Designing the Stereoscopic 3D Media Soundscape: An Exploration of the Perceptual Effects of Auditory Cues on Stereoscopic 3D Presentations

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The European Conference on Media, Communication & Film 2019
Official Conference Proceedings

Abstract
Assisted by the technological advances of the past decades, stereoscopic 3D media are currently making another attempt to be established as mainstream forms of entertainment. Arguably, the main focus of this effort is placed on the creation of immersive 3D visual worlds. However, with few exceptions, little attention has been given so far to the potential effect of the soundtrack on such media forms. The potential of sound both as a means to enhance the impact of the 3D visual information and to expand the 3D world beyond the boundaries of the visuals is large. In this context, we highlight some of the challenges 3D content producers face. Then, we propose a number of ways in which the soundtrack can be used to complement 3D media productions. These propositions are based on the unique spatial characteristics of stereoscopic 3D media and cover considerations on the spatial orientation of the soundtrack, the use of audio cues to direct visual attention, to support camera and 3D object movements as well as 3D material editing. Finally, we report on the results of a series of experiments we ran exploring the effectiveness of specific auditory cues in 3D audiovisual presentations. Results, although not conclusive, indicate that some of the studied auditory cues can influence the audience judgement of depth and immersion in 3D animation scenes, sometimes in unexpected ways. We conclude that 3D media content creation can benefit from further studies on the effectiveness of specific sound design techniques to enhance space perception and immersion.

Keywords: 3D, audio, sound, soundscape, soundtrack, stereoscopic

Introduction

Stereoscopic 3D media have a long and rather troubled history with many failed attempts to be established as a mainstream form of entertainment. Supported by the vast technological advances of the past decades, the format seems to be gaining traction and finding its place in the broader media and entertainment context. From the perspective of content creation, the introduction of stereoscopic visual cues brings its own unique requirements and challenges that could also affect the soundtrack. In a broader context, this study is an exploration of possible sound design approaches and techniques that could be used in the context of stereoscopic 3D media content creation in order to support and enhance the unique characteristics of the visual format.
The research question of the study was the following:

- Could sound designers utilise auditory cues as a means to affect the perception of the stereoscopic 3D visual space?

In relation to this, the aims set for the project were:

- To investigate possible ways of constructing soundscapes that support and enhance the unique spatial characteristics of the stereoscopic 3D media environment.
- To investigate the effectiveness of the proposed ideas through a number of experimental perceptual tests.

During the early stages of the study, we proposed that the unique spatial characteristics of the stereoscopic 3D visuals should be taken into account and we focused on the spatial orientation of the soundtrack. Some of the ideas we explored were the use of auditory cues to support or influence the perceived sense of depth of stereoscopic 3D environments or objects, to direct visual attention, to support camera and 3D object movements as well as to support 3D material editing and scene transitions.

In order to evaluate the effectiveness and validity of some of these ideas, a number of experiments were carried out studying whether the alteration of specific auditory cues within the soundtrack could influence the perceived sense of depth and distance of stereoscopic 3D objects and environments (Manolas & Pauletto, 2014). The parameters studied in these experiments were volume and high frequency content alteration. The results, although not conclusive, indicated that under certain circumstances a volume level increase of the soundtrack could affect the perceived depth of the stereoscopic 3D scene positively. Although this was in contrast with the initial assumption it was an interesting finding, as such a correlation could be a useful depth perception tool when designing soundtracks for stereoscopic 3D media.

This observation led to another round of comparative tests that is currently in progress. The tests were designed to further explore the effectiveness of volume level alteration as a means to influence sensory immersion in the stereoscopic 3D environment from the perspective of the audience. Preliminary results indicate that under certain conditions, increased volume levels are perceived to have a positive effect on the overall spatial perception of, and sensory immersion in, the stereoscopic 3D environment.

The ideas and auditory cues studied so far are only a few out of a large number of parameters that can be explored. As such, we propose that future work may expand upon these ideas and study a larger number of temporal, spectral or spatial auditory cues and alternative sound design techniques in the context of stereoscopic 3D media production. The effects of musical cues may also be an interesting area for further study. Finally, we propose that some of the ideas related to sound design for stereoscopic 3D content could be also studied in the context of virtual reality, an inherently stereoscopic medium.

