Mobile HCI Coursework – Group 08

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1 PROBLEM ANALYSIS

Our team decided to develop an AR application for cyclists to navigate to waypoints using a combination of binaural, peripheral audio and visual representations of the waypoints in their field of view using AR glasses.

We decided to focus on all-wheeled personal transit devices as our solution can be worn and used without the need for any mounting points, such as a bike frame. It was decided to design the application for smartphones as they are portable, widely used, and powerful enough to run AR applications. Our app aims to improve the rider's experience by providing a more intuitive and safer way of navigating through audio and visual cues. The user can keep their focus on the road while receiving audio cues and visual representations of the waypoints in their field of view.

The app will use the camera of the AR glasses and the GPS of the smartphone to overlay the waypoints onto the real world, making it easy for the user to navigate. The audio cues will be delivered through a combination of binaural and peripheral sound, which will provide an immersive experience and allow users to remain aware of their surroundings.

One of the challenges of our chosen usage context is potential distraction caused by both visual and auditory feedback. The visual cues could occlude nearby pedestrians or cars, whilst the auditory cues could prevent the user from hearing oncoming vehicles.

Our potential users are wheeled users who need to navigate to specific destinations safely. They want an application that is as easy or easier to use than conventional apps whilst not distracting them from their surroundings by making them look away from the road.

The novel selling points of our interaction ideas are the combination of binaural, peripheral audio and visual representations of the waypoints in their field of view, which we believe will complement each other and provide an immersive and intuitive navigation experience.

We chose this approach because it provides an immersive and interactive experience while remaining safe for the user. The combination of audio and visual cues allows the user to remain aware of their surroundings and the app is easy to use. We also considered other solutions, such as overlaying the path of the rider on top of the real-world road but discarded this idea as it lacks novelty while at the same time being non-trivial to implement. In contrast, our chosen solution provides a more novel and easily-implementable input, which explores old techniques under new contexts. Overall, our solution offers a unique and innovative way of navigating cyclists, which we believe will improve their experience and safety on the road.

2 INTERACTION CONCEPTS

A range of interaction concepts was chosen to be used for this project, to support and complement the various features and drawbacks of each concept.

The input interaction concepts decided upon were split into two sections. While setting up the tutorial that they wish to run and selecting the wheeled vehicle they will be running it with we felt it best to use a fairly ubiquitous touchscreen-based interaction. Allowing users to easily and understandably select the options they'd

like to form a potentially variable list. As the users would yet have started moving on their vehicles, we felt this was still a safe and appropriate method of interaction.
Once they had selected their tutorial course and begun moving, the primary input interaction would be via GPS location data. This would allow users to interact with the application in a safe and non-intrusive manner, it would not draw the users' attention and would allow them to focus on moving on their vehicle and reacting to the output information, as well as not using the users' hands, which they may need to use for their vehicle. Users would move through physical space, with this being recorded through changes in their location data, allowing the application to appropriately give feedback on where the users should aim to hit the checkpoints and to identify when users had reached said checkpoints.

The output interaction concepts chosen were as follows:

- Before the beginning movement, setup information would be relayed to the users through a visual user interface on a touchscreen device.
- Once the user had begun moving, information on where the checkpoints lay would be given to them through a multimodal mix of interactions. An AR (Augmented Reality) overlay would lie over their vision, this overlay would show the location of the checkpoint they were aiming for with a visual location marker. This would be appropriate for this context as it would not overly occlude the users' vision, split their attention between the road and a device, or require any amount of concentration from the users'. However, an issue with AR is its small field of vision, which may cause issues for the user if the new checkpoint appears outside of that field of vision.
- To combat this another output interaction would be used in combination with it. Bidirectional sound. This be used to channel sound into the users' awareness from the direction of the checkpoint, allowing users to be aware of it even in the extreme peripherals which are normally out of range to AR technology. Along with indicating the direction of the checkpoint, it could also be used to give an idea as to the distance to the checkpoint and whether a user is approaching it, this could be done through multiple potential options, such as increasing volume, frequency or rate of pulsing as users approach the checkpoint. A single major issue with bidirectional sound as an interaction method is that it does not allow for precise navigational assistance, as it can be difficult to navigate to a point in space solely using auditory cues. However, the addition of visual AR interaction mitigates this issue, allowing for the sound to be used to gain a rough heading and then the AR to be used to identify the precise point once it's in view.

