Reality Aware VR Headsets

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ABSTRACT
We present a model of a reality aware VR headset, a VR headset capable of identifying, interpreting and responding to elements of a user's reality. We report on an evaluation of 2 prototypes which investigated potential behaviours such a headset might have. Our first prototype compared 4 notifications to automatically notify a VR user to a bystander's presence. We compared notifying with and without information about the bystander's position. Our results highlight a subset of VR users who when notified of copresence without position were made uncomfortable. Our second prototype investigated how dynamic audio adjustment could react to audio events in the user's surroundings. We compared on-board headset audio and headphones with a dynamic audio version of each which decreased the application volume to direct attention to an audio source and increased application volume to block out an audio source. Our results found positive results when decreasing application volume but increasing volume to block out a nearby audio source was ineffective.

Author Keywords
Notifications; Head-Mounted Displays; Virtual Reality; Interruptions

INTRODUCTION
As virtual reality (VR) headsets become more common in everyday life interactions between VR users and reality will occur more often [13, 20, 31, 18, 12]. As VR overrides the visual, and often auditory, senses of the user, interactions with objects and people in the nearby area can be problematic [19, 9, 8]. On-going work seeks to develop systems to better facilitate a VR user's interaction with their surrounding reality. Systems which notify VR users to elements of their surrounding area are already supported to some extent by commercial VR headsets, e.g. Valve's chaperone [35] and Oculus' Guardian [23] both provide a virtual warning to ensure users stay within a defined play area. Researchers, meanwhile, have investigated how objects and people might be included within a VR user's virtual world [19, 6]. Such work envisions a future *"reality aware VR headset"*, a headset capable of identifying, interpreting and responding to the user's surrounding area.

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In this paper we propose a conceptual model of a "reality aware VR headset" and present the evaluation of two prototype systems. Our first prototype investigated the use of notifications to automatically inform a VR user when someone enters the nearby area. We compared 4 methods of communicating copresence: an avatar, text notifications, audio notifications and a sonar radar. Despite prior work [19] suggesting text notifications may be sufficient when communicating copresence our results show some users are uncomfortable when informed of copresence without indicating where the copresence is located in the surrounding area.

Recent consumer VR headsets [24, 25, 36] have adopted an open ear audio design. These system provide provide users with on-board application audio while leaving their ears uncovered to increase their auditory awareness of the surrounding area. Envisioning how such systems may develop our second prototype investigated how a VR headset might dynamically adjust the user's audio in response to audio events in the surrounding area. We compared on-board headset audio and headphones with a dynamic audio adjustment variant of each. Our results found decreasing volume to direct a user's attention toward a nearby audio event was a viable use of dynamic audio adjustment but increasing volume to block out nearby audio was ineffective.

RELATED WORK

Copresence Inclusion
Methods of increasing a VR user's awareness of copresence have focused on notifications for communicating the existence of the copresence to the VR user. McGill et al. proposed communicating copresence by automatically detecting a bystander's entrance and displaying a silhouette of them in the virtual environment [19]. McGill et al. found this approach significantly disrupted the VR user's sense of presence and concluded less disruptive notifications were required. Simeone developed a motion tracking widget which plotted a bystander's position relative to the VR user but conducted a very limited evaluation of the system [33]. Willich et al. compared 3 visualisations for the bystander: an abstract avatar, a photorealistic silhouette and a passthrough video of the bystander and some of the surrounding environment [37]. Willich et al. found users preferred the avatar or silhouette over the passthrough video and that the avatar was the most accurate method for allowing the VR user to locate the bystander's position relative to their own. Meanwhile, Ghosh et al. surveyed which elements of reality VR users most wanted to be informed about. They found awareness of physical space, e.g. "proximity to a wall", and awareness of sounds, e.g. "someone calling your

name", were most desired by users [9]. Ghosh et al. then completed a lab study which compared notifications using 6 modalities (audio, visual, haptic, audio + haptic, visual + haptic, audio + visual) for 5 usage scenarios (a person talking, an incoming call, an incoming message, a person in room, time spent in VR) for noticeability and perception but did not investigate impact on the user's sense of presence.