The Resurgence of Stereoscopic 3D Media

The idea of adding the illusion of realistic depth to visuals has been a prominent and long-lasting obsession of cinema inventors for a long time. Such a feature had been already achieved for still photographs long before the invention of cinema in the form of *stereoscopy* and it did not take long for early cinema inventors to introduce this technique to the moving images of cinema (Zone, 2007; Thompson & Bordwell, 2003). Leading early cinema figures, such as Thomas Edison and the Lumière brothers, appear to have been interested in giving *a stereoscopic effect to the pictures* as early as in the 1890s (Zone, 2007).

From these early experiments and until the early 1950s, a number of attempts were made towards the production and exhibition of stereoscopic 3D movies using various techniques. However, as '*the short stereoscopic films of the novelty period* [1838 to 1952] *were characterized by an emphasis on the technology of 3D or the "gimmick" of the off-the-screen imagery'* (Zone, 2007, pp. 1-2) they failed to be established as a long-term, commercially viable form of entertainment after their novelty value faded.

The next significant collective attempt to introduce the stereoscopic 3D format to the masses can be traced to the early 1950s (Cousins, 2004; Zone, 2007). Between 1952 and 1955, a '*protean 3D movie boom'* (Zone, 2007, p. 2) took place in Hollywood, with more than fifty stereoscopic films being released. However, stereoscopic 3D cinema failed again to be permanently established, for various reasons, such as the *'cumbersome, extremely hot filming conditions'* (Cousins, 2004, pp. 223-224) caused by the large amount of lights needed on the sets for such productions and the awkwardness of the glasses.

Despite the fact that stereoscopic cinema failed to become established as a widely accepted cinematic format on several occasions, the idea of using the stereoscopic medium for creative purposes survived. Over the past decades, stereoscopic 3D cinema made a strong commercial comeback that may be more than just a fading trend. At the same time, other forms of media utilising stereoscopic 3D visual cues, such as bespoke multi-sensory attractions and virtual reality systems have entered the mainstream media sector (DisneyWorld, 2019; CJ4DX, 2019; Merlin Entertainments, 2019; HTC Corporation, 2019). Supported by the power of modern digital systems, stereoscopic 3D technologies have overcome most of the major drawbacks of the past and seem to be gaining momentum. In this context, questioning whether such emerging stereoscopic 3D media formats would benefit from production techniques and approaches that are different to the ones used in traditional 2D media becomes relevant.

Unique Characteristics of the Stereoscopic 3D Medium

In order to consider new and creative ways to support storytelling in stereoscopic 3D media through sound design, one may need to consider the spatial characteristics of the stereoscopic 3D environment. The stereoscopic effect is based on stereopsis, the use of differences between the visual information on the left and right eyes '*to get a strong impression of depth'* (Snowden & Troscianko, 2006, pp. 200-204). In terms of the physical delivery of stereoscopic 3D content in its more common form (e.g. through projection or display of images on a screen), as the two different stereoscopic image streams (left and right eye) are actually projected onto the screen, the stereoscopic 3D space is shaped by the screen borders. The result is a viewing space '*more like a pyramidal box'* (Mendiburu, 2009, p. 27) in front of the viewer frequently referred to as the *Stereoscopic Window* (Clark, 2010; Autodesk, 2008) (Figure 1).

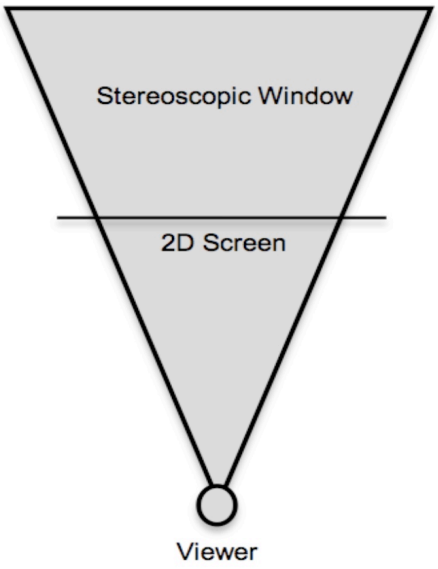

Figure 1: The Stereoscopic Window

One of the reasons that make this unique spatial layout important is that it greatly affects decisions regarding shot composition, camera placement and camera movement. In 3D '*you have to think in terms of volume composition, instead of picture composition'*, as '*you will box the action more than you will frame it'* (Mendiburu, 2009, p. 92). For example, in order '*to take advantage of the unique capabilities of 3D, scenes may be composed in a way that emphasizes the depth of the set'* (Clark, 2010, p. 8). This might include shots consisting of more depth layers or particular camera placements in order to stress the enhanced depth of the visual environment.