3 USER INTERFACE DESIGN

For the user-interface design, we aimed for the pages to be as simple as possible since the app will be being used often while on the move.

As depicted in figure 1, the home page is very simple - with just two buttons and potentially a logo - and these buttons are big and easy to tap so that the user can remain on the move while using the app.

Tapping the "Configure" button will take the user to the Configure page, where they can calibrate their sensors for the app, which is important to have as the app relies on GPS and accelerometer data for the user's movement in-game, and thus they should calibrate these sensors often. There is also a "Select Waypoint" field, where the user can select the look of the visual waypoints. This is on the configure page as it's unlikely that the user would want to change this often, so asking them to choose every time they want to start a game would be unnecessarily burdensome. Finally, there are User Account Settings, where the User will be able to change or set details like their name, email, password, and any other account settings that might be implemented in the future, as well as a log-out button. These would all be replaced with login and Sign Up buttons if the user was not logged into their account or did not have one.

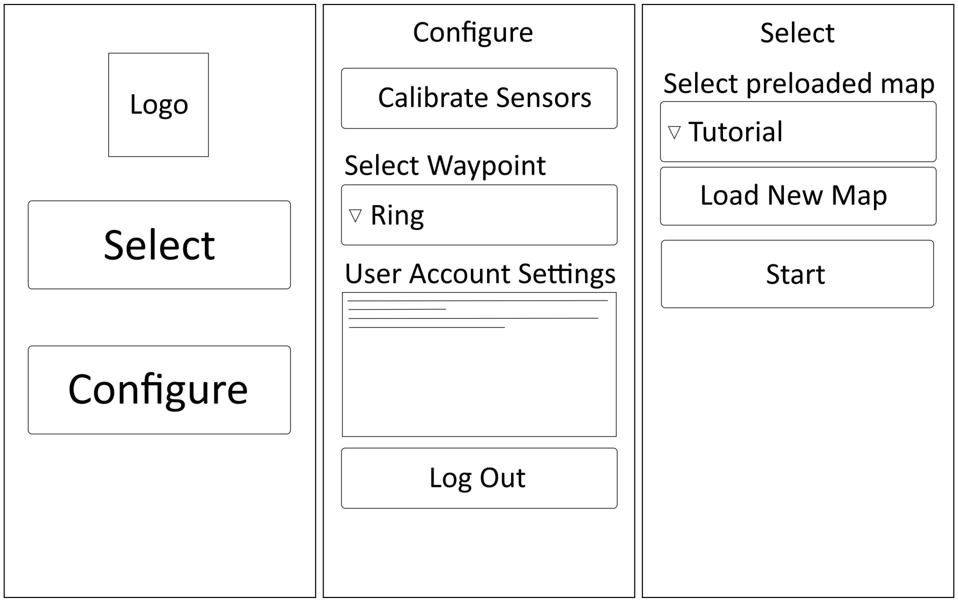

Fig. 1. *Wireframes for the main pages of the app. In order from left to right: Home, Configure, Select.*

Tapping the "Select" button on the home page will take the user to the Select page, which is very streamlined to make the process of starting a game as easy as possible for the user. The user will have to select a map from a list of the maps they have already loaded onto the app, this will likely include maps that come with the app (such as a tutorial map), and any maps that the user has downloaded from the internet. This is so that the user can choose to use maps created by the community. The start button, upon being clicked, starts the game for the user with the map and all the settings they've chosen. An example of how the game would look can be seen in figure 2.

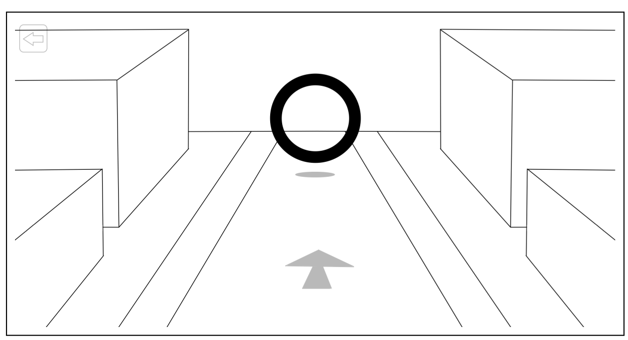

Fig. 2. *Wireframe depicting a ring waypoint on a one-way street.*

Here 2 we can see the user in-game, on a one-way street looking towards a ring checkpoint. We have deliberately chosen a very unobtrusive user interface for the in-game view as we want the user to be as attentive as possible, both so that they can focus on the checkpoints and so that they can focus on the environment around them, for their safety. The only visual elements will be the checkpoints, which will be either a ring, sphere, or cylinder depending on what the user chooses, and a small exit button, which is transparent and in a corner to be as unobtrusive as possible, while still being easily accessible for the user. This is all that should be needed as movement is controlled by the user's physical movement in real life.

