Combining Virtual Reality and Narrative Visualisation to Persuade

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***Abstract*—This paper combines narrative visualisations with modern 3D virtual reality technology to create an effective and focused presentation that persuades the user of a given theory or opinion. The aim of this is to show using virtual reality creates a more pleasing experience and allows a more powerful connection to be made between the user and the information. A user study was run to test these techniques. In the user study, thirty people explored a 3D space with data and narrative visualisations placed inside.**

I. Introduction

Narrative Visualisation, the incorporation of storytelling elements seen in other mediums like film and theatre, is a subset of visualisations that aim to aid with the comprehension of massive datasets by representing the data in a more compelling and empathetic manner. Narrative visualisation was first coined by Segel and Heer [1] as a means of incorporating the strengths of current narrative trends and applying them to the field of data visualisation. The research described in this paper is motivated to design a set of techniques that can be applied to any generic case when creating narrative visualisations. Specifically, narrative visualisations that are part of a virtual, immersive and 3D world. This research is also motivated to minimise the issues of bias raised in regards to narrative visualisations. To resolve bias, a technique for allowing viewers of narrative visualisations to see the author's message and the user's point of view through a favourite system is offered. The users will be able to record which facts presented supports their point of view. At the end of the session, the user is able to compare their supporting facts with those of the author.

Complicated datasets combined with an emotionally charged debate is an ideal subject to test the advantages of narrative visualisation. Enhancing data visualisations with narrative trends allows a clear and explicit message to be delivered, removing the ambiguity and concerns about bias reporting from the discussion. Furthermore, the advantages of presence found through Virtual Reality (VR) [2], [3] can be applied to these visualisations to strengthen the connection between the user and the data. We employ the following definition of presence "*the sensation the user gets from what they are experiencing through virtual reality despite knowing that what they are viewing is not physically real*" [2], and the follow definition of immersion "*the technical capability of the system to deliver a surrounding and a convincing environment with which the participant can interact*" [2]. VR allows a greater spatial understanding and can allow more natural interactions.

This paper aims to answer the following questions: 1) *Is a narrative visualisation enhanced by the inclusion of VR technology?* and 2) *What is the set of suitable techniques to develop narrative visualisations in VR?* To answer these questions, a user study will be performed with a set of data videos placed within a virtual space. The users will be asked to explore the environment and interact with each narrative visualisation in the order of their choosing. This enables the user to view the data video of most interest. This allows the user to feel in control of story that is unfolding and not forced down a particular narration. The study will be a between groups design: 1) use of a standard desktop display with a mouse and 2) use of a VR headset with a set of hand controllers. Throughout the experiment, the user will be able to favourite visualisations that they feel carried relevance or had an impact. At the conclusion of the study, the user will be able to compare the visualisations they favoured to the one's that the author felt were the most important visualisations. By opening this channel of communication between the end user and the author, the user will have a clearer understanding of the author's intentions.

This paper aims to make three contributions to the field of Virtual Reality and the field of Narrative Visualisation. The contributions made by this paper are as follows: 1) A VR narrative visualisation technique for creating an immersive experience by taking statistics gathered through data analysis and data video narrative visualisations to create an enhanced user experience. 2) A strategy for deploying these visualisations into a 3D VR environment allowing exploration and interaction on the part of the user or viewer. 3) Finally, a user study that tests the effectiveness of this VR strategy to induce a sense of presence from the user to create a convincing narrative.

This introduction is followed by a literature review of previous and related work to the paper. Following this, the techniques for the creation of thought provoking narrative visualisations are presented. The user study will then be discussed followed by the results of the user study. Finally,

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some concluding remarks will be provided.

II. Literature Review

In this section, an overview of the fields of Narrative Visualisation, Virtual Reality, Presence and Immersion.

A. Narrative Visualisation

Segel and Heer [1] observed an emerging trend of online journalists incorporating data visualisations into their articles to help tell stories. They defined this sub-genre of visualisation, *Narrative Visualisation*. They defined three different narrative structures: *Martini Glass*, *Interactive Slideshow*, and *Drill Down Story*.

