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Research article

Virtual reality in the zoo: A qualitative evaluation of a stereoscopic virtual reality video encounter with little penguins *Eudyptula minor*

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Abstract

Encounters between animals and humans in zoos and aquariums are being increasingly enhanced, mediated and extended using digital technologies. This article presents the results of research into the design, use and experience of stereoscopic (3D) 180° film viewed via a Virtual Reality (VR) headset at the zoo. This technology has recently emerged as an affordable consumer device with increasing uptake in education and museums. Drawing on research methodologies from the field of human-computer interaction, this project followed a 'research-through-design' approach, which sought to discover more about the potential of VR technologies in the zoo generally, through the process of designing a particular installation. This paper reports on the results of a qualitative interview-based study into zoo visitor experiences of using a specific VR installation, a 5-min video encounter that combined footage shot inside the little penguin *Eudyptula minor* enclosure during feeding, and behind-the-scenes preparation of food, with narration by the zookeeper in each scene. It was found that visitors had positive attitudes towards the use of VR video in the zoo as an addition to the experience of seeing live animals. The paper further discusses the specific opportunities for VR video via the key themes that emerged in the qualitative evaluation: cognitive immersion, emotional immersion, physical presence and social presence. This paper therefore supports further investigation of VR video as a form of visitor experience to be deployed alongside keeper talks, animal presentations and behind-the-scenes experiences, with clear opportunities for positive visitor experience, conservation caring, and ensuring the welfare of animals in captivity in zoos.

Introduction

Encounters between animals and humans in zoos and aquariums are being increasingly enhanced, mediated and extended using digital technologies, including visitor-facing e-signage and social media, as well as interactive systems for use by zoo animals (Perdue et al. 2012a; Webber et al. 2016; Rose et al. 2018). The introduction of digital technologies is not without tension and controversy. Zoos have, since the early 20th Century, sought to create naturalistic environments (Ogden et al. 1990; Coe 1992; Ross et al. 2008). The effects of naturalistic enclosure design have been extensively studied, with a focus on visitor opinions and behaviours (e.g. Ross et al. 2012). The concern is often expressed that unnaturalistic technologies might distract from animal encounters and detract from the sense of being immersed in a natural environment (Perdue et al. 2012a; Carter et al. 2015; Webber et al. 2016; Jacobson et al. 2017). However, existing work has also highlighted the positive impact of technology on visitor experience in improving conservation knowledge and stay-time at exhibits (Perdue et al. 2012b), suggesting a potential of such technology to enhance zoo experiences and improve education and conservation outcomes. Clay et al. (2011) argue that more research is needed to ensure that technological innovations do not negatively influence the zoo visitor, and Webber et al. (2016) argue that the tensions between technology and the 'natural' environment "may be mitigated through design choices" and through sensibly thinking about how technology can be integrated into the zoo visit (Webber et al. 2016, p. 17).

This article presents the results of research into the design, use and experience of stereoscopic (3D) 180° film viewed via a Virtual Reality (VR) headset at the zoo. This technology has recently emerged as an affordable consumer device with increasing uptake in education (Jensen et al. 2018) and museums (Shah et al. 2018). Research into VR has identified 'presence', including 'social presence', as an important concept for understanding the psychological effects of this type of technology (Schuemie et al. 2001). VR-based experiences have been shown to elicit physiological and psychological experiences comparable to a 'real' equivalent (Bohil et al. 2011), and Pimentel et al. (2011) argue that the use of VR-based exposure therapy for animal phobias (Suso-Ribera et al. 2019) support the conclusion that human-animal encounters in VR "may be analogous to similar interactions found in zoos and aquariums" (Pimentel et al. 2011, p. 519). Of special relevance to zoos and aquariums, empathy is often emphasised as one of the key opportunities for the medium of VR (Bailenson 2018), and indeed research has shown that interactive VR environments can change the way users think about the environment and environmental risk (Ahn et al. 2014; 2015). Other researchers have noted that VR video can afford experiences of telepresence, co-presence and experiential immediacy (Irom 2018, p. 4269) that are more authentically connected to the 'real', compared to computer-generated VR environments. Despite the potential opportunities for VR-based experiences to contribute to the work of zoos and aquariums, there are few reports of VR initiatives in this domain and the authors are not aware of any formal research into this topic.

