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User Experience of Stereo and Spatial Audio in 360° Live Music Videos

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ABSTRACT

360° music videos are becoming prevalent in music entertainment. Still, academic studies of the 360° live music experience covering both audio and visual experience are scarce. In this paper, we present a study of user experience of stereo and spatial audio in a 360° live music video setting with two different display types. The research was conducted in the form of a laboratory experiment, in which 20 participants watched and evaluated stereo and spatial audio versions of the same music video using a flat computer display and a head-mounted display (HMD). Based on the results, spatial audio combined with HMD scored highest in the quantitative metrics of perceived audio quality, presence, and overall listening experience. However, qualitative findings reveal that this combination of spatial audio and HMD does not fit well with the participants' listening habits. While nine participants preferred to use headphones to listen to music, thirteen participants viewed music listening as a secondary task – making the use of HMDs less suitable.

CCS CONCEPTS

• Human-centered computing~User studies • Human-centered computing~Virtual reality • Human-centered computing~Sound-based input / output • Human-centered computing~Laboratory experiments

KEYWORDS

User experience, 360° video, Music video, Virtual reality, Head-mounted display, Spatial audio, Ambisonics, Stereo

1 Introduction

Virtual Reality (VR) technology offers an attractive medium for providing multisensory experiences for people of all ages. VR has already been used for a variety of purposes, including industrial applications, education [31], travel [6], healthcare [24], and naturally entertainment (games, 360° videos, etc.). As with any novel technology, user experience (UX) is an important factor to consider when aiming at acceptable systems and services. By UX we mean users' perceptions and reactions to the use and anticipated use of the technology-mediated system [18].

During 2016-2017, the first author of this paper worked for Nokia Technologies doing UX design for the OZO Live (currently Imeve Live [17]) product. In collaboration with Tampere University of Applied Sciences (TAMK), we attended several live concerts, conducted live broadcasts, and edited several multi-camera 360° videos in post-production. To make sure that our workflows and solutions were equally efficient for different types of music, we worked with various Finnish bands including Nightwish, Steve 'N' Seagulls, Amorphis, The 69 Eyes, Popeda, and Hurriganes,

While most of the post-production work also involved spatial audio, its benefits were not always that clear. Many bands still wanted to use conservative stereo mixes, there were many of interoperability issues, and making spatial audio mixes was more expensive than stereo mixes. So, the practical question is, is spatial audio still worth producing? The related scientific research questions are: ***1) How do users experience spatial audio compared to stereo audio in 360° music videos? and 2) How do listening habits impact the user experience of spatial audio in 360° music videos?***

In this paper, we present the results of a study investigating the user experience of stereo and spatial audio in a 360° music video setting, viewed both using a flat computer display and a head-mounted display (HMD).

2 Background and Related Work

While 360° music videos are becoming prevalent in music entertainment, academic studies of the 360° live music experience, covering both audio and visual experience, are still scarce. Studies such as [23], [21], and [1] do not cover the research presented in this paper.

2.1 Audio in 360° Videos

360° videos are special video recordings, where a view in every direction is recorded at the same time, capturing the entire sphere

around the camera. The videos are typically recorded using a dedicated omnidirectional camera (e.g., Nokia OZO or Insta360 Pro) or a rig of multiple cameras. After recording, the overlapping angles are "stitched" together, i.e., merged into one spherical video, either by the camera itself or using dedicated video editing software. [32][22]

360° videos can be consumed using various devices including computers, mobile devices, and HMDs. During the playback, the user can control the viewing direction by, e.g., moving his/her head, moving the device, or clicking and dragging on the screen. In addition to web browsers, YouTube, Facebook and Vimeo, various applications from smaller companies now support the playback of 360° videos.

The audio track of a 360° video is typically stereo or spatial, with the latter gradually increasing in popularity as the quality and accessibility of suitable gear and software improves. In most cases, the only practical spatial audio format is Ambisonics [3], with first-order Ambisonics still being the most common.

2.2 Examples of 360° Music Videos

Several interesting acted 360° music videos have already been created [2] [11]. For example, the Swiss musician Seven stitched together three different scenes where he is performing the same song in a different setting. The 360° video of School of Rock uses only one camera, but there is a lot of scripted action around it. OneRepublic, in collaboration with Nokia, took the concept further by moving a single OZO camera between two buildings, and shooting everything on one take.