Obstacle Avoidance

Due to VR's occupation of the user's visual sense, room-scale VR headsets require safety systems to prevent users colliding with nearby objects. Afonso et al. proposed the use of audio feedback for Obstacle avoidance with positive results [1, 2]. A variation of Afonso et al's work is included in current, consumer VR headsets. Valve's chaperone [35] and Oculus' Guardian [23] both build on Afonso et al's system and provide users with a visual warning when they are about to stray out of a defined "safe" play area. Iterating on the systems found in current consumer headsets Yang et al. proposed a sensor based system to allow a copresence to define restricted areas within the user's "safe" play area the VR user should avoid wandering into [40]. Meanwhile, Huang et al. expanded on the existing systems by investigating how depth sensing could be used to create a depth map of the surroundings to provide a grid-like view to outline objects in the surrounding area [14]. Sakata et al. proposed 2 methods of increasing a user's awareness of the surrounding area by superimposing 3D point clouds and virtual models of objects in the surrounding area in the user's virtual environment [15]. The latter being an extension of Simeone's work on Substitutional Reality [32, 34] for obstacle avoidance rather than application design.

Object Inclusion & Peripheral Usage

Increasing awareness of objects and peripherals has primarily focused on efforts to solidify VR's use in the workplace [41]. McGill et al. [19] and Perez et al. [26] both investigated how food items could be blended into a virtual environment. Desai et al. proposed a system to allow users to use a smartphone while in VR [5]. However the majority of work has instead considered keyboard inclusion and usage in VR [6]. Grubert et al. [10] and Bovet et al. [3] both documented the impact caused by the limited visual feedback when no object inclusion or user assistance is provided, highlighting users retain at best 60% of their non-VR typing speed. A range of systems have been proposed to improve this. McGill et al. [19], Pham et al. [27] and Lin et al. [17] all investigated how a view of the keyboard might be included within the user's virtual environment. Walker et al. developed a virtual keyboard assistant to show users which keys their fingers were touching on the keyboard [38]. Meanwhile Grubert et al. [11] and Knierim1 et al. [16] investigated the effects of representing the user's hands in an avatar and realistic manner and found experienced typists almost achieved their non-VR typing performance when using the proposed systems.

REALITY AWARE VR HEADSETS

A reality aware VR headset is one that is capable of identifying, interpreting and responding to the user's reality. Such a headset is composed of one or many reality aware behaviours. A reality aware behaviour is the identification, interpretation and response to an element of the user's reality. The automatic detection of nearby bystanders is a one such behaviour. Detecting when a VR user leaves a designated play area is another. McGill et al's silhouettes [19] and Simeone's radar [33] are different implementations of the same behaviour, copresence inclusion. McGill et al's silhouettes [19] and Valve's Chaperone [35] are implementations of different behaviours, copresence inclusion and obstacle avoidance. Behaviour responses can also be categorised. Four high level response states we identify are:

- ***Ignore:*** The system ignores the identified element of reality
- ***Observe:*** The system continues to observe the identified element of reality, possibly awaiting some trigger condition to cause a change in response
- ***Communicate:*** The system communicates information about the identified element of reality to the user
- ***React:*** The system responds directly to the identified element of reality on the user's behalf

For example, consider a headset that can automatically detect when someone enters the room. To ignore might be to detect the bystander, do nothing and discard the information. To observe might be to track the bystander's position until they enter into the VR user's designated play area when a communicative or reactive response is triggered. To communicate might be send a notification to the VR user stating *"someone has entered the play area"* and to react might be to pause the user's application in use.

PROTOTYPES OVERVIEW

We developed 2 prototypes to illustrate and investigate reality aware VR headsets. Our first prototype investigated how a VR user might automatically be notified of a copresence's existence. We were interested in comparing notification modality (visual and audio) and information about the bystander communicated to the VR user (copresence existence vs copresence existence and position). Our second prototype investigated how a reality aware headset might react to audio events in the nearby area. It is a response to Ghosh et al's survey [9] which identified 13 scenarios VR users desired more awareness of, 8 of which concerned a desire for increased awareness of nearby sounds. Our prototype was built to investigate how a reactive variant of the existing audio systems used by VR headsets (headphones and open ear audio) could dynamically alter the user's volume in response to a nearby audio event.