Another important concept related to the spatial characteristics of the stereoscopic 3D media production is that the use of selective focus to '*direct the viewer's eyes to the key point'* does not work in stereoscopic 3D in the same manner as it does in 2D (Bayon, 2010; Lelyveld, 2009). Subtle use of selective focus is possible and it is

successfully utilised in commercial 3D media releases (Gardner, 2009). However, out-of-focus portions of a 3D scene could also create *visual confusion* and *discomfort* (Bayon, 2010; Lelyveld, 2009). This results in content creators frequently avoiding the use of selective focus as an attention-guiding device. In such cases, other visual means are commonly used, such as stronger lighting and color cues or drastic changes in the structure of the shot composition (Bayon, 2010; Clark, 2010). In this case too, the reduced effectiveness of selective focus can affect creative and aesthetic decisions.

Finally, post-production, and in particular editing, could be affected by the introduction of stereoscopic cues (Mendiburu, 2009; Autodesk, 2008). Traditional editing techniques that work well in 2D are not guaranteed to be as effective in 3D, while new ones, specifically designed for 3D editing, could be established. For instance, the presence of stereoscopic depth cues creates the need for longer playing time of particular scenes or sequences (Clark, 2010; Bayon, 2009) that should also be '*blended together at a slower pace'* (Mendiburu, 2009, pp. 26, 151). This is in sharp contrast to the increasingly faster editing pace commonly used in modern 2D productions (Kerins, 2006). Additionally, scene cuts or transitions have to conform to certain rules related to stereoscopic depth, a concept commonly known as *depth continuity*. Viewers have to readjust their point of focus (or convergence) between scenes that employ different stereoscopic depth, which has to be matched during editing (Clark, 2010; Lelyveld, 2009). This is something that could make stereoscopic 3D editing different to 2D.

Soundscape Orientation

While setting the context for this project, one of the main ideas we explored was that soundtrack mixes for stereoscopic 3D content are likely to be in need of a pronounced front-to-back orientation (Figure 2). In addition to matching the visuals orientation, such an audio spatialisation approach is less likely to draw the viewers' attention towards the borders of, or outside, the stereoscopic window.

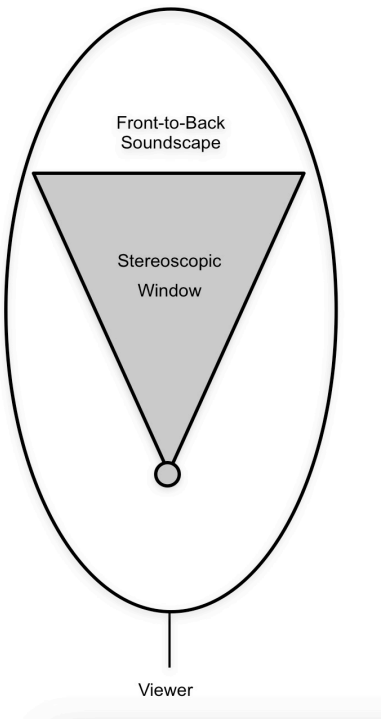

Figure 2: Soundscape orientation

Distracting the viewers/listeners' attention from the screen is a heavily discussed concern in 2D filmmaking (Chion, 1994; DeLancie, 2000; Kerins, 2011). In stereoscopic 3D these effects could be even greater, as the edges of the stereoscopic window *'are dangerous places where images can be painful'* (Mendiburu, 2009, pp. 27, 87, 92). A front-to-back sound spatialisation approach is likely to keep the viewers/listeners' attention to the safer parts of the stereoscopic 3D space: the front and centre of the stereoscopic window and, possibly, the rear where the viewer/listener is unlikely to turn and look at as long as the visual content is projected on a screen in the front.

