 / **4%**
4	Always	0 / **0%**
5	Never	0 / **0%**
6	Often	0 / **0%**

1.1.6

User’s comments

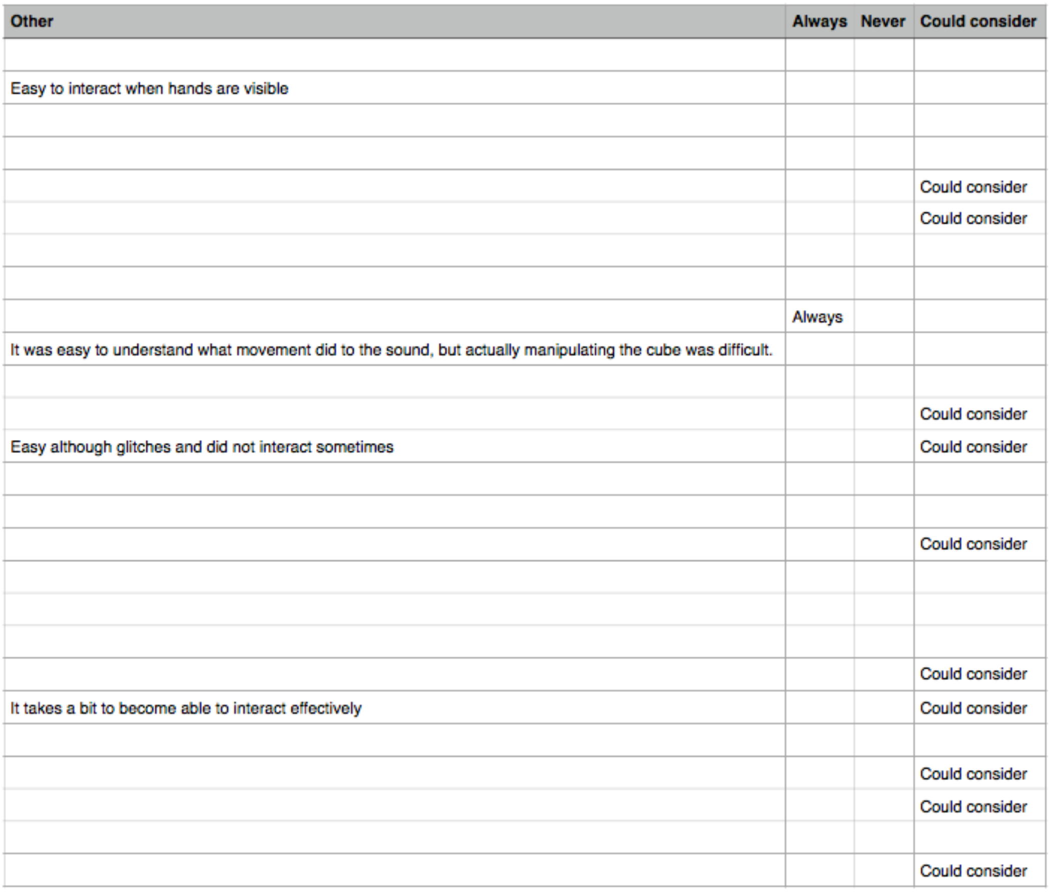
Table 1



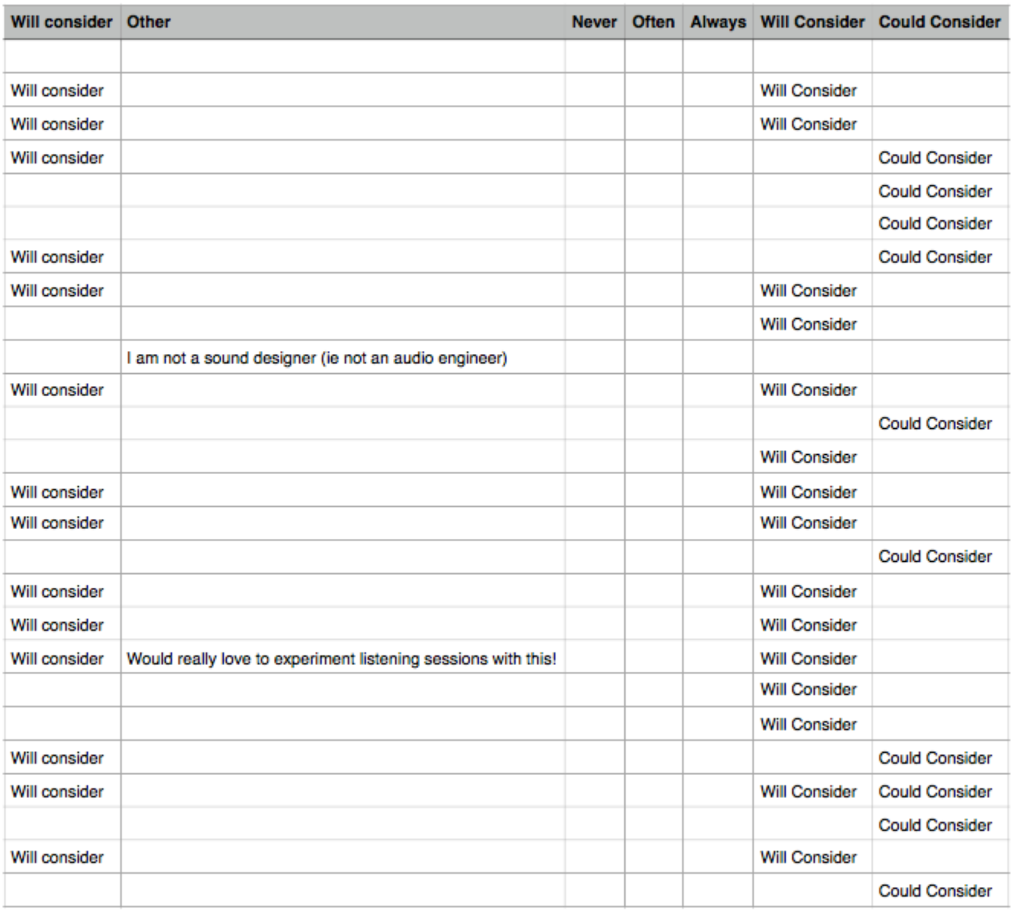


#	Uncomfortable	Confortable	Nervous	Relaxed	Amazed	Creative	Suprised	Bored	Interested	Other	Confusing	Same	Higher sense of immersion	Lower sense of immersion	Unrealistic	Realistic	More Spatial
fd21e4e693c987aa6c12bcfabb08eef5																	
bab5bb15d9c02c3e5e00afa6354aa858									Interested								More Spatial
7b6d6e59652d4b492da5bd5a0edf0399		Confortable											Higher sense of immersion				
898a1169a186f78d62381258b9b39ad4									Interested							Realistic	
b42be1a4138d3c8ba8b4daee87feb2a2									Interested								More Spatial
89c0c5b6caa804997050bd8ac30d811f	Uncomfortable		Nervous			Creative							Higher sense of immersion				More Spatial
25fda999355f08909e0a0e61740428c0					Amazed								Higher sense of immersion				
0b89a1ff66896a6982be29074c431be4					Amazed		Suprised		Interested				Higher sense of immersion				More Spatial
49e0e2bee4600d9f0f6f6efce10482a9					Amazed	Creative			Interested				Higher sense of immersion			Realistic	More Spatial
27d13a8879663e0c720d5a1e516a7781	Uncomfortable					Creative	Suprised		Interested		Confusing		Higher sense of immersion				More Spatial
99ce3704e786a35740bb829d8952dba4							Suprised						Higher sense of immersion				