PROTOTYPE 1: COPRESENCE NOTIFICATIONS

Our first prototype compared 4 notifications to automatically notify a VR user to the entrance of a copresence: an avatar, text notifications, audio notifications, a sonar radar. We were interested in how notifications which did and did not communicate the bystander's position would be perceived by the VR user. We designed 2 types of notification: one which only communicated copresence and one which communicated copresence and position. The 4 notifications are detailed below:

- ***Text Notification:*** When a bystander enters a temporary (4 second) text notification is displayed to the VR user stating *"Presence detected"*. When the bystander exits the nearby area a temporary text notification is displayed with the text *"Presence left area"*. Communicates copresence existence only. (Figure 1)
- ***Avatar Representation:*** The bystander is represented as transparent avatar in the VR user's the virtual environment. Communicates copresence existence and position. (Figure 1)
- ***Audio Notification:*** An audio equivalent of the text notification which triggered an audio notification (a beep) when the bystander entered and left the nearby area. Communicates copresence existence only.
- ***Sonar Rader:*** A sonar radar with varying frequency of beeps was used to signal the bystander's distance from the VR user. Distances less than 1.0m from the bystander played at 160 beats per minute (BPM), distances between 1.0m and 2.0m at 80 BPM and distances greater than 2.0m at 40 BPM. Communicates copresence existence and position.

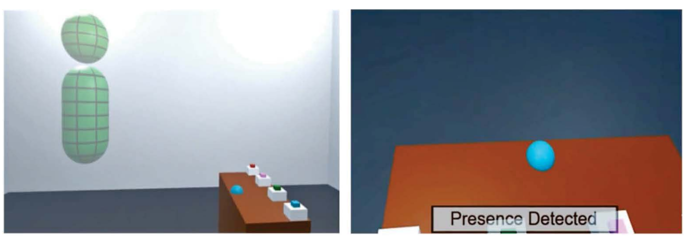

Figure 1. Left: The avatar representation; Right: The text notification

Experimental Design

We designed 2 tasks to compare our notifications:

- ***Button Task:*** Participants played a button pushing colour matching game for 1 minute (Figure 1). A target randomly displayed 1 of 4 colours with participants being required to push the button which matched the coloured target.
- ***Video Task:*** Participants watched 1 of 5, 1 minute videos.

The tasks were designed to test the notifications in a passive *(video task)* and more interactive *(button task)* scenario. Both notification and task type were counterbalanced across participants. While the participants performed the task one of the notifications or a baseline (no notification) was tested. Participants initiated the start of both tasks. In the video task participants pushed a button to play the video. In the button task the timer began upon the first button press. In both tasks participants were limited to use one controller.

Apparatus

A Microsoft Kinect 2.0 was used to detect copresence and to track bystander's position and map the information into the virtual environment in realtime. The Kinect was positioned on a table which the VR user stood behind. The difference in position of Kinect and VR user was offset in the application such that the avatar accurately mapped to the bystander's position. A HTC Vive was used and participants wore a pair of consumer Sony on-the-ear headphones.

Participants & Procedure

Participants were recruited using social media and mailing lists. 15 participants (5 female) completed the study. Participants ranged in age from 20 to 36 (M=25.1, SD=4.74). 7 reported prior experience with VR headsets. Upon arrival the session's purpose was explained and a consent form and demographic questionnaire given to the participant. The participant was then fit with the headset and positioned behind a table on which a Kinect sat. This fixed, standing position was used for both tasks. The experimenter then setup the first task and notification being tested and left the room. The participant was then instructed to start the task. After 20 seconds the experimenter entered the room and walked 1 of 5 set routes around the room. All routes began and ended at the door of the room. The door was left open to avoid noise disruption from its opening and closing. All routes spanned a range of approximately 2.5 metres to 0.5 metres from the VR user. The experimenter was copresent for a total of 25 seconds. When the task ended participants were told to remove the headset and were given the Igroup Presence Questionnaire (IPQ) [30] to complete while the experimenter setup the next task and notification to be tested. This process was repeated until all notifications were tested using both tasks. A semi-structured interview was then conducted to elicit participant feedback on the notifications design.