Drawing on research methodologies from the fields of human-computer interaction, this project followed a 'research-through-design' approach, which sought to discover more about the potential of VR technologies in the zoo generally, through the process of designing a particular installation (Zimmerman 2007). This paper reports on the results of a qualitative interview-based study into zoo visitor experiences of using a VR installation conducted as part of the design process. This study sought to better understand and characterise the experience of recorded images of animals through a VR display, and used the research-through-design process, as well as the visitor evaluation, to identify the opportunities and potential risks for using this emerging technology in zoos, in alignment with their conservation and educational goals.

Material and methods

Research-through-design

The research project involved a research-through-design (RtD) process at Zoos Victoria, investigating the research question by way of designing something that could be evaluated (Zimmerman et al. 2007). This research method, commonly used in the field of human-computer interaction, acknowledges that insights and contributions to knowledge are generated through the process of design and the produced artefact (Hengeveld et al. 2016), and not just through evaluation of the artefact's effects. The study began with a review of existing VR footage of animals. Eight exemplar VR-film animal encounters were identified and evaluated in focus groups with zoo staff (n=16) and other participants (n=10). Subsequently, footage was produced, via the filming of four zoo animal species (giraffes, crocodiles, elephants and red pandas), and a further user study was conducted with zoo staff (n=16) and other participants (n=10). Key findings from this process emphasised the very 'real' sensation of physical presence afforded by VR video. The study drew on the insights collected through this process to inform the selection of VR technology, animal, conservation story, and encounter design for the formally evaluated narrative-driven VR video experience described below.

It is argued that this iterative RtD approach is a strength of the present project. This process allowed for development of an intervention which responded to the practical, logistical and attitudinal constraints identified through repeated enquiry, co-design and consultation with stakeholders (Zimmerman and Forlizzi 2014). While research into the use of technology in the zoo often focuses on evaluating the effects of a pre-designed technological solution, an important challenge for zoo and aquarium research in this domain lies in identifying how specific design choices impact the efficacy of technology interventions. In this vein, the project aimed to investigate opportunities, challenges and risks associated with a VR video at the zoo and identify design choices which could mitigate issues while maximising benefits. In presenting and discussing the results, this paper draws attention to factors in the design that impact on visitor experiences, with a view to informing future research and design of VR interventions for zoos.

PenguinVR

The design artefact was 'PenguinVR', a 5-min 30-sec 180° VR video encounter that combined footage shot inside the little penguin *Eudyptula minor* enclosure during feeding, and behind-the-scenes preparation of food, with narration by the zookeeper in each scene. The narrative of the video focuses on the work of food preparation and animal care. Each penguin receives a fish with vitamin supplement each day, and consumption is tracked and monitored at each feeding. The narration subsequently links animal care to the issues of plastic pollution and world-wide declining sea bird populations (Paleczny et al. 2015). The video concludes with the zoo's 'Bubbles not Balloons' conservation call-to-action, with bubbles floating through the scene. Footage shot inside the enclosure is from two angles. Below is a brief description and justification of two key decisions made in production that drew on the RtD process.

Firstly, the in-enclosure shots were designed to be animal-centric. They are in close proximity to handfeeding, which gives the user good visibility of the animals and the feeding activity. This vantage point is far closer to the penguin feeding event than visitors would generally be permitted to approach (even if participating in a behind-the-scenes tour), as the presence of visitors this close could adversely affect animal wellbeing. In one shot, the camera was placed low on the floor of the enclosure. This camera position, at eye level with the penguins, was selected to promote respect and empathy (Coe 1985) rather than looking down at the animal. In the second shot, the camera was suspended over the water. This shot was included to explore how VR could disconnect the human viewer from their body, and in the results section below, the unusual sensation that this provided is discussed. This shot also provided a close view of the penguins' powerful and fast swimming in juxtaposition to their on-land movement.