In the case of live music, the situation is still slightly different. While some popular artists such as Metallica [25] and Quincy Jones [20] have experimented with live 360° videos, the quality has often been surprisingly low, a common problem being the non-optimal camera placements. Both stereo and spatial audio have been used, with stereo mixes still being more popular.

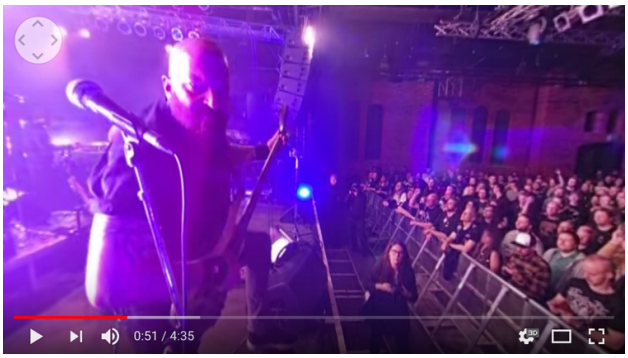

Figure 1: Screenshot from our Timo Rautiainen & Trio Niskalaukaus [29] 360° music video.

At the time of writing, the total number of our own 360° live music videos was approx. 20, the list of bands including, e.g., Steve 'N' Seagulls [35], The 69 Eyes [37], Nightwish [26], Timo Rautiainen & Trio Niskalaukaus [29], Tampere Philharmonic Orchestra [36], and Popeda [28]. In most of these videos, there is a different spatial audio mix for each camera location (as described in [14]), and if the cameras are moving, the audio "moves" as well (see, e.g., [29]).

2.3 Presence and Immersion

In the context of VR and 360° videos, term ***immersion*** refers to the characteristic of the display system [9]. It is affected by, e.g., isolation from the physical environment and the natural modes of interaction such as rotating one's head to look around [10]. Term ***presence***, on the other hand, refers to the individual human reaction to immersion. Presence "indicates the user's sense of being in the virtual environment, disassociated from the real world" [9].

Compared to flat screens such as mobile phones and computer displays, more immersive devices such as HMDs induce a greater feeling of presence [30] [9]. Several studies such as [4], [9] and [10] have already shown that 360° videos can be highly immersive. For example, Bindman et al. [9] studied presence in the context of animated 360° videos. However, to the best of our knowledge, presence and immersion have not yet been studied in the context of 360° live music videos.

Tse et al. [38] showed that in the case of HMD, the use of headphones increases presence as the viewer is then cut off from sounds emanating from the real world. This idea was also supported by their interview data. However, in the case of a mobile phone, the use of headphones decreased presence. Two potential explanations were given: 1) Some participants were used to viewing videos without headphones, and 2) "if a person is able to see things in their peripheral vision, but unable to hear the sound, that this is more distracting than if they heard that sound and chose to block it out to focus on the video."

In addition to the use HMDs and headphones, another way to increase presence is to use directional audio cues, i.e., to use spatial audio instead of a stereo soundtrack. As stated by Bala et al. [5], "sound often emerges as a helpful element in attracting viewers' attention in a 360° video". Sound can reduce the time required to locate objects [12], and binaural audio renderings can help spatial visual processing and localization [13]. In [33] Sheikh et al. showed that the combination of audio and visual cues can be more effective than visual cues alone.

3 Study on User Experience of Stereo and Spatial Audio in 360° Live Music Videos

When editing the multi-camera 360° live music videos, we were often faced with the same problem: While most of the work involved also spatial audio, its benefits were not always that clear. As many bands still wanted to stick with conservative stereo mixes, there were lots of interoperability issues, and making spatial audio mixes was more expensive than stereo mixes, was it still worth doing?

To study the user experience of stereo and spatial audio in a 360° live music video setting, we conducted a mixed-method laboratory study. The research questions were formulated as:

1) ***How do users experience spatial audio compared to stereo audio in 360° music videos?***
2) ***How do listening habits impact the user experience of spatial audio in 360° music videos?***

To conduct the tests, two different versions (stereo and spatial audio) of the song "Helvetin pitkä perjantai" [28] by a Finnish rock band called Popeda were created. Each version was a 4K, 3D and 360°, and cuts from one camera to another occurred roughly every 30 seconds. In the case of spatial audio (first-order Ambisonics), there was a different mix for each camera, while in the case of stereo, the audio remained always the same.