Limitations

Due to time constraints the task times used in the study are short which limits participants exposure to the notifications and subsequent scores on the IPQ questions asked.

COPRESENCE NOTIFICATIONS RESULTS

A Friedman test was used to find significant differences between IPQ scores across task and notification. No significant differences were found across any comparison. For brevity the mean IPQ scores are omitted, the lack of differences liking due to the short exposure time participants had to task and notifications. Interview transcripts were coded using initial coding [4] where participants' statements were assigned emergent codes over repeated cycles with the codes grouped using a thematic approach.

Copresence Without Position Created Discomfort

6 participants commented being made aware of copresence without the bystander's position made them uncomfortable, *P5: "Knowing someone was there with no idea where felt a bit creepy. It made me wonder where you were in the room. I preferred the avatar which told me exactly where you were"*. As one participant described it they were left feeling *"in the dark"* comparing the situation to being in a pitch black room and told someone was in the room with them. For this subset of participants great discomfort was created by the omission of positional information about the copresence.

5 participants compared the avatar and sonar radar notifications directly. They felt the sonar did not provide enough positional information about the point of interest, *P11: "I didn't know if*

you were to my left, right or straight ahead. It didn't really help or add anything to the experience". However, 2 participants did like the rapid beeping of the sonar and felt it conveyed a more urgent warning the bystander was in close proximity to them, *P3: "I thought the increase in intensity was good when someone gets up close and it starts beeping like crazy... I think it's a good warning"*

Notifications Risk Being Masked By Application In Use
8 participants said they felt notifications risked of being masked by the application in use. Participants said the audio notifications could be mistaken for the application's audio or vice versa, *P15: "With the audio it's like when you think your phone goes off or makes a noise and it's actually something in the film that you mistake for your own phone"*. Participants also felt the avatar could be mistaken for part of the experience itself, *P1: "With a game that's more intensive there's always the danger of people thinking the avatar is part of the game."* Rzayev et al. [28] have explored this risk in depth by investigating the effect of notification placement, task and environment on the user's perception of a notification and derived a set of design recommendations for displaying digital notifications in VR.

Personification of the Avatar
5 participants in our study made comments suggesting they personified the avatar. 2 spoke of it positively, *P7: "I gave him a wave because when he popped up I wanted to say hello to him"*. 2 spoke negatively, *P10: "It gave me the impression that it was always watching me and it was a little creepy and freaky"*. The 5th expressed a desire to be able to customise the appearance of the avatar *P11: "I would want to be able to dress it up and make it look like I wanted"*. As Scavarelli et al. [29] also documented the personification of avatars by users in a similar to ours the concept is worth exploring further. Future work could compare a user's ability to identify an avatar in a crowded scene where they have and have not customised the appearance of the avatar. Does allowing a user to customise the avatar's appearance make it more recognisable?

PROTOTYPE 2: DYNAMIC AUDIO ADJUSTMENT

Our second prototype implemented a reactive response to audio events in the user's surrounding area. Rather than speculate on future hardware design our proposed solution was designed to iterate on the existing capabilities of consumer headsets. Our prototype dynamically alters the user's audio by temporarily increasing or decreasing the user's volume in response to some external sound. We attempted to increase a user's awareness of a door knock sound by decreasing the application volume and decrease their awareness of a vacuum cleaner sound by increasing the application volume. We compared two existing audio systems (open ear audio and on-the-ear headphones) with our prototype dynamic variants of each.