Observer-target Distance

We propose that a possible way to expand the sense of depth (e.g. front-to-back orientation) of the soundtrack mix is to introduce sound objects with strong or exaggerated distance cues (Turner, Berry & Holliman, 2011; DeLancie, 2000). By altering the timbral and dynamic characteristics of audio objects their perceived distance from the viewer could be increased or decreased as required (Kaye & Lebrecht 2009; Mastoropoulou, 2006). As distance perception is a multimodal process greatly affected by auditory cues, it is proposed that this audio processing technique could also affect the impression of depth of the stereoscopic 3D environment as a whole (Turner et al., 2011) (Figure 3). For example, let us consider a scene where characters are located around the viewer and at various distances. Characters appearing at a given stereoscopic visual depth within the stereoscopic window could seem more intimate to the audience if the sounds they produce are dry, loud and at their full frequency range.

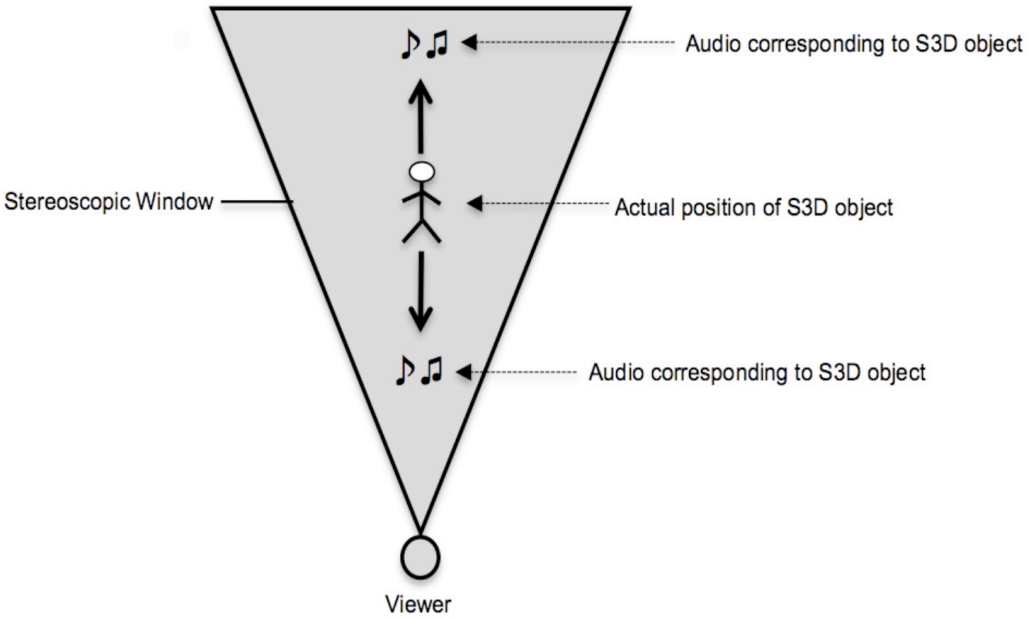

Figure 3: Auditory distance cues as a means to affect S3D object distance perception

Similarly, sounds produced by characters further away from the viewer could be filtered (e.g. attenuate high frequencies), quieter and with a certain amount of reverberation added (Kaye & Lebrecht, 2009). This is in line with relevant research exploring whether the introduction of distinctive audio samples could significantly affect the viewers' perception of stereoscopic visual depth of a given stereoscopic 3D object. Turner et al. (2011) reported results that indicate that audio depth cues have the ability to influence the depth perception of stereoscopic 3D visuals. Manolas and Pauletto (2014) reported that, in scenes with relatively simple stereoscopic 3D visual background, volume level alteration could affect the perception of depth of the scene from the perspective of the viewer/listener. Additionally, a mixture of sound objects representing characters located at different distances from the viewer can be panned to the rear. This could perceptually expand the cinematic world backwards enhancing the overall immersion of the scene.

The use of audio distance cues in cinema is not a new concept. Filtering, reverberation and volume level control have been consistently used in cinema for the enhancement of depth perception. However, such audio processes could be more important in an environment heavily based on visual depth cues, such as in stereoscopic 3D media, than they are in 2D.