Secondly, keeper-centric footage shows Liz the zookeeper preparing fish for feeding, to draw attention to the zoo's care for their animals and concern for their well-being. 'Keeper talks', where a keeper or zoo staff member talks to visitors about the animals, are conducted daily across a range of species at Zoos Victoria properties and provide an opportunity to demonstrate how the animals are cared for and what visitors can do to help them. One finding that emerged in the RtD process was the powerful sensation of social presence and interaction that emerged when a person spoke directly to the camera. Consequently, Liz speaks to the camera directly (and narrates other scenes), a technique which was adopted to explore the opportunity for VR video to provide a personal connection that might impact the effectiveness of the conservation message. The evaluation sought to explore this aspect, as well as visitors' broader experiences and attitudes towards the video.

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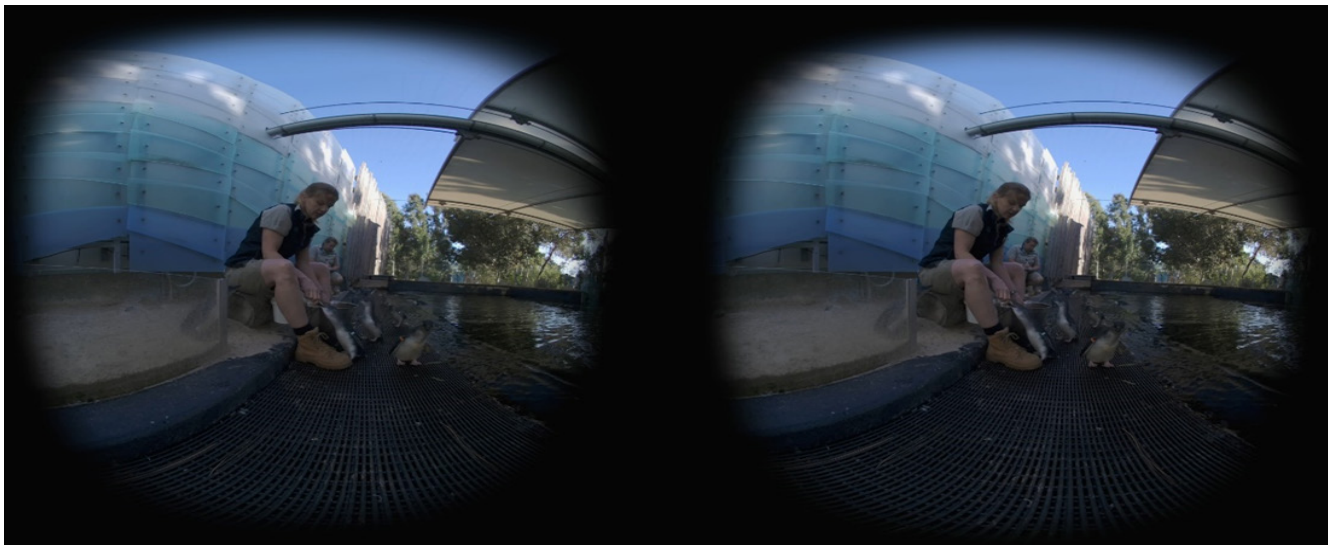