Experimental Design

We developed a task where participants watched the first 8 minutes a nature documentary [7], presented in sequential 90 second videos, while using the tested audio conditions. As participants watched the video a 10 second audio clip was played through a nearby set of speakers. This occurred after 25 and 60 seconds. There were 2 audio clips: a door knock and a vacuum cleaner being started and used. Audio clip order was counterbalanced and controlled by a Unity application. The volume of the audio clips was corrected to match the decibel levels of an actual door knock or vacuum cleaner being used in the surrounding area. There were 4 audio conditions tested (open ear, dynamic open ear, headphones, dynamic headphones) which were counterbalanced across participants. The non-dynamic variants acted as the existing baseline methods. The dynamic variants would temporarily decrease the application audio in response to the door knock and temporarily increase in response to the vacuum cleaner. Audio adjustment was done via a linear interpolation method. A pilot test determined the volume changes and transition times. Four participants provided qualitative feedback on a range of volume changes and times to find a noticeable volume change and smooth transition time. Participants who did the pilot test did not do the experiment. The software audio started at 60%. The temporary decrease in audio reduced the audio to 12.5% over 0.5 seconds. It remained at this for 9 seconds then returned to 60% over 1 second. The temporary increase in audio increased the audio to 100% over 0.5 seconds. It remained at this for 9 seconds then returned to 60% over 1 second. Volume adjustment was also applied to the vacuum audio clip to fade the audio out rather than hard cut to silence when it ended. Participants were not required to provide input during the experiment. Instead the experimenter used the headset's controller to start each condition and to cause the dynamic change in application audio if necessary.

Apparatus

An Oculus Go headset was used in the study. Participants used the headset's open ear audio and a pair of consumer Sony on-the-ear headphones. The audio stimuli was produced using a pair of consumer speakers attached to a laptop positioned 2.5 metres from the seated participant.

Participants & Procedure

Participants were recruited using social media and mailing lists. A total of 16 participants (7 females) completed the study. Participants ranged in age from 19 to 31 (M=23.13, SD=3.56), 10 reported previous experience using VR headsets and 4 reported prior experience with open ear audio technology.

Upon arrival the session's purpose was explained and a consent form and demographics questionnaire was given to the participant. The participant was then fit with the headset and headphones. Participants were required to calibrate the volume to be used in the experiment for the open ear audio and headphones conditions. Participants were instructed to set the volume as if they were using the headset at home. First the headphone volume was set using a 45 second video after which participants were instructed to remove the headphones. A 45 second video was then used to set the open ear audio volume. Participants were then setup with the first audio condition being tested and the experimenter started a 90 second video and the Unity application used to trigger the audio stimuli. As participants watched the video the first 10 second audio stimuli was triggered after 25 seconds and the second after 60 seconds. If required by the tested condition upon hearing the audio stimuli the experimenter would trigger the relevant audio adjustment (a temporary decrease for the door knock, a temporary increase for the vacuum). At the end of the video a notification instructed participants to remove the headset. Participants were then given a paper questionnaire with nine 7-point scale questions to investigate their experience with the tested condition. The questions asked are summarised below:

- ***Distraction:*** Distraction from VR due to reality
- ***Awareness:*** Awareness of surrounding reality
- ***Comfort:*** Comfort in personal space
- ***Present:*** Feeling of being present in the virtual world
- ***Mental:*** Mental immersion in the experience
- ***Involvement:*** Subset of the IPQ questionnaire [30]
- ***Sense of Being There:*** Subset of the IPQ questionnaire
- ***Awareness Vacuum:*** Awareness of the vacuum sound
- ***Awareness Door Knock:*** Awareness of door knock sound

Participants were setup with the next condition being tested and the process was repeated for all remaining conditions. Upon completion of all the conditions participants were asked to rank the audio conditions by preference. A semi-structured interview was conducted where participants were asked to justify their rankings.

Limitations

The condition specific questions asked, particularly the IPQ subset questions, are not as accurate as they would be had participants been exposed to longer videos (15+ minutes). Audio adjustment could have been triggered by software rather than by the experimenter. However as a reality aware headset will vary its response time by scenario we felt a human experimenter's reaction would suffice. The audio solutions considered in our study are limited to the system's open ear audio and on the ear headphones. Alternative audio solutions such as open back or bone conductance headphones are worth exploring in future work.