ce7eaa2f9d3b4529e8e7d93d9f19197d					Amazed		Suprised		Interested				Higher sense of immersion				More Spatial
a7f4fd13542a1131ff06a370e09874a2									Interested		Confusing						
95727da67441deb1a32ee257a9f15a23					Amazed								Higher sense of immersion				
e85ffe7043c2899e2dcb0e5a3707c7f6		Confortable		Relaxed					Interested				Higher sense of immersion				More Spatial
735cf1d594bce66c902e735ad9aa5d8e									Interested				Higher sense of immersion				More Spatial
b26931a66f2bde3a9b2b33da8ea16607				Relaxed								Same					
d07efbc37bd28a81003d5d22ab90c098									Interested								More Spatial
2a3f492f64dd75817e316124de18b665					Amazed								Higher sense of immersion				
01f975a8b2160276c82934e4a3badd33						Creative			Interested				Higher sense of immersion				More Spatial
a36dc1eb5d77d8bdc13cfd88552ad3f7					Amazed	Creative	Suprised		Interested				Higher sense of immersion			Realistic	More Spatial
6abb7e3ce7944a69dda5fa4632ebfb77		Confortable							Interested							Realistic	
567f8c58b2dc809ae401a1d957aa452c				Relaxed		Creative	Suprised		Interested		Confusing				Unrealistic		More Spatial
222462570fcab54c33f462122edd0994									Interested				Higher sense of immersion				
a627c07d933e915181cec6e43fc5c076		Confortable							Interested				Higher sense of immersion				More Spatial
50fc4f87df8c36de1f3c9ce9b79df773							Suprised						Higher sense of immersion				