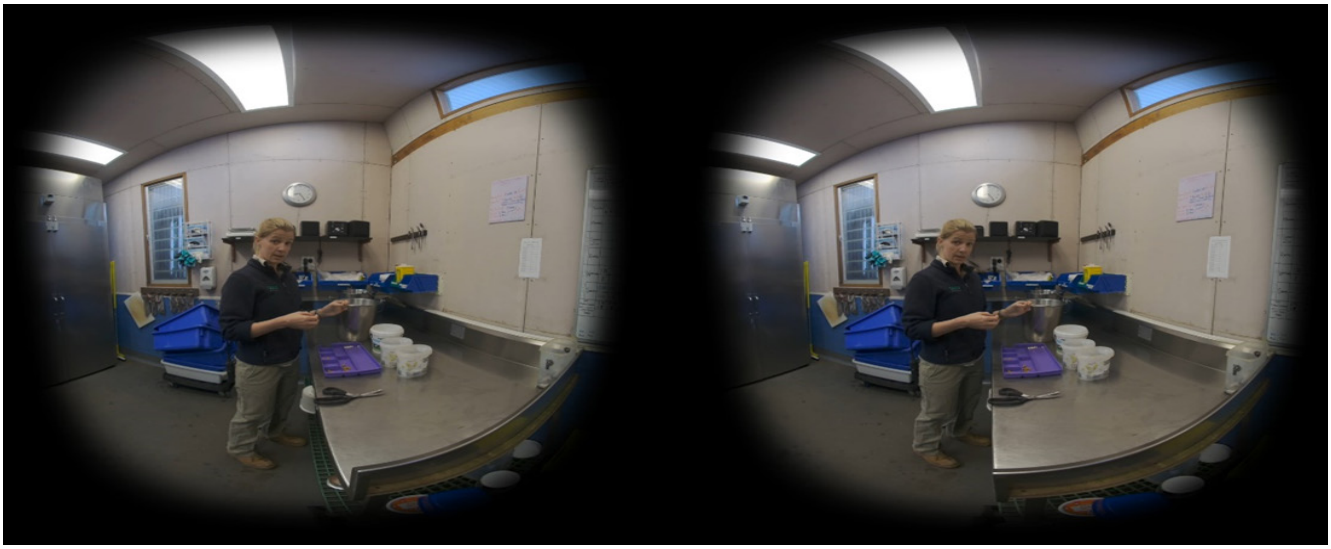

Figures 1–3. Screenshots from the PenguinVR video showing the different views.

User study

Semi-structured interviews were conducted with 67 people who viewed PenguinVR using an Oculus Go, a mobile VR headset; 31 offsite participants (watching at a university campus, P1 to P31), nine teachers (P32 to P40), and 27 zoo visitors (P41 to P67). This study design was intended to probe any differences in experience when viewing the VR at the zoo, near the penguins, or offsite. None emerged in the analysis. The initial interview questions were designed to explore and probe overarching pre-conceptions, how VR video differed from watching a 2D video, and the sensations experienced viewing the footage. Thus, not all informants were asked the same questions. A zoo volunteer positioned near the entrance of the penguin exhibit invited visitors to participate in the study. Several groups declined with the majority giving reasons such as lack of intention to visit the penguins, and lack of time. It is noted that this recruitment approach may introduce a self-selection bias in favour of technologies in the zoo. Participants passed through the exhibit, having the opportunity to view the penguins, prior to undertaking the PenguinVR encounter adjacent to the penguin pool. Interviews were conducted individually and in the small groups of 2–3 people who had attended the zoo that day together. All participants were over the age of 18.

Analysis

Interviews were recorded and transcribed. An initial codebook was developed from themes identified in a first, high-level review of the data. Author 1 created memos based on the responses of off-site participants, while Author 2 conducted a qualitative thematic analysis, identifying recurring themes in the interviews with visitors and teachers at the zoo. Concepts identified in these two high-level analyses were combined to create an initial codebook, which was then reviewed for intercoder agreement and further refined by the researchers following procedures outlined by Guest et al. (2011). Through ongoing discussion and reflection among the research team, key themes relating to attitudes, immersion, presence and participation emerged, which help understand the opportunities and limitations of this emerging technology.