The empirical research was conducted in the form of a laboratory experiment consisting of evaluation, questionnaires, and a semi-structured interview. All 20 the participants (15 male, 5 female) were recruited from Tampere, Finland. They were 22-34 years old (mean=26), and nine of them played a musical instrument.

During the study, each participant watched four versions ("scenarios") of the 360° video:

- Flat computer display, 2D video, stereo audio
- Flat computer display, 2D video, spatial audio
- Head-mounted display, 3D video, stereo audio
- Head-mounted display, 3D video, spatial audio

The flat display variations were always presented first, followed by HMD. If the order had been randomized, the novelty effect of HMD would have affected the UX of the less novel computer display. In both cases, the two audio variations were played in a random order without telling the participants which one was playing.

After watching each video, the participants filled in a questionnaire focusing on their first impressions. A 7-point Likert scale was used. After watching all four videos, there was also a semi-structured interview focusing on the differences between the four scenarios. In total, each test lasted less than an hour.

The experiments took place in a room without external noise sources that could interfere with the experience. The audio was played using a pair of noise-cancelling headphones (Bose QuietComfort 35 Series I). For the computer display condition, a 27-inch Lenovo Ultra HD 4K monitor was used along with a 100 mbps network connection. For the HMD condition, two pieces (the 2nd one as a backup) of Samsung Gear VR were used with Samsung Galaxy S7 edge and Samsung Galaxy S8 mobile phones.

4 Quantitative Results

In this section, we discuss the results of the user evaluation questionnaires, which focused on participants' immediate experiences after watching each video, and resulted in a collection of quantitative data.

Figure 2: Snapshots from the different cameras of the "Helvetin pitkä perjantai" 360° music video [28].

4.1 Familiarity with Used Technology

To determine how familiar the participants were with the technologies used in the test, we used a 7-point Likert scale (1=not familiar, 7=familiar). For VR, 360° videos, 360° music videos and

spatial audio, the median scores were 3.0, 3.0, 1.0 and 2.0, signaling low familiarity with the used technologies. To be more accurate, 25% of the participants were completely unfamiliar with VR (giving a score of 1.0), 15% with 360° videos, 55% with 360° music videos, and 45% with spatial audio.

4.2 Listening Habits

None of test participants considered themselves a hi-fi listener; however, some expressed their wish to become one once it was within their means. 65% listened to music as a secondary or background task, but only when it did not interfere with their main task. Main tasks mentioned included, e.g., commuting, sports, cooking, studying, and working. This type of behavior is well in line with, e.g., the IFPI Music Consumer Insight Report [16]. Only 10% of participants explicitly dedicated time for listening to music, while for 25% the way of listening depended on their mood and situation.

As many as 45% of the participants preferred to use headphones when listening to music, while only 10% preferred loudspeakers. For 45% of the participants, the preferred setup depended on the listening context (e.g., commuting vs. meeting friends).

90% of the participants preferred audio-only experiences instead of, e.g., watching concerts or music videos. However, most participants expressed that they would watch a video clip if it was recommended by a friend, and sometimes even just out of curiosity.

4.3 Stereo vs. Spatial Audio

In this subsection, we illustrate the performance of stereo and spatial audio using three metrics: audio quality, presence (feeling of being on the stage), and overall listening experience. The results are visualized using boxplots [8]. Again, we used a 7-point Likert scale with varying labels for the min and max values.

4.3.1 Flat computer display. In the case of a computer display, the participants considered stereo and spatial audio to have equal audio quality (Figure 3). The single 1.0 value given for stereo is most likely explained by the headset not being properly plugged in, which may have affected the answer of one participant.

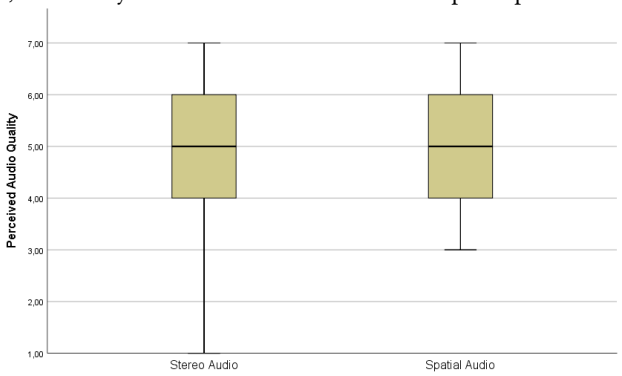

Figure 3: Perceived audio quality in case of computer display (1=very poor, 7=very good, and *N*=20).