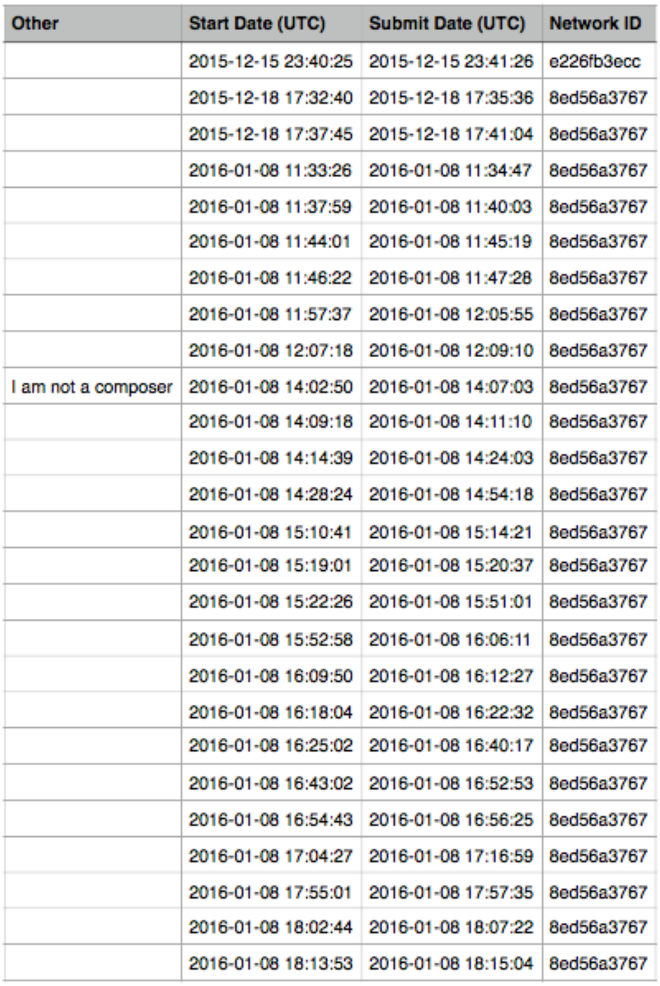
Less Spatial	Other	Easy to interactive	Diffucult to interact	Very interactive	Not interactive
			Diffucult to interact		
		Easy to interactive			
			Diffucult to interact		
			Diffucult to interact		
			Diffucult to interact		
		Easy to interactive			
				Very interactive	
				Very interactive	
		Easy to interactive			
				Very interactive	
				Very interactive	
		Easy to interactive			
				Very interactive	
			Diffucult to interact		
		Easy to interactive			
		Easy to interactive			
		Easy to interactive			
			Diffucult to interact		
			Diffucult to interact	Very interactive	
			Diffucult to interact		
			Diffucult to interact		
			Diffucult to interact		