Results

Attitudes towards PenguinVR

Evaluations of technology are often affected by an acquiescence bias in which participants, who self-selected into the study, report favourably on a presented artefact through an implicit desire to please the designers and researchers. Mindful of this bias, the interviews did not dwell on summative appraisals of the PenguinVR but put emphasis on probing the nature of the experiences created. However, for completeness of reporting, it is noted that 61 participants were expressly positive about their experience and felt that it was appropriate for use in the zoo. PenguinVR was generally compared favourably to the experience of a keeper talk or a behind-the-scenes encounter. Such experiences have been found to enhance the visitor experience and strengthen conservation caring. Many visitors commented favourably on the logistical benefits of VR video; 27 (40.29%) made reference to being able to access unique content, 18 (26.87%) highlighted access to behind-the-scenes content, and 10 (14.93%) mentioned the logistical benefit of on-demand content, as it can be difficult to be at the right enclosure at the right time to see a keeper talk or feeding. A total of 20 (29.85%) visitors commented regarding the unique closeness of the experience. When viewing penguins in their enclosure, they could see them only at a distance and the birds were inactive, in comparison to which PenguinVR could provide a more satisfying experience:

"I think this is great!! If I had this kind of thing at the zoo when I used to go all the time as a kid, it would make my trips so much better because half the time I would be sad that I missed the feeding times, and animals would all be asleep and 'boring'" – (P7)

It was clear, though, that visitors considered VR video a valuable addition to the experience of seeing live animals, rather than as a replacement. Four (5.97%) participants expressed that they "prefer live to film" (P51), that the sense of connection with the animal "can't be replaced with VR" (P57) and that "you can't beat" (P61) looking at them in real life. However, this did not appear to translate into an overall negative attitude towards PenguinVR, which was thought to offer potential enhancements to the visitor experience. One concern about use of VR at the zoo was expressed by three (4.48%) participants, who commented that children are always "on screens" and the emphasis of the zoo visit should remain on the physical encounter, a finding which echoes prior research (Webber et al. 2015).

This study found that viewing PenguinVR encouraged engagement with ideas about animal care. The focus of the video narrative on the careful preparation and delivery of fish to the penguins was the most commonly reported learning experience (n=47, 70.15%). It is argued that this highlights the power of the narrative to convey information, and the powerful impact of the participatory nature of VR video content. Participants were positive about the opportunity to see "how they're fed, the care-taking" (P57). Of the visitors, 20 (29.85%) had not previously thought about nutrition and the animals, expressing that it was "really amazing" (P45) and "interesting" (P57), particularly the smaller details such as hiding vitamin pills in the fish and the way that keepers track the penguins' food intake. P58 felt strongly that this was better than hearing about it (for instance, during a keeper talk) because "with this, you virtually get to see it". Viewers, like P32, left with the impression that they more closely understood "life in a zoo" (P32).

Visitors' positive experiences of PenguinVR were associated with positive attitudes towards the zoo, seen in how participants felt they had learnt "how much is put into tending for these little creatures" (P48) and that the zoo is "meticulous in caring for animals" (P9). This was reflected in positive attitudes towards the keeper, with participants commenting that she "obviously loves them" (P50), that "she was caring and loves what she does" (P49), encouraging them to reflect that keepers must do "a lot more that no one knows about" (P45). Two participants also commented on how VR video "talks to how progressive the zoo is. By introducing new tech. New technologies that perhaps other zoos around the world aren't really doing" (P56).

Immersion

VR content is inherently immersive, in the sense that a head-mounted display blocks everything else from view and places the viewer inside a virtual environment that they view by turning their head. However, the semi-structured interviews and analysis identified two different forms of immersion involved in the experience with VR video in the zoo: cognitive immersion and emotional immersion.

Cognitive immersion refers to the viewer's close attention to the content. This aspect of immersion results in part from the fact that the VR headset minimises the opportunities for visual distraction. This was strongly felt to be a significant advantage for children (especially school students), as VR ensures they are "totally engaged and taking in all the information" (P49) and it "prevents distractions" (P58). This was also suggested to be beneficial for adults: P54 explained how they "don't remember what's said in an actual presentation really generally, 'cause you're not paying that much attention usually. I think [VR video] just brings your attention more to what they're saying" and P57 similarly described how the "full immersion captures your attention". These responses suggest that VR video demands the purposeful attention of the

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user, in contrast to other forms of content deployed in zoos. This highlights the potential of VR video as a basis for new kinds of visitor experiences and message delivery.