DYNAMIC AUDIO INVESTIGATION RESULTS

As reality aware VR headsets typically increase a user's awareness of reality at the cost of immersion within VR we evaluated our prototypes to see what impact (if any) they would have on the user's experience. The results are shown in Table 1. A Friedman test was used to find significant differences between factors. Pairwise comparisons using Wilcoxon Signed Rank test with Bonferroni corrected p-values *($p < 0.0083$)* revealed significant differences between only headphones and the dynamic open ear / dynamic headphones for awareness of the door knock sound. Participants commented that the vacuum sound was loud enough to be disruptive over the increase in volume. In the other factors all of the audio conditions performed similarly suggesting all can provide a sufficient quality audio experience. While our results are limited they are positive and identify audio reduction to direct attention as a viable use of dynamic audio adjustment.

Factor	OE	DOE	H	DH	Wilcoxon ($p < 0.0083$)
Distraction	3.875 (1.452)	4.25 (1.25)	3.938 (1.519)	4.188 (1.379)	*NA*
Awareness	4.563 (1.368)	4.25 (1.521)	3.688 (1.530)	4.23 (1.521)	*NA*
Comfort	4.875 (1.615)	4.563 (1.223)	4.688 (1.488)	4.438 (1.657)	*NA*
Present	3.813 (1.667)	4.188 (1.509)	4.313 (1.570)	3.938 (1.853)	*NA*
Mental	3.688 (1.210)	4.0 (1.5)	4.25 (1.25)	4.0 (1.581)	*NA*
IPQ PRES	3.438 (1.456)	3.688 (1.609)	3.875 (1.615)	3.563 (1.836)	*NA*
IPQ INV	3.406 (0.537)	3.422 (0.584)	3.438 (0.742)	3.531 (0.717)	*NA*
Vacuum Awareness	6.75 (0.559)	6.934 (0.242)	5.438 (2.235)	6.0 (1.837)	*NA*
Door Knock Awareness	4.5 (1.837)	5.75 (1.199)	3.5 (1.904)	6.125 (0.927)	*DOE - H* *DH - H*

Table 1. Audio condition specific questions; Mean (Std Dev). [OE: Open Ear, DOE: Dynamic Open Ear, H: Headphones, DH: Dynamic Headphones]. Results show only significant differences in awareness of door knock sound

PC / AC	1st	2nd	3rd	4th	Average Ranking
OE	3 (18.75%)	4 (25%)	4 (25%)	5 (31.25%)	2.313
DOE	3 (18.75%)	3 (18.75%)	7 (43.75%)	3 (18.75%)	2.375
H	8 (50%)	3 (18.75%)	1 (6.25%)	4 (25%)	2.938
DH	2 (12.5%)	6 (37.5%)	4 (25%)	4 (25%)	2.375

Table 2. Preference ranking of audio conditions; PC: Preference Counts; AC: Audio Conditions [OE: Open Ear, Dynamic Open Ear, Headphones, Dynamic Headphones]

Preference Ranking

Participants were asked to rank the audio conditions in order of preference. The average ranking is shown in Table 2. Headphones were the preferred audio condition, dynamic headphones and dynamic open ear audio were tied second with open ear audio ranking last.

When asked why they preferred headphones 8 participants said headphones block out external sounds which they felt is important for creating a high quality, immersive experience, *"that's just how I like my audio to sound, isolating"*. 2 said headphones provided an "audio consistency" not guaranteed with open ear audio. 7 participants said the audio quality of open ear audio was their biggest complaint with it, *"[Open ear audio] the quality wasn't that great, the sound was not that immersive"*. 4 said if the audio quality was better it would prefer it over headphones.

Participants who preferred open ear audio indicated comfort and convenience made it preferable to headphones. 6 participants expressed a direct desire to avoid wearing headphones wherever possible. When asked why they did not like wearing headphones participants said they did not like being unaware of their surroundings with audio awareness being a factor of this, *"I don't like not having an awareness of my surroundings, audio is an element of that"*.

Despite both dynamic variants being tied second participant comments of dynamic audio adjustment was mixed. 6 participants said they liked the use of dynamic audio but felt it should be included as an optional setting as not all users would want it, *"The option should be there if you want it, I think some people definitely would use it"*. 7 participants commented the dynamic adjustment felt unnecessary and the standard open ear audio was sufficient if increased awareness was desired, *"If I want awareness open ear is enough"*. 3 participants believed there would be too much variability in whether they wanted to hear an external sound or not and would prefer to decide and adjust the volume directly, *"I would rather decide and change the volume myself because sometimes things I don't want to hear could change into something I do want to hear"*.