Other	Always	Never	Could consider
Easy to interact when hands are visible			
			Could consider
			Could consider
	Always		
It was easy to understand what movement did to the sound, but actually manipulating the cube was difficult.			
			Could consider
Easy although glitches and did not interact sometimes			Could consider
			Could consider
			Could consider
It takes a bit to become able to interact effectively			Could consider
			Could consider
			Could consider
			Could consider



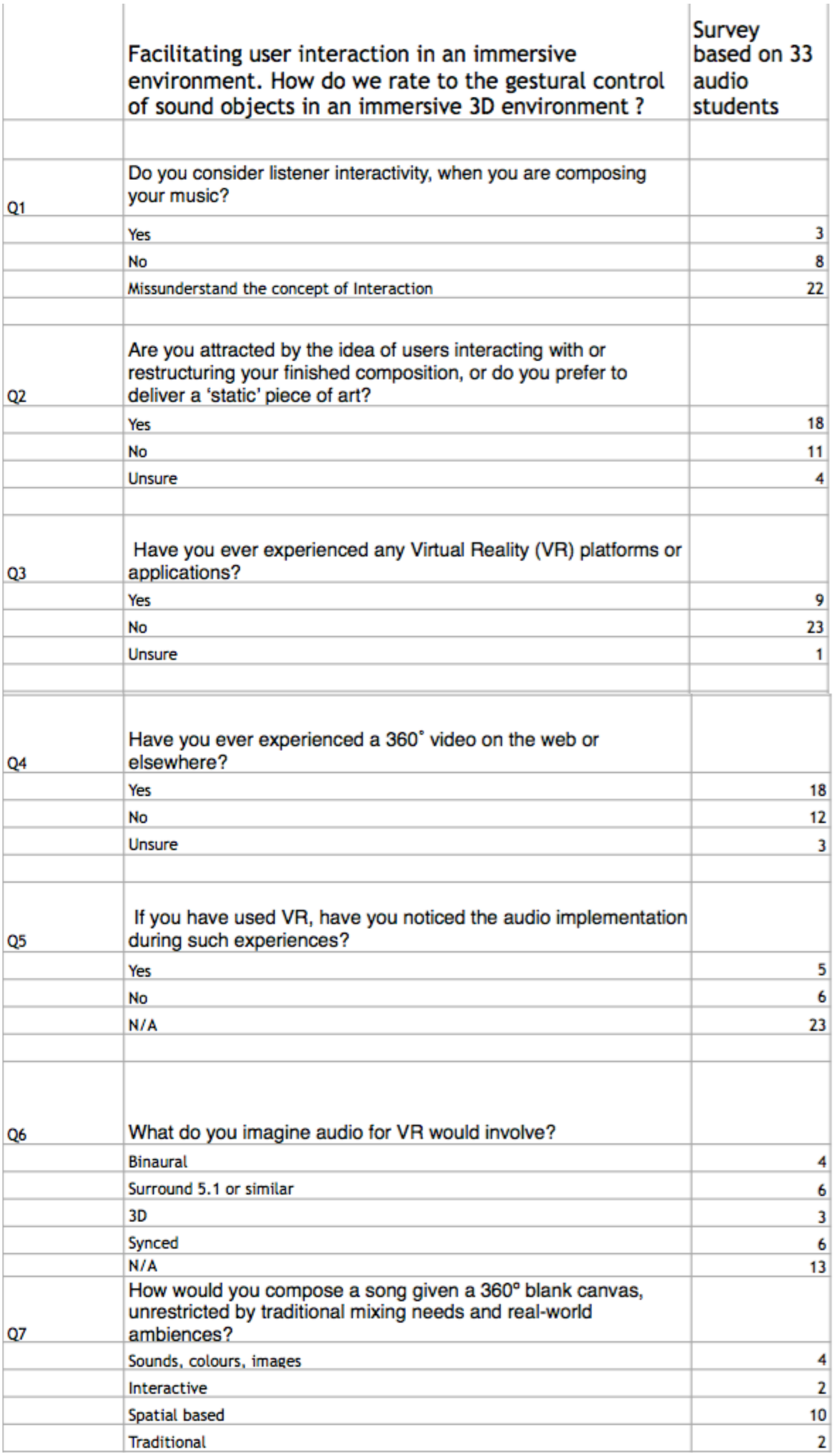
Will consider	Other	Never	Often	Always	Will Consider	Could Consider
Will consider					Will Consider	
Will consider					Will Consider	
Will consider						Could Consider
						Could Consider
						Could Consider
Will consider						Could Consider
Will consider					Will Consider	
					Will Consider	
	I am not a sound designer (ie not an audio engineer)					
Will consider					Will Consider	
						Could Consider
					Will Consider	
Will consider					Will Consider	
Will consider					Will Consider	
						Could Consider
Will consider					Will Consider	
Will consider					Will Consider	
Will consider	Would really love to experiment listening sessions with this!				Will Consider	
					Will Consider	
					Will Consider	
Will consider						Could Consider
Will consider					Will Consider	Could Consider
						Could Consider
Will consider					Will Consider	
						Could Consider