Hullman and Diakopoulos [4] discussed bias and the disparity between standard visualisations and visualisations with an intended end goal of persuasion. They investigated what rhetorics the designer uses, with rhetoric referring to "*the set of processes intended meanings represented in the visualisation via a designers choices*". The rhetoric choices by the author can be small, for example changing the phrasing of a fact or by drawing focus to and from certain pieces of information. Hullman and Diakopoulos defined four stages in which an author can potentially, either by choice or unintentionally, add bias to a visualisation. At the data stage, visual representation stage, textual annotations and the interactivity. Hullman et al. [5] focused on how the sequence of information in a narrative visualisation effects the final product. Jacobs et al. [6] looked at the early stages of data analysis and how framing the information in a way as to create narrative visualisations can aid in finding patterns or useful stories. They argue that while attempting to analyse the data and find effective methods of displaying the data it is easier to see them as narratives instead of statistics and extract and relate the data based off of these stories.

A data video [7] could be described as a short video that takes collected data that has been analysed and visualises it interestingly. They generally include a point or message, and the data videos require little to no input from the user. A lack of interaction differentiates data videos from narrative visualisation, as research has shown that interaction is one of the key qualities that help a user to engage with the data [8]. As well as sharing common techniques, it was observed that the data videos often followed Cohns theory of Visual Narrative Structure [9].

B. Virtual Reality

Roussou et al. [10] investigated how virtual reality and the paradigms and methodologies surrounding it could be applied to an application that intends to teach or educate. Educating users on certain facts is part of our goal with VR narrative visualisations. Roussou et al. stated VR is unique in terms of the qualities of immersion and presence. To capitalise on these qualities, we aim to focus on the interaction as other studies [11], [12] have found that interaction [13] is a key quality in immersion and can have a higher impact on learning than the immersion itself.

De la Peña et al. [14] explored the concept of immersive journalism, the ability for the participant to enter a virtual scenario representing a particular news story, to enhance a news story and create a possible emotion connection between the participant and the story. They investigated the advantages that VR affords, whether it be through an HMD or a CAVE style system, to convey a news story or world event. The key value the study measured was what they called *Response As If Real* (RAIR), which closely maps to other definitions of presence.

Introducing data visualisations into a virtual environment poses a few conceptual and technological questions to be resolved. Glyphs have been employed to display individual points of data [15]. Glyphs are objects displayed within the environment with different properties (colour, orientation, size, shape and position) to represent different variables. Glyphs are efficient in representing multivariate data through a single object, in a comprehensive fashion. A strength of glyphs is the patterns and trends that these properties can reveal, which are easily discovered by users. An application of glyphs for data visualisation within VR is a weather system tool [16]. Data visualisation and VR have been applied to clustering within a 3D space for analysis [17], [18] for interaction and selection. Hentschel et al. used cubes created by the user with a brush tool to allow the user the ability to grab any cluster of data by simply tracing a cube around that information. The use of immediate feedback of highlighting selected data as the cube is drawn allowed the user a clear understanding.

C. Presence and Immersion

Questionnaires have been developed to measure the presence of a user within a VR application [3], [19]. The important technological properties for immersion include the following: field of view, framerate, latency, tracking, realism, quality of rendering, and the number of sensory systems. Perhaps one of the most interesting differences between immersion and presence is the importance of realism and quality of the rendering. While immersion considers the realism of the scene, to what extent do the objects and interactions available within the virtual world compare to the real-world counterparts; important it has been showed that presence can be obtained and does not appear to be connected with the realism of the scene at all [2], [10]. In fact, one of the most powerful factors in producing high levels of presence in a VR experience, more important than realism, is sound and audio. In particular, it has been found that specialised sound, a sound that realistically originates from its source in 3D space, has a massive effect on a user's belief that they are really in the virtual space.

III. Narrative Visualisation Design

This section contains a description of the process and underlying techniques for designing a narrative visualisation, specifically in the format of a series of data videos, that aims to persuade the viewer of a given point. The section provides a detailed example of an implementation of these techniques used in the final prototype for the user study. The visualisations

designed in this section are expected to have minimal to no interaction just like normal data videos. An interactive map allows the user to explore deeper into the concepts from the data videos.