Emotional immersion involves the viewer's affective engagement in an experience, or a willingness to "find an emotional bond with the story or the narrative" (P50). P55 was excited about the "opportunity to have something like this and immerse myself in the entire experience", contrasting with the existing forms of signage and media at the zoo. Nine (13.43%) participants described the VR video as "a very personal experience" (P40), or "one on one as opposed to a whole group experience" (P39). The 'personal' nature of the experience, and viewers' sense of 'social presence' (described below), seem to contribute significantly to emotional responses. These findings suggest a significant opportunity for VR video to foster affective engagement of visitors with specific narratives and issues, something that can be difficult to achieve in the crowded zoo setting.

Presence

A total of 38 (56.72%) participants indicated that they experienced a sense of presence in the VR video. Two types of presence were identified in visitor responses: physical presence and social presence.

Physical presence referred to the extent to which someone feels like they are 'really there', in the environment represented (i.e. the penguin enclosure and food preparation area). This was where participants referred to feeling "like you were there" (P23), "as if you're standing beside the keeper" (P15), of being "just in front of the penguins" (P12) and of being "transported" to the zoo (P30). This resulted in a sense of proximity not usually possible for zoo visitors because it did not feel like "there's a barrier between you and the animal" (P62). A total of 15 (22.39%) participants described an impression of physical interaction with the penguins: "I want to touch those penguins as they are so cute and so near to me" (P17), or with the water; "like I had my feet in the water" (P32). Three (4.48%) respondents suggested that VR video was better than a live keeper presentation because of the sense of proximity ("you're right there with her as she's feeding them" (P48)), and visibility ("with all the crowd, you're jammed somewhere, you can't really see" (P52)) associated with physical presence. Probing this aspect of the VR video, physical presence was found to be associated with characteristics of the head-mounted display (depth perception, high resolution, and the ability to look around by turning one's head) and also with the choice of camera placement in proximity to the penguins, and low to the water.

Social presence, or the sense of being co-present with the keeper in the VR video environment, was expressed by 24 (35.82%) participants. Six (9.84%) viewers referred to the "intimate" (P32) nature of the encounter with the keeper. This sense of a one-on-one interaction was described as a "private VIP tour" (P1), "a private viewing with the keeper" (P37) and as though "somebody is putting on a show just for you" (P51). P66 described how she responded as though the keeper were talking to them directly, as she "kept nodding when she's talking, the keeper. I'm going 'yeah yeah'". These findings point to the potential for VR video to replicate the psychological experience of being present with another person. Furthermore, social presence was strengthened by the nature of the content, in particular the performance of an experienced zookeeper. Six (8.96%) respondents drew attention to the feeling of eye-contact with the keeper, which was important for making it feel "really intimate" (P5) and commented on how they "liked it when she spoke to you … that made a difference to me … I thought that was more personal" (P41). These aspects of social presence have relevance for zoo conservation education tactics. Five (7.46%) participants felt that the sense of personal engagement created by the experience "makes you feel more accountable" (P50), in comparison to watching similar content on a video screen or iPad. This theme highlights how VR video might simulate the experience of being spoken to one-on-one, a mode of delivery which is highly effective for zoo conservation education aims, but which is cost-prohibitive to deploy at scale.

Participation

A final theme that emerged in the interviews was the idea that PenguinVR was a participatory experience, even though it is a linear video. This was expressed, in simple terms, in visitors' reflections on the interaction involved in watching the video, in looking around at what was going on, and having the choice of where to direct their attention. Sixteen (23.88%) participants described PenguinVR as being "much more interactive" (P20) than watching on an iPad or that the "VR film encourages to give you a participatory experience" (P15) due to the freedom to look around. Like the ideas around immersion, this makes it "more engaging" (P16), beneficial for delivering educational content because "watching video on an iPad can be tedious" (P16). In contrast, P7 described a feeling of frustration from not being able to interact the way they felt they should.