Other	Start Date (UTC)	Submit Date (UTC)	Network ID
	2015-12-15 23:40:25	2015-12-15 23:41:26	e226fb3ecc
	2015-12-18 17:32:40	2015-12-18 17:35:36	8ed56a3767
	2015-12-18 17:37:45	2015-12-18 17:41:04	8ed56a3767
	2016-01-08 11:33:26	2016-01-08 11:34:47	8ed56a3767
	2016-01-08 11:37:59	2016-01-08 11:40:03	8ed56a3767
	2016-01-08 11:44:01	2016-01-08 11:45:19	8ed56a3767
	2016-01-08 11:46:22	2016-01-08 11:47:28	8ed56a3767
	2016-01-08 11:57:37	2016-01-08 12:05:55	8ed56a3767
	2016-01-08 12:07:18	2016-01-08 12:09:10	8ed56a3767
I am not a composer	2016-01-08 14:02:50	2016-01-08 14:07:03	8ed56a3767
	2016-01-08 14:09:18	2016-01-08 14:11:10	8ed56a3767
	2016-01-08 14:14:39	2016-01-08 14:24:03	8ed56a3767
	2016-01-08 14:28:24	2016-01-08 14:54:18	8ed56a3767
	2016-01-08 15:10:41	2016-01-08 15:14:21	8ed56a3767
	2016-01-08 15:19:01	2016-01-08 15:20:37	8ed56a3767
	2016-01-08 15:22:26	2016-01-08 15:51:01	8ed56a3767
	2016-01-08 15:52:58	2016-01-08 16:06:11	8ed56a3767
	2016-01-08 16:09:50	2016-01-08 16:12:27	8ed56a3767
	2016-01-08 16:18:04	2016-01-08 16:22:32	8ed56a3767
	2016-01-08 16:25:02	2016-01-08 16:40:17	8ed56a3767
	2016-01-08 16:43:02	2016-01-08 16:52:53	8ed56a3767
	2016-01-08 16:54:43	2016-01-08 16:56:25	8ed56a3767
	2016-01-08 17:04:27	2016-01-08 17:16:59	8ed56a3767
	2016-01-08 17:55:01	2016-01-08 17:57:35	8ed56a3767
	2016-01-08 18:02:44	2016-01-08 18:07:22	8ed56a3767
	2016-01-08 18:13:53	2016-01-08 18:15:04	8ed56a3767

1.1.7

Results data from the survey of thirty-three audio engineering students



	Facilitating user interaction in an immersive environment. How do we rate to the gestural control of sound objects in an immersive 3D environment ?	Survey based on 33 audio students
Q1	Do you consider listener interactivity, when you are composing your music?	
	Yes	3
	No	8
	Missunderstand the concept of Interaction	22
Q2	Are you attracted by the idea of users interacting with or restructuring your finished composition, or do you prefer to deliver a 'static' piece of art?	
	Yes	18
	No	11
	Unsure	4
Q3	Have you ever experienced any Virtual Reality (VR) platforms or applications?	
	Yes	9
	No	23
	Unsure	1
Q4	Have you ever experienced a 360˚ video on the web or elsewhere?	
	Yes	18
	No	12
	Unsure	3
Q5	If you have used VR, have you noticed the audio implementation during such experiences?	
	Yes	5
	No	6
	N/A	23
Q6	What do you imagine audio for VR would involve?	
	Binaural	4
	Surround 5.1 or similar	6
	3D	3
	Synced	6
	N/A	13
Q7	How would you compose a song given a 360º blank canvas, unrestricted by traditional mixing needs and real-world ambiences?	
	Sounds, colours, images	4
	Interactive	2
	Spatial based	10
	Traditional	2