4 PROTOTYPE IMPLEMENTATION

Development was carried out in two main stages; visual design of the waypoints and implementation of the auditory experience. These two stages also align with the user experience, as one is concerned with the peripheral, rough awareness and the other with the visual, specific awareness.

The tools used to implement it was a mixture of native JavaScript APIs and the A-Frame framework. The reason behind these choices is that A-Frame provides a collection of high-level functions for creating augmented reality applications, including loading in virtual scenes and primitive shapes, while the JavaScript APIs provide access to underlying device faculties, such as sensor data and speaker output.

4.1 Waypoint designs

The implementation of the waypoint designs was carried out by using the A-Frame primitive shapes torus, sphere, and cylinder. These shapes were chosen both to contrast with the surrounding environment, ie. not being square-like buildings and also to be visually appealing to the user.

Using the documentation for A-frame primitives [5] the dimensions, look and animations of the objects could be defined.

Primitive objects are instantiated by creating an 'HTML' element with the appropriate tag, such as 'a-cylinder', and defining the various properties of that primitive as seen in the following sample code. Here we see the position, radius, height and colour being defined:

```
<a-cylinder position="1 0.75 -3" radius="0.5" height="1.5" color="#FFC65D"></a-cylinder>
```

The waypoints were designed to appear in the user's field of view as animated geometric shapes, since non-static objects are far better at attracting human attention [4]. The properties of the primitives, including the opacity, size and position, were hence modulated with respect to time.

The animations were defined by specifying the property of the primitive to animate, its target value, duration and various other properties, as seen in the following sample code:

```
"property: material.opacity; to: 0.3; loop: true; dur: 1000; easing: linear; dir: alternate;"
```

During the implementation process, several design decisions were made to ensure that the core interactions could be explored. For example, the visual waypoints were designed to be large and brightly coloured, to ensure that users could easily identify them while cycling.

Looking at Figure 3, we can see the various visual representations of the waypoints, which are described in the following list.

- A large, brightly coloured yellow ring, which rotated about its y-axis (y-axis going towards the sky) and also translated along its y-axis in an alternating fashion.
- A 200-metre-tall green column with a radius of 3 metres, which had its opacity change with respect to time, such as to give it a flashing effect.
- A large, red sphere with a radius of 5 metres, which grew and shrank in size in synchrony to its opacity increasing and decreasing.

4.2 Binaural audio

In terms of sound feedback, binaural audio was used to provide the user with peripheral feedback. Binaural refers to the quality of having two channels, which output separate sounds.

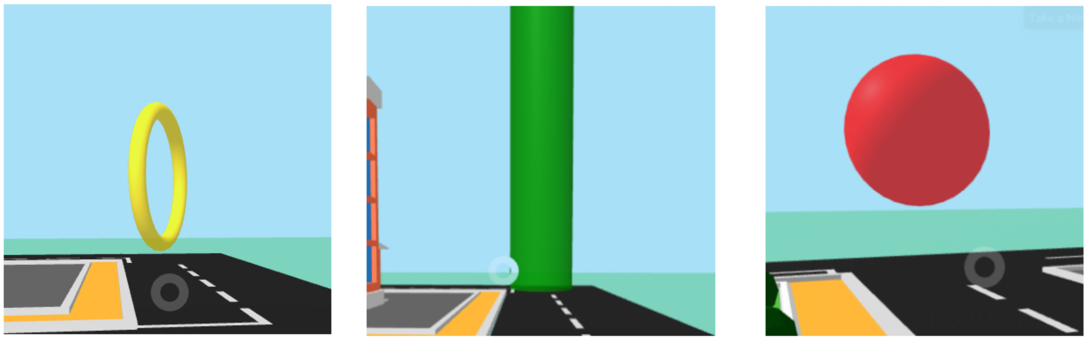

Fig. 3. *An overview of the three different waypoints used. Going left from right: a yellow ring, a green column and a red sphere.*

The implementation involves the modulation of volume, frequency, and pulse length of the sound feedback based on the user's location and direction. These features were chosen to explore which auditory feedback methods would be most effective and comfortable for the user to navigate their environment.