Spatial audio seemed to have effect on the perceived presence of being on the stage (Figure 4), making the video feel more immersive.

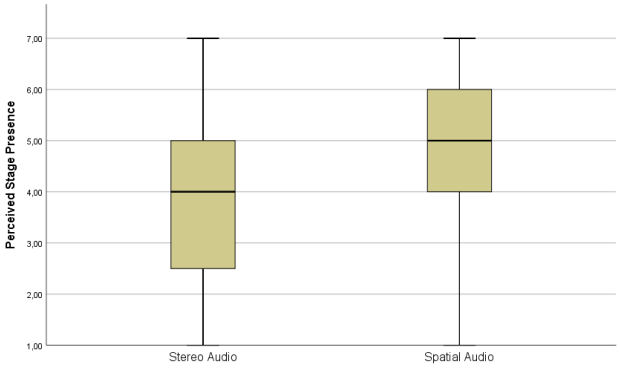

Figure 4: Perceived presence in case of computer display (1=not present at all, 7=completely present, and *N*=20).

The overall listening experience of spatial audio also scored higher (Figure 5), and it could be an outcome of the results of the previous metrics, as they both are factors that affect the overall experience.

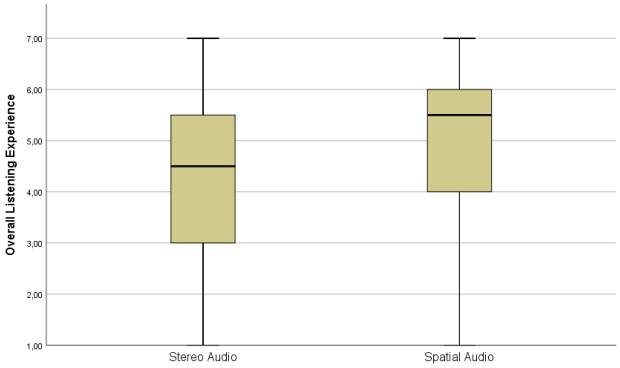

Figure 5: Overall listening experience in case of computer display (1=very unpleasant, 7=very pleasant, and *N*=20).

While spatial audio scored higher than stereo in all used metrics, the differences were rather small. Interestingly, participants who played a musical instrument had higher means in all metrics.

4.3.2 Head-Mounted display. In the case of HMD, the participants considered spatial audio to have a slightly better audio quality than stereo (Figure 6). However, in practice the difference is not that relevant. For example, the outlier of stereo was given by a participant who kept skipping on the videos, even though (s)he was instructed to watch them from beginning to end.

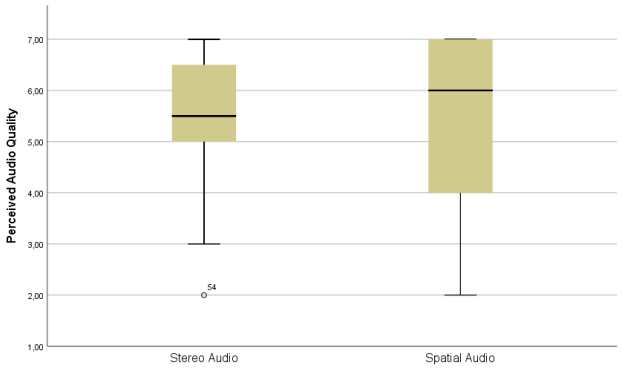

Figure 6: Perceived audio quality in case of HMD (*N*=20).

In the case of presence (Figure 7), there's was a more noticeable difference in favour of spatial audio. Both audio formats were rated higher than in the case of computer display (Figure 4). The outlier of spatial audio can be explained by a participant who commented that the audio came from the "wrong side", i.e., (s)he had possibly worn the headset wrong way around.