A. The Narrative Visualisation Task

The narrative visualisation task explored in this paper is gun control. Gun crime across the United States and the discussion of gun control that ensues continues to divide people across the globe. Some people point to other countries with stricter gun control as proof of its success, while others point just as quickly to countries with no gun laws that experience minimal gun related crime. Others debate that the United States is a unique case and as such other countries experiences cannot be used as examples. This line of discussion leads to questions of poverty, ethnic backgrounds, mental illness, and gun laws themselves as the possible causes of the violence. With so many conflicting statistics, multiple variables, and complex ecosystems the debate surrounding gun control has become an issue of big data analytics and has already seen some attention in data visualisation [20], [21], [22]. However, the debate surrounding gun control is not simply a discussion of statistics as people have vested interest and therefore emotions in the outcome. Specifically, those living within the United States are swayed by emotions whether it be fear of mass shootings, the want to be able to own a gun, or those that feel that it is their constitutional right to own a weapon and defend themselves. This unique combination of complicated statistics, divisive opinions, and emotionally charged debate creates a hostile environment for discussion and statistical analysis. The combination of data visualisation's data centric approach and narrative visualisation's advantage of being emotionally impactful lends perfectly to this complicated debate.

B. Design Stages

When designing a visualisation with narrative elements, a set of defined steps were developed: 1) data collection, 2) data analysis/narrative construction, 3) modelling data, and 4) narrative integration. The first stage involves collecting the data to use for the visualisations. Any information that has value should be collected, as no clear narrative or goal should be defined at this stage. During this stage, the author may notice trends or constants in the data. These trends could possibly be converted to narratives in the third and fourth stages. For this project, information was gathered through visiting web pages that had pre-analysed data. Sample data websites from both sides of the gun control debate were selected in an attempt to receive a balanced argument.

At the second stage, all of the data gathered should be compiled and analysed. Narrative construction involves finding narratives or possible narrative elements from the analysed datasets. The following are some example datasets: 1) A dataset in which a story can be extracted. (For example, datasets that show increased temperatures related to carbon emissions can be represented by a story of the planet's decline into pollution.) 2) A dataset in which the data can be symbolised or used as part of an analogy to symbolise images or concepts from the world. (Using the same example as above the increased planet-wide temperature could be represented by an increasing red hue over the planets surface. In this case, the analogy is how red is commonly associated with heat and temperature.) 3) A dataset that can be visualised as to create an emotional connection. (These are more powerful examples of the previous datasets in which through symbolism data is represented with the express purpose of causing an emotional reaction from the viewer. With the same example representing decreasing populations as a series of endangered animals fading away can represent the percentile decrease of the population, while deliberately causing an emotional reaction.)

Once the data has been analysed and each possible dataset has been checked for narrative capabilities, the visualisation method of the data must be decided. The first step in this stage is to decide on what equipment and software will be used to design each visualisation. This stage is similar to modelling when creating a data visualisation. Each dataset must be represented through a graphics technique. The representations range from new and novel concepts specific for the VR presentation or the standard form of visualisation, including charts (bar, line, pie). This stage is open ended and can differ from one design to another.

The fourth and final stage is the most important stage. By now each visualisation should have been built. Each visualisation should be grouped by a narrative thread. This could include a variety of factors including data, tone, timeline and message. Once each visualisation belongs to a narrative thread the data video should be designed. This stage is best compared to the storyboarding of a novel or film. The structure is crucial, and the visualisations should follow logically and create a natural story arc. A crucial part of this stage is the incorporation of all elements that do not pertain to the dataset itself. This could include adding interactions, music or audio cues and any other narrative structures into the visualisation. If during this stage a particular visualisation does not fit or cannot logically be placed before or after a part of the narrative, consider going back to the second or third stage and recreating the visualisation to fit with a different narrative or more closely follow the current story. At the end of this stage, a set of modelled visualisations that contain narrative elements should have been combined into a data video that tells one concise story.

C. Practical Example of Narrative Design

To understand this process more clearly, an example data video "Suicide Rates and Gun Control" is examined, which was created for the purpose of the final product. This visualisation was chosen as it contains one single narrative, uses symbolism to explain the statistics, evokes an emotional response, and was created using only two sets of statistics. This narrative visualisation technique is an example that can extract a stronger emotional response and convey more meaning than a simple data visualisation.

The first stage of creating a narrative visualisation is data collection. For this specific visualisation the statistics were gathered as part of a web article that contained a set of data visualisations about guns, and what affect guns have on different parts of society[1].