Generally though participants were more divided by audio type: those who preferred open ear audio (standard or dynamic) and those preferred headphones (standard or dynamic). Ordering within audio type may have been harder which might explain the tied second place ranks.

DISCUSSION

Copresence With and Without Position

Notifications which communicate a bystander's position to the VR user have proven disruptive to a VR user's sense of presence in VR [19]. Less intrusive notifications, such as text notifications, have been suggested as sufficient for communicating copresence [9, 19]. Our first prototype investigated communicating copresence with and without positional information and highlighted a subset of VR users who when informed of copresence without position were made uncomfortable. They compared the sensation to being in a pitch black room and told someone was in the room with them. This made them uncomfortable and would likely result in removal of the headset, a complete break in presence. Ultimately a range of solutions will be required to accommodate the differing needs of users [39]. Users comfortable with notifications which omit positional information can use those while users not comfortable can use an alternative which does. Future work can explore both notification types. One immediate follow up to our work is to compare a direct map of the bystander's position in the virtual world (e.g. an avatar [19, 37]) with a visualisation of the bystander's position (e.g. a radar [33]) to see what impact this has on presence and comfort.

Dynamic Audio Adjustment

Participants responded positively to dynamic audio adjustment which lowered the application volume to direct attention. Dynamic audio adjustment which increased the application volume to block out a nearby sound proved ineffective. This makes sense from a perceptual standpoint as lowering the volume of an audio source to heighten another is typically more effective than attempting to increase the volume of an audio source to overpower a competing audio source. Anyone who has lowered a television's volume to hear someone nearby speaking and attempted to increase a television's volume to be heard clearly over a nearby vacuum cleaner is familiar with. Of the two approaches we believe altering volume to direct attention is the more promising direction and suggest future work should expand on it.

Future Reality Aware VR Headsets

While consumer headsets already feature reality aware behaviours the full extent of their capabilities has yet to be explored. Future work could extend the existing work by contextualising the inclusion of objects into VR, e.g. to identify when a user reaches towards a cup of coffee and blending it into the virtual world. Work might even look to contextualise bystander inclusion so that familiar, trusted persons are identified and ignored but users are warned when a stranger enters the nearby area. Alternatively work explore new reality aware behaviours. For example, no system at present can identify and communicate the copresence of pets which can be problematic and hazardous for some VR users. Current research has been limited in both the reality aware behaviours and proposed solutions. Future work should explore the entire possibility space and propose a variety of systems for a range of reality aware behaviours.

Future Virtuality Headsets

Currently augmented reality (AR) and VR are two separate entities. As AR advances it will be capable of overlaying more of the user's reality with virtuality, eventually being capable of overlaying all of the user's reality and becoming a VR experience. Likewise as VR develops the amount of reality incorporated will increase and the experience tend towards an AR experience. Eventually the two will converge and headsets will emerge which allow users to tailor their experience to a range of positions on Milgrim's reality-virtuality continuum [22, 21]. These future headsets will be capable of allowing users to specify which elements of reality (if any) they want communicated to them. Such headsets will allow users to experience a pure VR where no element of reality is communicated or an AR experience where minimal virtual elements augment reality. Reality aware VR headsets are a step towards these future headsets. There is much debate and speculation on-going about whether AR or VR will be the more widely adopted technology in future. We envision both coexisting with experiences tending towards AR or VR as they are currently thought of being dependent on the application's purpose and user's desired experience with it.

CONCLUSION

This paper presents a conceptual model of a reality aware VR headset alongside two prototypes to investigate potential reality aware behaviours of such a headset. Our first prototype investigated the automatic communication of bystander existence to the VR user and compared notifying with and without information about the bystander's position. We identify a subset of VR users who when notified of copresence without position are made uncomfortable. Our second prototype investigated how dynamic audio adjustment could be used to react to audio events in the user's surroundings. We highlight positive results when decreasing application volume to direct the user's attention to some audio event.

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