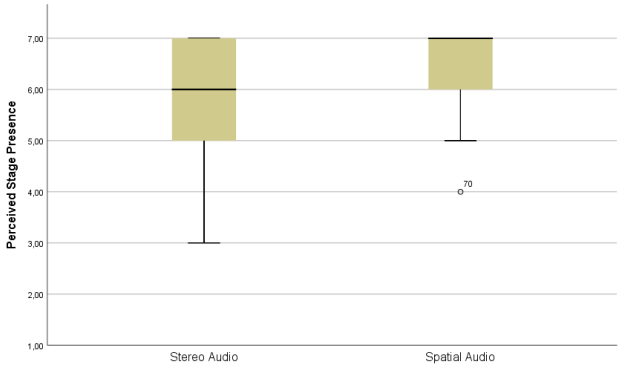

Figure 7: Perceived presence in case of HMD (*N*=20).

The overall listening experience was the same for stereo and spatial audio (Figure 8), but both were higher than in the case of computer display (Figure 5). Thus, the use of HMD seemed to improve the overall listening experience.

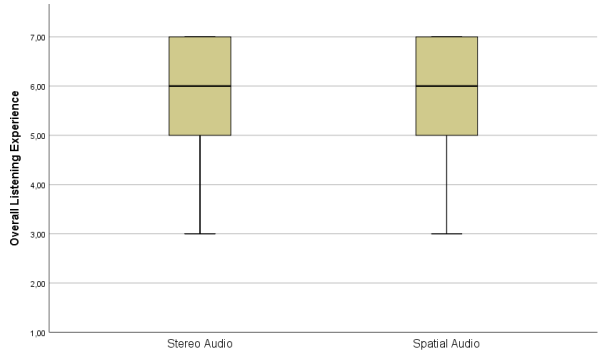

Figure 8: Overall listening experience in case of HMD (*N*=20).

In the case of HMD, the difference in metrics between participants who played and did not play a musical instrument was smaller, perhaps due to increased focus on the visual aspects of the video.

4.4 Flat Computer Display vs. HMD

A comparison of metrics between computer and head-mounted displays showed differences in favor of HMD.

4.4.1 Stereo audio. Despite the same stereo audio track, there was a small increase in perceived audio quality when moving from computer to head-mounted display (Figure 9). This is a further indicator that HMDs can provide stronger experiences than flat displays; however, as many participants were new to VR, the effect could as well fade over time.

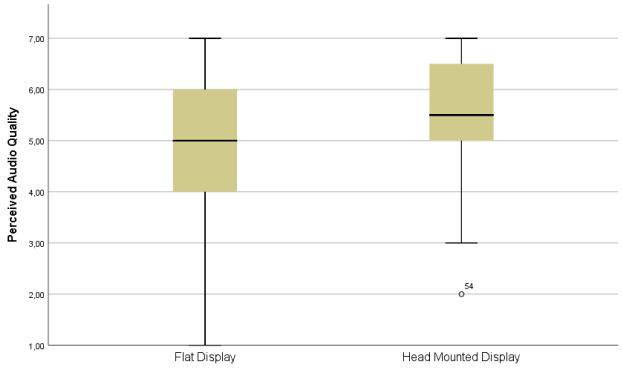

Figure 9: Perceived audio quality in case of stereo audio (*N*=20).

As one could expect, the presence (Figure 10) and overall listening experience (Figure 11) also improved. The results are well in line with [15], where 85% of the participants reported that 360° music videos viewed on HMD were more enjoying and exciting, and that the visual experience was more realistic than on a computer display. Authors such as Rupp [30] have also shown how more immersive devices can induce greater feelings of presence.

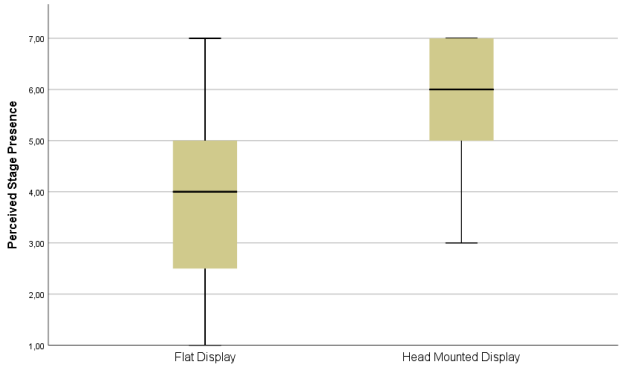

Figure 10: Perceived presence in case of stereo audio (*N*=20).