The next stage is data analysis/narrative construction. As a majority of the statistics gathered for this project were gathered from websites and journals, the data had already been analysed, and trends had been discovered. At this stage, the statistics are grouped into relevance, any connecting factors including changes over time, similarities in location, similarities in gun control laws or statistics that could be built into a narrative. Two statistics were discovered and grouped, claiming that other forms of suicide including cutting and poison have a 7% success rate, whereas guns were successful in causing death a majority of the time at an approximate 96% success rate. These statistics were promising in their capacity to be constructed into a narrative, as the statistics were related to a controversial and emotional issue.

In the data modelling stage, the GoAnimate [2] online infographics generation tool is used to model the statistics. This tool was chosen as its style and functionality aligned with the intended look and feel of the final visualisations. The data is represented in a symbolical and impactful way. Instead of representing percentages as a standard pie chart, the visualisation shows percentages by differentiating the symbols. The method of differentiating the symbols can differ from colour changes to completely different symbols. In total three different visualisations had to be created in this structure. One that represented the entire set of symbols, unaffected by the data, and two visualisations representing the data set with and without gun access.

With all three visualisations modelled, the final step was to introduce narrative integration. Both the narrative structure and symbolism must be decided and implemented. For this visualisation, it was decided that the visualisation would represent a group of twenty people. To represent each symbol as a person an animation of a heart rate monitor was used. This symbolism allowed immediate recognition of a human life as well as allowing for a natural progression between the two states, alive and dead. After the symbolism was chosen the visualisation had to be ordered. Using narrative trends often found in film, it was decided that the best way to start the visualisation was with the unaffected data, showing 25 heartbeats (Fig. 1).

The data video follows with the statistic of 6% mortality rate for non-gun related suicides represented by a short animation of a number counting up to 6. This same animation method was used again to represent the gun related statistic of 96% later in the visualisation. The repetition allowed a second method to show the disparity between the two values. As in the same space of time, the 0 to 96 counter went through far more numbers than the less lethal 6 counter. After the

[1]http://www.vox.com/cards/gun-violence-facts

[2]http://goanimate.com/

Fig. 1. Suicide visualisation showing all 25 heart rates.

Fig. 2. Suicide visualisation showing only on survivor of a gun related suicide attempt.

counter was the visualisation of the 25 heartbeats using non-gun forms of suicide. This visualisation showed one of the 25 heartbeats had flat lined. To emphasise this point, over the course of the animation the camera focused and zoomed on this heartbeat. Following this was the 96 counter, and the visualisation for the 25 people after attempting suicide using guns. In this visualisation, only one of the 25 survived (Fig. 2), as opposed to the non-gun visualisation where only one flat lined.

The symmetrical nature of this result was the reason for specifically 25 heartrates. Similar to the "non-gun" visualisation the "with guns" visualisations zoomed in on the one survivor, to emphasise the result. At this stage, the data has successfully been visualised with a narrative structure, but to end the narrative a message or opinion should be stated. To accomplish this the initial visualisation is displayed again. This technique mirrors the "Bookending" technique in cinematic narratives to begin and end with the same image. The final addition to the visualisation is the audio output. While no music was added, narration was used for each stage of the visualisation. This narration simply described the visualisations as they appeared and was generated using a text-to-speech voice emulator. In the final visualisation, the voice recording was used to summarise the method of the visualisation, in this case that the intended goal is for there to be no successful or even attempted suicides while also stating that the removal of guns is one step towards this goal.

IV. Virtual Environment Design

The HTC Vive was chosen for the VR hardware. The Vive offers two controllers that are tracked in real time along with the headset. The Unity Engine was the final choice for the

Fig. 3. Live updating list of visualisations the user has 'favourited'.

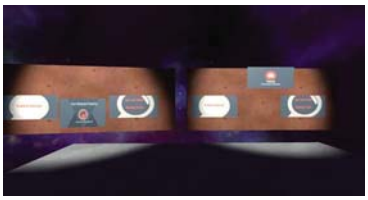

Fig. 4. Final scene shows users choices (on the right) and the authors choices (on the left).

games engine due to a particular set of qualities; in particular, the engine has a SteamVR plugin which is designed for simple drag and drop implementation of the Vive system.