Q8	What problems would you expect in composing for a 360° blank canvas?	
	Perception of volume level	4
	Perception of volume pan	2
	Perception of space	5
	Perception of direction	3
	Perception of front	2
	Pashing	1
	Making it feel real or believable	3
	Needing content to fill the all space	3
	Technical	3
	N/A	7
Q9	How do you think you'd have to change your working methods to compose audio for VR?	
	Consider Interaction	1
	Consider Narrative	1
	Consider Spatiality	8
	Making it feel real or believable	2
	more freedom, nn real world restriction	3
	Technical	3
	None	2
	N/A	12

Q10	When you listen to music do you feel you are on the outside looking in, or are you fully immeshed in the sound environment?	
	In - Fully immersed	19
	Out - nn Immersed	3
	Depending on reproduction (Headphones, speakers, mix)	7
	N/A	4
Q11	Does it change for different types of music?	
	Yes	23
	No	6
	Song not genre	2
	Environment	2
	N/A	
Q12	How would you interact with a 3D immersive environment?	
	Depending on the environment	1
	Interaction	8
	In need of details	1
	Same as in real life	3
	Any available options	1
	more freedom, nn real world restriction	1
	N/A	18

2. Appendix (Digital)

2.1 CD/DVD content

Max/MSP/Jitter prototype's patch
Tutorial Video

2.2 Cycling 74 forum's conversations and resources

Conversations between Francesco Redente and Graham Wakefield (Oculus Rift/Jitter Developer). Date - from May/2015 to December/2015

https://cycling74.com/forums/topic/oculus-rift/

Conversations between Francesco Redente and Jakob Hougaard Andersen (FFT-based binaural panner developer) Date - from October/2015 to December/2015

https://cycling74.com/toolbox/fft-based-binaural-panner/#.VpeGD5OLSHo

Conversations between Francesco Redente and Rob Ramirez (Cycling 74 developer)
Date - October/2015

https://cycling74.com/forums/topic/jit-phys-multiple-reposition-but-forces-are-reset/

Max/MSP/Jitter Documentation and Resources updated by Rob Ramirez

https://cycling74.com/wiki/index.php?title=Position_Rotation_and_Scaling_on_Matrix_Data

Glossary

Ames: NASA research centre.

API: Application programming language.

Attributes: commands used to set the specific behaviour of Max/MSP/Jitter's objects.

CIPIC: Center for Image Processing and Integrated Computing.

Jit: Abbreviation of Jitter, used by Max/MSP's Jitter objects.

Jitter: Max/MSP's library responsible for graphical processing commands via OpenGL.

FFT: Fast Fourier transform, a simplified method to implement a mathematical formula in oder to calculate the frequency, phase, and amplitude of a periodic wave's sinusoidal components.

HCI: Human Computer Interaction.

HMD: Head mounted display.

IRCAM: *Institut de Recherche et Coordination Acoustique/Musique* - (Institute for Research and Coordination Acoustic / Music).

MSP: Max signal processing.

Objects: The building blocks used by Max/MSP/Jitter to create a patch.

OpenGL: Open graphic library. A computer language responsible to send graphic based commands to the computer's graphic hardware, the latter responsible for the rending and drawing of 2D and 3D images on a computer's screen.

Patch: Max document or program, consisting of visual objects which are connected tother using patch cords.

R&D: Research And Development

SDK: Software Development Kit

UI: User Interface

UX: User Experience

VIEWlab: Virtual Environment Workstation Project by NASA