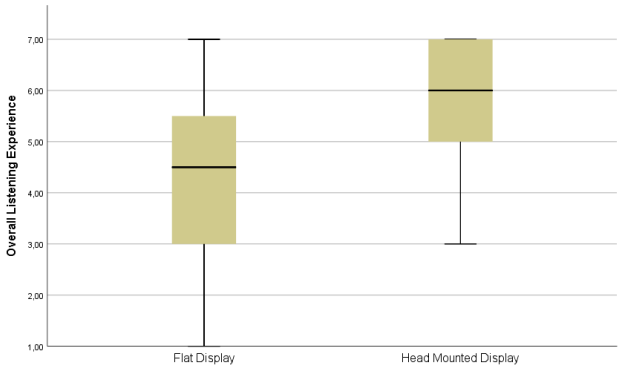

Figure 11: Overall listening experience in case of stereo audio (*N*=20).

4.4.2 Spatial audio. In the case of spatial audio, HMD again outscored the computer display in all metrics. Only one participant perceived audio quality to be lower in HMD than on computer display (Figure 12), but as discussed earlier, that participant may have worn the headphones the wrong way. The same participant can also seen as an outlier in Figure 13.

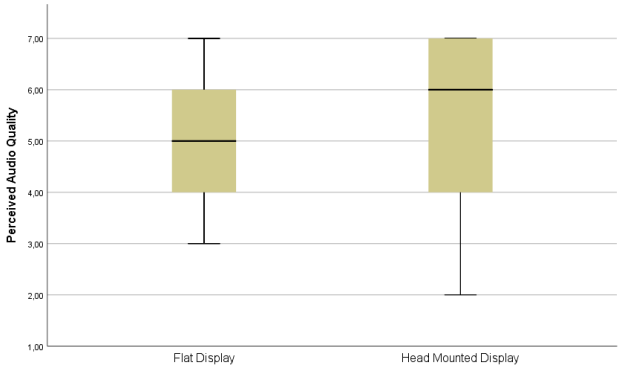

Figure 12: Perceived audio quality in case of spatial audio (*N*=20).

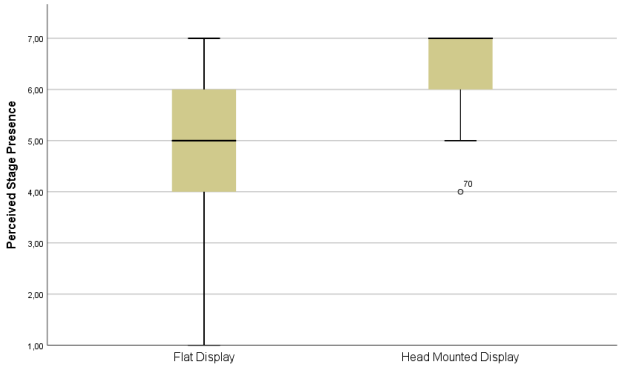

Figure 13: Perceived presence in case of spatial audio (*N*=20).

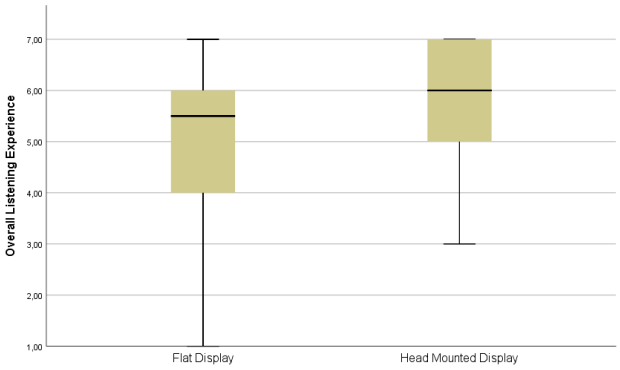

Figure 14: Overall listening experience in case of spatial audio (*N*=20).

5 Qualitative Findings

After participants had watched all four videos, we conducted a short semi-structured interview focusing on collecting qualitative data.