The development involved using the Web Audio API [2] to instantiate the various components needed as seen in Figure 4.

Two oscillators are instantiated, one to act as the carrier frequency (main tone heard by the user) and the other to act as a low-frequency pulse, controlling the gain of the carrier frequency.

The sound is passed through a low-pass filter to remove uncomfortable, high-pitch components. Following this step, it is passed through a panning node, which enables the balance of the sound to be moved from the left to the right ear and back. Lastly, it is passed through another gain step, allowing for a master volume control, before being output to the speaker or earphones connected.

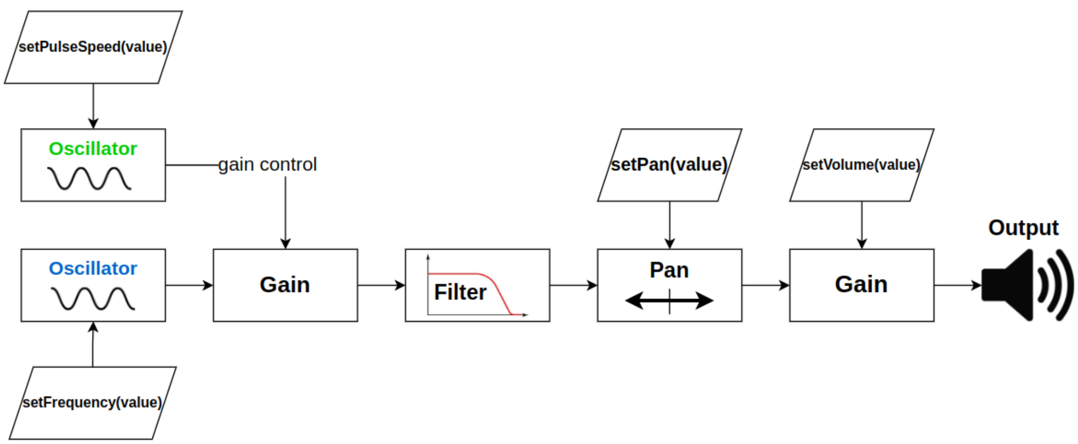

Fig. 4. *An overview of the audio pipeline, allowing for control of various properties such as volume, pan, frequency and pulse.*

To drive the various features of the sound, the distance and direction of the user must be obtained.

The distance could be obtained by taking the difference in (x,y) coordinates between the user's location and the waypoint to create a vector. The magnitude of that vector then became the distance.

Furthermore, that same vector could be used to determine if the waypoint was on the right or left of the user. This was done by finding the angle between the vector and the 'camera' vector, which could be converted to a value between -1 and 1 to drive the panning of the audio from left to right.

For conveying information about the distance, three different directions were explored; volume, pulse frequency and carrier frequency.

The volume was set to be the inverse of the distance, so the smaller the distance, the greater the volume. This was done to mimic the natural world, in which objects in closer proximity are louder than those in the distance. The pulse frequency was set to be the logarithm of the distance, such that it would tend towards infinity at zero distance and drop off exponentially as the user moved away. Pulse frequency was chosen with inspiration from a modern car's parking mechanism, in which pulses become closer and closer as the car reverses near a wall. Lastly, the carrier frequency was also set to be the logarithm of the distance, but orders of magnitudes were higher to be in the auditory range. Since humans are very perceptive to changes in frequencies vs. changes to amplitude [1], this was thought to be another good direction of exploration.

Since one of the main developers was absent for the most part, there was less time to be spent on developing alternative designs and a visually appealing user interface for selecting scenarios. For this reason, only three scenarios came to exist for the visuals and audio, respectively.

5 EVALUATION

With the prototyping for the interaction concepts completed the next step of the process was the evaluation. We decided on a user study style evaluation design with a focus on identifying the best formats for the output interaction methods we had decided to use.