Camera and Visual Object Movements

One of the most commonly exploited features of stereoscopic 3D media is the *viewer space* effect (Autodesk, 2008). This term refers to the creation of the illusion of front-to-back/back-to-front visual object movements between the viewer and the actual screen. It is suggested that this may also create a need for strong corresponding sound movements within the soundscape, in order for these visual movements to become more pronounced and imposing. Content creators and sound designers have been using appropriate sound spatialisation to create the broadly known *fly-over effects* for decades (Vanhoutte, Joris, Debackere and Wynants, 2010; Nudds, 2007). However, such uses of sound are rather limited and used selectively in contemporary stereoscopic 3D productions. In many instances, the *viewer space* objects are silent. The reason for this could be that fly-over effects can be distracting when viewing 2D versions of the visuals that use the same soundtrack of the 3D version. Admittedly, not every visual object or action within the story world needs to be consistently supported by a corresponding sound event. However, in the case of viewer space effects, the aesthetic intention is arguably to create the illusion that the objects are actually moving within the viewing space. This illusion could be enhanced and/or extended beyond the viewing space if the movement was supported by the corresponding fly-over sound effects, as '*our auditory experience of sounds commits us to the existence of objects.'* (Nudds, 2007, p. 37). We propose that viewer space visual object movements in stereoscopic 3D might benefit by the extensive and consistent accompaniment of corresponding and appropriate sound events (Woszczyk, Bech & Hansen, 1995).

The above concept could apply not only to the typical *viewer space* effects intended to surprise and impress the viewer, but also to various other 3D objects that have no particular narrative or emotional significance, and that appear to move within the viewing space as the camera moves through the stereoscopic 3D world. For example, let us consider a scene that takes place inside a forest. As the camera moves through

the forest with a forward direction, subtle symbolic or realistic sounds could accompany the trees movements across the theatre space (Figure 4). As the trees exit the stereoscopic window the sounds could be panned to the rear, expanding the

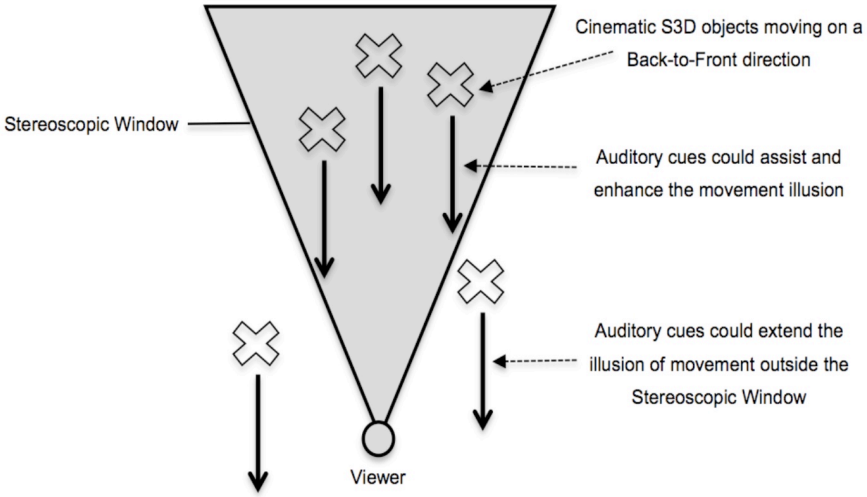

Figure 4: Auditory object movements

cinematic world backwards. This could be used to create a sense of the viewer actually traveling through the forest while leaving the trees behind. Such a use of sound could accentuate the apparent movement of the camera and enhance the overall sense of immersion of the scene (Woszczyk et al., 1995; Nudds, 2007).

Visual Focus Within the Stereoscopic Window

Guiding the viewers' attention to particular visual objects or areas within a scene is a different task in stereoscopic 3D than it is in 2D (Bayon, 2010; Mendiburu, 2009). To a large extent, this is because *selective focus* and *depth of field* do not work in 3D as effectively as in 2D (Clark, 2010; Lelyveld, 2009; Bayon, 2010), although such techniques have proven to be possible in stereoscopic 3D productions. From a practical perspective, a reduced control over selective focus is arguably an undesired feature. This is because content creators, in most occasions, need to guide the viewers' visual attention to particular areas or subjects of a given scene. Considering that human visual attention and localisation are multisensory perceptual processes that rely heavily on audition (Mastoropoulou et al., 2005), we propose that strong direction and distance audio cues could be used as a visual attention-guiding device. This is especially relevant when large-format projection screens or stereoscopic environments are used (Lantz, 2006; British Film Institute, 2019). Taking into account that modern cinematic audio systems have increased spatialisation capabilities, it is expected that the required level of control over the positioning of sounds across the stereoscopic window is possible. Additionally, modern audio technologies allow for detailed manipulation of the timbral and dynamic characteristics of the sound elements. This means that filmmakers could adjust not only the perceived position of the sound across the length of the viewing space, but also the perceived depth of these sources within the 3D environment. Therefore, the viewers' visual attention could be guided even more accurately towards the positions of visual objects within the 3D scene by means of appropriately processed audio cues.