The quantitative results (see the previous section) showed HMD and spatial audio as the preferred combination, with highest scores in all used metrics. During the interview, one participant commented that ***"It was cool to experience VR glasses because I'd never used them before, and I had never seen 360° music videos so that was nice"***. One participant even described VR as ***"the illusion of better quality"***.

However, in the interview 11 participants (55%) did not specify a preference between any of the combinations. Only two participants (10%) chose HMD and spatial as their favorite. Five participants (25%) voted for the computer display and stereo audio combination, because that is what they were used to.

Three participants commented that they did not notice a difference between spatial and stereo audio. Other participants reported that the difference was more apparent on HMD due to easier movements and control over the environment, and some participants felt that interaction with the mouse on a flat display was "unnatural".

The main problem with the combination of HMD and spatial audio was that it did not fit to participants' current music listening habits. As many as 45% of the participants preferred to use headphones when listening to music, mostly due to the context where they typically listen to music. While they agreed that listening to spatial audio would work best as the main task, they viewed listening to music as a secondary task. For their usual listening experiences, most participants preferred familiar stereo audio, and some felt that spatial audio does not present the music piece completely "as it is intended to be listened to".

However, in the case of live concerts, the value of spatial audio was believed to be superior due to its novelty value and the higher presence and engagement it can provide.

6 Discussion

When studying the results, it is important to take into account the "wow factor" of first-time users of virtual reality. As the use of HMD and spatial audio added to the novelty of the experience, they may also have affected the participants' responses. While the long-term reactions to the technology are not yet known, the results indicate that the wow factor of HMD was stronger than that of spatial audio. The results are well in line with other authors such as Rupp [30], who have shown how more immersive devices can induce greater feelings of presence and result in a better user experience.

For their usual listening experiences, most participants preferred familiar stereo audio. However, in the case of, e.g., live concerts, spatial audio could be used to increase the feeling of being physically immersed in the concert venue and thus engage the users more. As discussed in [19], this feeling is the most important part of presence.

Interestingly, some participants expressed that they would like to have an option to switch between the audio formats depending on their mood and preferences at the time, while agreeing on HMD as the preferred display. Unfortunately, while some current digital audio workstations let the content creator to add head-locked stereo/non-spatialized audio as a part of the mix [34], it is played at the same as the spatialized part when the video is viewed.

There were some limitations in our study. The qualitative results from the post-test interview were unstructured, and more structured questions could have provided more concrete answers. The music video material used in the test was in Finnish, and as many participants did not speak the language, this may have had a minor effect on how the videos were perceived. The participants were 22-34 years old (median age 26), and the results (especially the listening habits) may be slightly different in older age groups. The number of participants was relatively low, and test was conducted in a laboratory which may have an effect on the ecological validity of the quantitative findings. Still, we argue that the results provide good indication of the user experience and preferences of audio use with 360° live music videos.

With the rise of VR, more and more concerts and movies will eventually become broadly available in 360° form, and this is likely to boost the demand for spatial audio as well. We believe 360° would be a perfect fit to especially bands near retirement, bands playing sold-out concerts, and bands from exotic places that people cannot visit.

7 Conclusions and Future Work

In this paper, we presented the results of a study investigating the user experience of stereo and spatial audio in a 360° music video setting, viewed both using a flat computer display and a head-mounted display. For the given content (a Finnish rock band shot with four high-quality 360° cameras), the combination of HMD and spatial audio scored highest in all used metrics. Both also increased the perceived presence of being on the stage.

However, the importance of listening habits plays an important role in understanding the potential markets for spatial audio. Spatial audio is arguably not for background listening. Instead, it presents a new way to consume music, and by targeting at the right audience using the right applications (e.g., live streams from sold-out concerts), it could become a part of the mass consumer market.

We find it is necessary to study and practice as many types of video production techniques as possible. We have to be prepared for the next steps of the VR industry and thus gather practical experience in all aspects of 360° videos. For example, we recently conducted a study on the effects of different cutting rates of 360° live music videos [15] and are also experimenting with fast-paced "overcapture videos" (see, e.g., [26]).

We have recently moved slightly away from the mainstream music business, now focusing on social and healthcare instead. In many places such as hospitals, retirement homes, prisons, and other such places where people may be forced to live inside a single building for the rest of their lives, even a simple 360° video can bring lots of joy to their lives. One example of such a project can be found from [27].

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