A stronger and more surprising expression of this sense of participation came in the nine (13.43%) responses that reflected a sense that engagement was collaborative, as though viewers had participated in the acts of preparing the fish and then feeding the penguins. P53, P54, P60 and P65 all described how they felt "more involved" in what was going on, in comparison to watching a 2D video. P46 described the sensation as having "felt like I was sitting there feeding them" and P50 said that "it felt like you were in there, that you were almost the helper, helping her and sitting there and you could, I could have counted the tags for her". Here it is clear how VR video is not just participatory in the sense that it induces movement, but that can sometimes also generate the sensation of having taken part in the depicted events and narrative.

Discussion

This analysis of visitor responses to PenguinVR have provided a deeper understanding of the experience of viewing animals via VR that might be operationalised in future VR experience design. Although VR is not considered a replacement for 'real' animal encounters, the study has described the way that visitors are positive about the use of VR in the zoo, and the results highlight some of the opportunities for VR video use in this context. This provides support for further investigation of VR video as a form of visitor experience to be deployed alongside keeper talks, animal presentations and behind-the-scenes experiences. Here, the key opportunities for this emerging technology are discussed.

Practical enhancements to the zoo visit

Firstly, practical enhancements to visitor experiences are made possible by VR video. Whereas live keeper talks and animal presentations must take place at specific times of day and are often of short duration, VR video can be offered at any time, without restriction on the number of offerings. As keeper talks can be more effective at generating conservation action post-visit than exhibit displays and signage (Litchfield et al. 2019), VR video may be able to increase engagement with the zoo's conservation campaigns and foster conservation behaviours in a larger sample of visitors beyond those who attend keeper talks. This approach might also be suitable for animals that are difficult to include in live presentations (such as nocturnal animals). The teachers interviewed emphasised the inclusion and accessibility opportunities of VR video, as it could provide animal-encounter experiences to students who cannot attend the zoo (for cost,

mobility or distance reasons). For this study, researchers provided headsets and facilitated use of the device, however low-cost mobile VR technology (such as the Samsung Gear VR or Google Cardboard VR) might provide a low-cost approach to offering VR video to large numbers of zoo visitors. VR also presents an opportunity for organisations to produce multiple targeted experiences and interpretations to cater to the different needs, motivations and desired outcomes of zoo visitors.

New ways of experiencing animals and their ecology

Secondly, for the broader population of zoo visitors, VR video might allow a greater proportion of visitors safe access to zoo 'backstage' areas, through experiences which are immersive and social. It is proposed that there are clear opportunities for VR video to experience the work of zoos in the realms of animal care and conservation work. The focus of PenguinVR on the labour that goes into preparing food for the penguins each day resulted in a profound attention to animal well-being and engendered a positive attitude towards the zoo and zookeeper. This also extends to opportunities for profiling the zoos' wildlife conservation activities conducted behind the scenes and offsite. For example, in PenguinVR, the narrative focused on a specific penguin, Bump, who had been rescued from the wild with a concussion, connecting visitors to the animal rescue work of the zoo. As Bouquet et al. (2004) argue, privileged access to backstage areas of the zoo invites people to imagine themselves in the role of zookeeper, and to assume greater responsibility and concern for the animals (Bouquet et al. 2004, p. 14). Additionally, proximity to, and perceived interaction with, zoo animals are some of the key ways visitors feel a sense of connection with the animals they view (Howell et al. 2019). This sense of connection is associated with greater conservation caring and desire to perform behaviours to help these animals (Skibins and Powell 2013; Howell et al. 2019). PenguinVR appeared to create a sense of immersion in the penguin exhibit and feelings of interaction with, and proximity to, the penguins and keeper. In this respect, VR video might allow a greater proportion of visitors to engage and connect with zoo animal care and conservation work which is otherwise invisible to the public.