For the evaluation, several different question types were chosen to draw varied and extensive responses from the participants. Participants were asked to rate the clarity for each of the 3 options for both the visual waypoints and auditory direction guidance, this rating was done on a basic 5-point Likert scale. They were also asked to rate how likely they would be to use the application with the given option, again on a 5-point Likert scale. Alongside this, they were asked to rank the three options for each interaction modality by preference. Finally, participants were asked to answer a series of short open-ended questions on whether there were any major issues they had identified with any of the features shown or whether there was any feature they especially liked.

The general layout of the evaluation consisted of users being asked to explore the prototype application while using a specified option, and then giving feedback on that option with the two Likert-scale type questions. Once all three options from an output modality had been explored, they were asked to rank them. Then Once each modality section had been completed fully they were asked to complete the open-ended questions.

We felt it was best to aim for 12-15 responses for our evaluation. The reasoning for this was due to the recommended sample size for medium-to-large scale user study being 15 ([3]). At the completion of our evaluation period, we collected 13 responses, which we felt were within range of our preferred amount, so we chose not to extend our evaluation period.

5.1 Likert Scale Analysis

The survey's goal was to determine the most preferred sound option and checkpoint design for the app. This was accomplished by assessing the clarity of the various sound options and designs, as well as asking participants if they would be more or less likely to use the app with a specific design in place. Finally, participants were asked to rank their preferred options on a scale of 1 to 3, with 1 being their top choice.

5.1.1 Bidirectional Sound. The aim of using Bidirectional sound, as mentioned before, was to alert the user to their proximity to a certain point. We thought of 3 methods by which this information can be delivered using bidirectional. We can change the volume, frequency and pulse.

Volume

According to the survey results, all participants perceived the volume change as clear, with the majority agreeing. However, when compared to the clarity of the volume change, a significant number of participants stated that if the volume method was used, they would not use the app. Despite this, a large majority of respondents said they would use the app if the volume method was implemented.

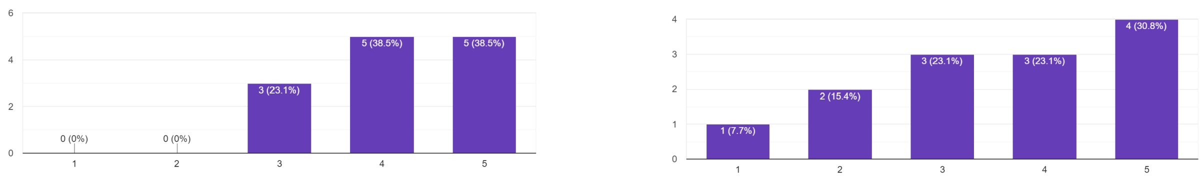

Chart showing the clarity of changing Volume, 5 being "Very Clear"

Chart showing how likely they would be to use the app if this method was used, 5 being "Very Likely"

Fig. 5. Evaluation results for Volume

Frequency

The results for this method show the highest degree of variability, as seen in the graph where 11 out of 13 participants found the information delivered by the sound to be extremely clear. This finding is also supported by the conclusion, where a majority of participants expressed a strong likelihood of using the product if this method was implemented.

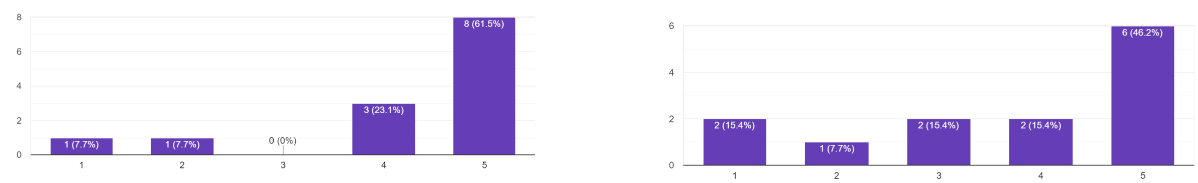

Chart showing the clarity of changing frequency, 5 being "Very Clear"

Chart showing how likely they would be to use the app if this method was used, 5 being "Very Likely"

Fig. 6. Evaluation results for Frequncy

Pulse

This method received mostly positive feedback, though it was not as varied as the frequency method and performed better than the volume method. The majority of users stated that if this method was used, they would be more likely to use the product. Surprisingly, a large percentage of users indicated that the implementation of a pulse method would not change their likelihood of using the app.