In addition to position, what attracts attention is to make the sound of a certain object prominent in the mix. This can be done by choosing the sound carefully in relation to

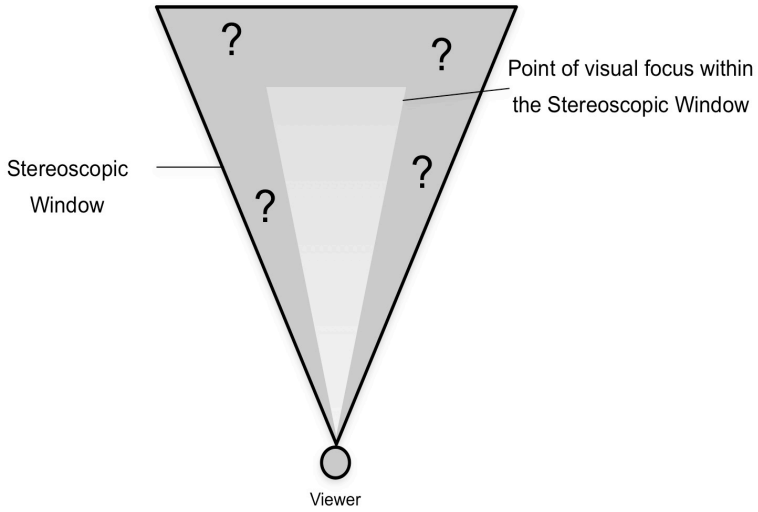

Figure 5: Visual focus within the Stereoscopic Window

what else is in the mix at the same time and balancing it appropriately. Although this is a rather common mixing task, it may become increasingly relevant in the context of stereoscopic 3D productions. In addition, increased levels of attention and detail may be required while working with this aspect of mixing for stereoscopic 3D media as opposed to 2D.

Scene Transitions

The introduction of stereoscopic cues affects decisions related not only to the spatial character of each scene, but also with how different scenes are combined together during editing (Autodesk, 2008; Mendiburu, 2009). For instance, a cut between a scene where the main object appears to be in front of the screen to one where it is far beyond it would be frequently avoided. This is because it can cause visual discomfort and confusion to the viewer (Mendiburu, 2009; Lelyveld, 2009). Stereoscopic 3D content creators usually take this into account during the preproduction and production phases and opt to adjust the depth of succeeding scenes according to a relevant *depth script* (Autodesk, 2008; Mendiburu, 2009). However, this compromises the options and the creative input of the editor, as direct cuts between existing scenes with great stereoscopic depth differences (commonly known as *jump cuts*) would be generally avoided. As an example, we propose that one possible way to achieve transitions between such scenes is a combination of visual fades with appropriate audio cross-fades. In particular, a gradual cross fade between the soundscapes of the two succeeding scenes can start before the first scene ends. The visuals of the first scene can then fade to black, while the soundscape of the second scene becomes prominent. The fact that the visuals fade to black is crucial here, as '*once we remove visual stimulus and surround ourselves with appropriate auditory cues immersion into a virtual environment is almost guaranteed'* (Haines & Hooker, 1997, p. 3). It is possible that by creating an appropriate soundscape that includes strong distance and directional cues the viewers' spatial perception of the cinematic

world can be manipulated (Chueng & Marsden, 2002). This could be viewed not merely as a transition from one soundscape to another, as is the case in many audio transitions in 2D, but as a transition from one acoustical space with its unique shape and dimensions to another. After the desired spatial expectation has been established by means of sound, the visuals of the second scene can fade in. This approach could assist in achieving two goals. Firstly, the creation of a more immersive and imposing transition effect. Secondly, the preparation of the audience for the change of stereoscopic 3D depth between the scenes, especially if the sound transition occurs slightly in advance of the visual one.