Substituting for up-close animal encounters

Third, it is argued that VR video animal encounters might generate animal welfare benefits. Up-close animal encounters, a common feature in many zoos and aquariums, can have mixed welfare outcomes for the animals, depending on the encounter format, species, and the individual animal's history (Fernandez et al. 2009). Formats which entail regular handling or limited choice for animals as to whether to participate have been found to result in negative welfare outcomes (Hartell-De Nardo 2014; Baird et al. 2016) and avoidance behaviour (Hogan et al. 2011). For visitors, up-close encounters can be a profound experience that can help shape attitudes towards animals. Visitor reports of up-close experiences in the course of the zoo visit have been associated with greater connection to, and concern for, the animals (Hacker and Miller 2016; Luebke 2018). McLeod and Rawson (2019) experimentally tested one such encounter with a Lord Howe Island stick insect (LHISI) *Dryococelus australis* and found that participating school students reported higher levels of care towards the LHISI than other students. However, it is noted that this study indicated that the inclusion of a live LHISI in the encounter was not necessary to achieve greater engagement with the species (McLeod and Rawson 2019).

As with keeper talks, opportunities for visitors to participate in up-close encounters are limited: they are usually offered only once a day to a small number of visitors. VR animal encounters could provide an alternative to up-close encounters with animals, increasing their reach. The combination of close-up VR video and at-a-distance 'real' animal viewing might meet visitors' demands for engaging encounters and opportunities to view active animals in proximity (Fernandez 2009). In this respect, there is potential for VR video at the zoo, and of offering video of the zoo animals in their enclosures (rather than generic footage), as the VR experience is consequently more closely tied to, and contextualised by, the 'real' experience. Emerging technologies, such as live-streamed VR video, could also be useful for this purpose. Such approaches might provide a positive visitor experience while allowing for animal welfare-centric enclosure design which gives animals more control and choice over their visibility to guests.

In the context of increasing concern about the ethics of zoos (Hutchins et al. 2003), it is worth considering the negative potential of VR videos to exacerbate what has been referred to as the 'pornographic' viewing quality of zoos (Acampora 2015). Acampora (2015) argues that the process of (re)presenting animals and making them visible to guests erases the 'natural' and the 'wild', degrading animals in captivity and reinforcing problematic human/non-human power relationships. The on-demand nature of VR could, via this line of argument, be interpreted as the complete erasure of the animal's ability to elude interactions with people (Acampora 2015, p. 70). However, in the present VR video the animals shown clearly have a choice as to whether they approach the staff, or VR camera, or not. In addition, the way VR feels real, but is, crucially, not – may conceal the artificial quality of the encounter leading to unintentional consequences from VR (Carter and Egliston 2020, p. 25–26). For example, comments from visitors such as "I want to touch those penguins as they are so cute and so near to me" (P17) indicate the possibility of VR film experiences adding to the objectification of zoo animals and diminishment of empathy. This, it is argued, remains a key challenge for conservation focused VR film to continue to engage with, which should be approached with similar principles to contemporary exhibit design; to "stimulate visitor interest, foster appreciation for the natural world, and provide effective opportunities for conservation education" (Coe 1985; Ross et al. 2012).

Conclusion

While zoos have so far resisted incorporating digital technologies into animal encounters, the results of this study highlight some of the immediate and longer-term opportunities that head-mounted virtual reality presents the zoo visit. The powerful sensation of presence, personal involvement and deeper engagement have identified here present clear opportunities for positive visitor experience, conservation caring and education. Future research is also necessary to further investigate the strength of these effects, and the impact of other variables, such as the impact of socially isolating viewers. Other mixed reality technologies, such as interactive virtual environments (Pimentel et al. 2018) and augmented reality (such as in Pokémon Go, Dorward et al. 2017) present similar exciting opportunities that may come to characterise the experience of visiting zoos in the future. As noted, research into the use of technology in the zoo often focuses on evaluating the effects of a pre-designed technological solution, whereas an important challenge for zoos and aquarium research in this domain lies in identifying how specific design choices impact the efficacy of technology intervention. In presenting this study and analysing the results in this regard, it is hoped that this paper will contribute more deeply to this rich terrain of design possibilities, depending on the very many different contexts within the zoo.

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