5.1.2 Waypoint Options. The aim of comparing the waypoint methods was to identify the most visually appealing and most understandable design for indicating the next direction. Three different designs and methods were put to the test: a Sphere, a Column, and a Sonic Ring.

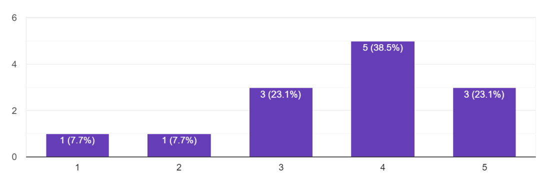

Chart showing the clarity of changing pulse, 5 being "Very Clear"

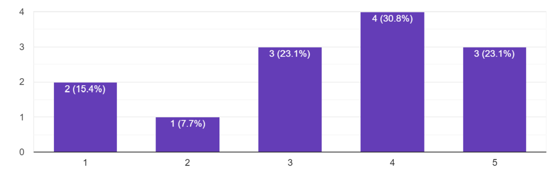

Chart showing how likely they would be to use the app if this method was used, 5 being "Very Likely"

Fig. 7. Evaluation results for Pulse

Sphere

More than half of the participants found this method simple to understand, but a significant number found it difficult. This is evident in the responses to the question "How likely would you be to use the app if it used this method?", where more participants than desired indicated that they would not use the app if this method was used.

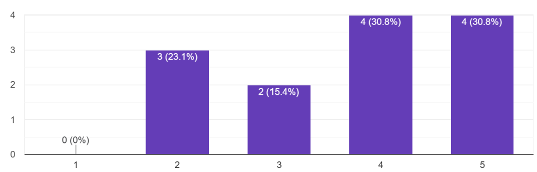

Chart showing the clarity sphere waypoint, 5 being "Very Clear"

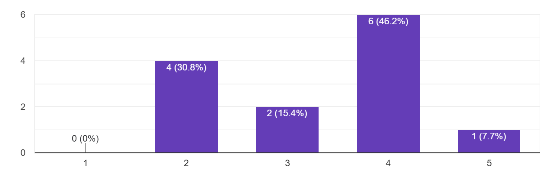

Chart showing how likely they would be to use the app if this method was used, 5 being "Very Likely"

Fig. 8. Evaluation results for Sphere

Column

This method received overwhelmingly positive feedback, with more than 80% of the participants (11 out of 13) reporting that it was extremely simple to interpret. Furthermore, if the Column method was developed, 12 out of 13 participants either expressed a neutral stance or reported a higher likelihood of using the application.

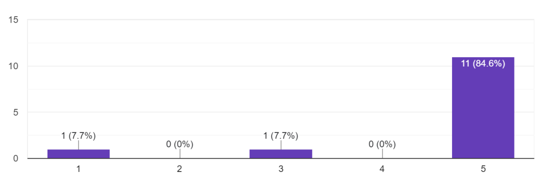

Chart showing the clarity column waypoint, 5 being "Very Clear"

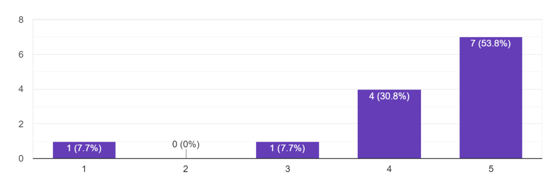

Chart showing how likely they would be to use the app if this method was used, 5 being "Very Likely"

Fig. 9. Evaluation results for Column

Sonic Rings

This method produced uniformly distributed results, with a fairly even distribution of feedback. Based on this method, it is difficult to draw a conclusive interpretation of user opinion. Similarly, the feedback on the likelihood of increasing app usage was not strongly skewed in either direction, though there was a slight tendency to use the app more.

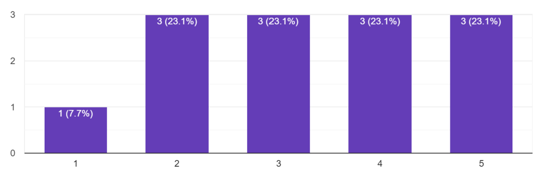

Chart showing the clarity Sonic Ring waypoint, 5 being "Very Clear"

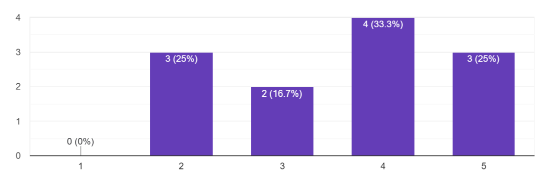

Chart showing how likely they would be to use the app if this method was used, 5 being "Very Likely"

Fig. 10. Evaluation results for Sphere

5.2 Ranking Analysis

In order to best analyse the ranking data we had collected from our participants and obtain a singular highest-ranked option for both interaction modalities we decided to use the Schulze method.