Experimental Perceptual Tests

In the context of this study, a number of perceptual tests were designed and carried out in order to evaluate the effectiveness and validity of some of the proposed sound design ideas. The first round of tests (Phase 1) focused on the use of auditory depth cues as a means of affecting the perception of depth within stereoscopic 3D animation presentations (Manolas & Pauletto, 2014). The tests studied two main distance-related auditory cues: high-end frequency loss and overall volume attenuation. Results, although not conclusive, indicated volume level alteration can influence the audience judgement of depth in stereoscopic 3D animation presentations, sometimes in unexpected ways. In particular, increased volume levels in some instances resulted in the stereoscopic 3D environment being perceived as having increased stereoscopic 3D depth. This was contrary to expectations, as in real life situation increased distance between the viewer/listener and the sound emitting object would result in a decrease of the volume levels of the sound emitted by the object. It is possible that the perception of stereoscopic 3D depth is influenced by a change in sensory immersion levels (Jones, 2018) caused by the increased volume levels of the soundtrack.

This observation led to another round of tests (Phase 2) that are currently in progress. These tests focus specifically on volume level alteration of elements, or the entirety, of the soundtrack with a view to influence the levels of sensory immersion and/or the perception of depth of the stereoscopic 3D visual environment. Preliminary results suggest that there may be substance to this claim, but this cannot be verified until the results of the tests are analysed.

In a broader context, these tests are aiming less at proving the validity of a certain idea and more on identifying general sound design approaches that seem to be efficient and useful in the context of stereoscopic 3D media production. As such, the tests should be regarded as a starting point for further experimentation with an increasing number of auditory cues and parameters that could be useful to stereoscopic 3D content creators rather than as a thorough study of specific audiovisual perceptual functions.

Further Work

In terms of potential directions for further study and the continuation of this work it is proposed that, in addition to volume and high frequency alteration, the effectiveness of other auditory cues could be tested. This could include spectral, temporal and spatial auditory cues, as well as their combinations. Such work would be valuable in

understanding and identifying the unique perceptual mechanisms that may be in place in the context of audiovisual presentations with stereoscopic 3D visual content.

In the same context, musical cues could be also tested, as there may be potential in utilising the musical stems of the soundtrack to affect perception of the stereoscopic 3D space. Such a relationship may not be instantly evident or obvious in a realistic sense, as our everyday life is not accompanied by relevant musicals cues. However, previous observations suggest that in the context of audiovisual media presentations perceptual mechanisms could work in unexpected and unique ways. Testing the perceptual effect of musical cues on the perception of stereoscopic 3D content in a systematic manner may provide useful insights in this direction.

Finally, ideas similar to the ones presented in this study may be also relevant in the virtual reality context. This stems from the notion of visual representation in virtual reality systems being inherently stereoscopic. As such, sound design techniques or ideas that are effective in other stereoscopic 3D media could potentially translate well to the virtual reality environment. However, as this particular medium is both more complex and realistic in terms of spatial representation, there is no guarantee that auditory cues would work in exactly the same way as in stereoscopic 3D media that utilise projection or display on a 2D screen. It may be, therefore, appropriate to study some of the proposed ideas in this context in order to understand whether certain sound design ideas and auditory cue alterations may be also appropriate for a medium utilising stereoscopic 3D visual content but also incorporating a strong sense of spatial realism.

Conclusion

Stereoscopic 3D media are in the process of being established as mainstream forms of entertainment. The main focus of this effort is placed on the creation of immersive 3D visual worlds. However, with few exceptions, little attention has been given so far to the potential effect of the soundtrack on such media forms. The potential of sound both as a means to enhance the impact of the 3D visual information and to expand the 3D world beyond the boundaries of the visuals is large.

In this context, we proposed a number of ways in which the soundtrack can be used to complement 3D media productions. These propositions are based on the unique spatial characteristics of stereoscopic 3D media and cover considerations on the spatial orientation of the soundtrack, the use of audio cues to direct visual attention, to support camera and 3D object movements as well as 3D material editing.

Finally, we report on the results of a series of experiments we ran exploring the effectiveness of specific auditory cues in 3D audiovisual presentations and on our current work in this direction. We conclude that stereoscopic 3D media content creation can benefit from further studies on the effectiveness of specific sound design techniques to enhance space perception and immersion and we identify potential areas for future work.

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