The Schulze method is a Condorcet method of selecting a single 'winner' from a set of ranking/preference responses. It works based on finding the strongest path between each pair of points/options and then using values associated with these paths to identify the overall most highly ranked option.

5.2.1 Auditory Ranking. The Condorcet table for the auditory ranking can be seen in table 1.

	[*, Volume]	[*, Frequency]	[*, Pulse]
[Volume, *]	0	6	6
[Frequency, *]	7	0	4
[Pulse, *]	7	9	0

Table 1. Condorcet matrix for the ranking data collected. Cell [X,Y] contains the number of participants who ranked higher X than Y, for example, cell [Volume, Frequency] holds the number of participants who ranked the volume option higher than the frequency (6), and cell [Frequency, Volume] holds the number who ranked the frequency option higher than the volume (7). As participants must have one task higher than the other for any given pair, the complementary values add to the total number of participants, e.g. [Volume, Frequency] + [Frequency, Volume] = 6 + 7 = 13

Using the Schulze method on this Condorcet matrix we obtain the overall 'winning' option to be the **Pulse** option.

5.2.2 Visual Ranking. The Condorcet table for the visual ranking can be seen in table 2.

	[*, Sphere]	[*, Column]	[*, Ring]
[Sphere, *]	0	3	3
[Column, *]	10	0	9
[Ring, *]	9	4	0

Table 2. Condorcet matrix for the ranking data collected. Cell [X, Y] contains the number of participants who ranked higher X than Y, for example, cell [Sphere, Column] holds the number of participants who ranked the sphere option higher than column (3), and cell [Column, Sphere] holds the number who ranked the column option higher than the sphere (10). As participants must have one task higher than the other for any given pair, the complementary values add to the total number of participants, e.g. [Sphere, Column] + [Column, Sphere] = 3 + 10 = 13

Using the Schulze method on this Condorcet matrix we obtain the overall 'winning' option to be the **Column** option.

5.3 Open-ended Analysis

Users were asked open-ended qualitative questions at the end of the user assessment process to provide any extra feedback or remarks that they may not have had the opportunity to mention during the evaluation. As open-ended questions allow users to express their thoughts and feelings in their own words, these questions seek to generate more detailed and richer input from them. The advantage of such questions is that they can lead to unexpected discoveries or views that were ignored or not explored in the user survey, which could serve as the basis for further research and development.

The only issue that occurred with the web design visuals was that the web application's home screen lacked mobile responsiveness, compromising its general usability. This was only reported by one user.

According to the qualitative feedback received from survey participants about the audio feature, the change in volume/frequency/pulsation of the sound did not change linearly with distance to the target. Instead, it seemed to change step-by-step, which made it difficult for users to perceive the change accurately, particularly when there was no visual on the target. Some users also reported a distorted glitch sound when the bi-directional sound switched from one direction to another. While the sound switching between right and left was smooth, it felt a bit abrupt when it switched from one side to both. To improve this, some users suggested a slight fade-in of noise in the opposite ear as they faced the waypoint directly. Additionally, some users found certain options harder to identify than others, and based on their experience, the frequency sound option was better than the other two options.

Interestingly, some users preferred the pulse option because it was the gentlest sound and combined the best aspects of all sound options while remaining non-aggressive. As users got closer to the waypoint, the volume and frequency increased, making it easier to identify. Overall, these findings can help to improve the app's audio feature for a better user experience.

In terms of the waypoint feature, some users felt that the column was better suited as an endpoint rather than a waypoint. They preferred the ring option as a waypoint, but they did not like the rotation in the ring. However, one user reported liking the column because it was easy to see from a distance and visible over the top of the buildings. Another user appreciated the size of the column.

While the column was well-made, some users felt that they had seen it in other games as an endpoint and therefore, it would be more suitable as an endpoint rather than a waypoint.

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