A. Environment Design

We defined a set of system design requirements. Firstly, the user should be allowed free movement (walking, hands, and head) at all times. Secondly, control should never be taken away from the user. This design decision was crucial as to prevent disorientation and motion sickness for the user in an immersive environment. Thirdly from the initial display, the user should have an overview of the virtual environment to orient themselves in the immersive environment. This architecture would closely follow the inverse of the Martini Glass structure or the Drill Down Story, in that the original view is open ended and with user interaction becomes more focused. Fourthly, both the narrative visualisations and the more simple data visualisations will be presented in the virtual space. Fifthly, the user has the ability to highlight or "favourite" (similar to a like) of any visualisation that was relevant or impactful. A final screen in which all selected favourites could be viewed is displayed.

The virtual area is designed to be structured such that the user was able to interact with the visualisations and consider the possibly difficult decisions and concepts that arose from the topic. The aesthetic and theme of the virtual environment are not distracting or confusing to the user. The virtual area's theme is deliberately abstract, with no analogy to a real-life location or concept. This is achieved by placing the scene in what appears to be outer-space. Using a space skybox also avoided any feeling of enclosed space that rooms could often exhibit in a virtual world. For the collection of data videos, a simple table and chair were placed in the centre of the area. Two wooden billboards were placed in the scene, one directly to the front and the other on the right side. These two billboards were intended to be used for any additional data visualisations added and for the favourite visualisations the user had selected throughout the experience (Fig. 3).

The final element of the scene was a quit button which was placed above the scene as to not be accidentally activated prematurely. Upon activating this button, the user is taken to a separate room, which has a similar set-up to the first. In this room, a narrator shows the user the visualisations that they chose as their favourites as well as the ones selected by the author (Fig. 4). The narration asks the users to compare these choices. The then experience ends.

Fig. 5. Burglary Rate visualisation being played in 3D space.

B. Visualisation Implementation

The modular visualisation structure of the virtual environment led to the design of "Area Spheres". These spheres were simple grey orbs that were chosen to deliberately have no symbolic representation to store each visualisation or set of visualisations. Each sphere was given a brief title that summarised the theme or message of the data video held within. These orbs, upon picking and activating, float to the centre of the room and activate the attached data video.

An interactive map of the United States of America is placed onto a large wooden billboard behind the table. Unlike the data video visualisations available on the table, the interactive map was designed to state the statistics with no narrative elements. Each state on the map, upon selection, displays a set of statistics about the state in regards to gun control. The information available was the percentage of gun ownership within the state, the amount of murders committed per 1,000 residents, and the amount of gun related murders committed per 1,000 residents. Implementing the narrative visualisation data videos into the virtual scene was the final step. The simplest solution was to place the videos onto an object into the scene. Doing this allowed the viewer to manipulate their viewpoint to see the video from different directions.

C. Interaction

The system supports interaction techniques to select, favourite and view the visualisations available. For the VR system, movement of both the avatar and the viewport was handled by the HTC Vives tracking system. All other interactions are handled by the Vive controllers.

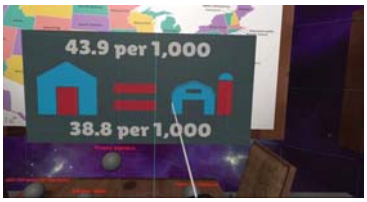

Fig. 6. Visualisation 3. poverty and uses of symbolism.

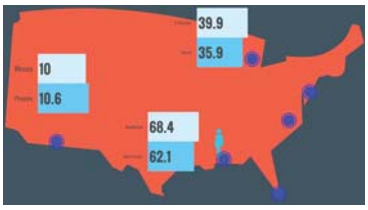

Fig. 7. Visualisation of homicide rates in other countries compared to states within the U.S.

The dominate hand controller is nominated as the *main controller* and has two unique properties. The first property allows the controller to be placed into any of the "Area Spheres", then activated by using the trigger, to start playing the attached data video. The second property is activated by squeezing both of the side buttons of the controller to activate a laser pointer. A laser is used to activate: 1) the instructions, 2) the data visualisation of the U.S.A to display its information above the other controller, 3) adding or removing data videos from the favourites billboard, and 4) the quit button.

We developed our system to work within a VR setting and with a traditional desktop system. Interaction methods for the desktop system required different forms of control. The users move their head with the mouse and could walk forward, left, back, and right with W, A, S and, D keys respectively. All other interactions are similar the VR methods of interactions. The laser is activated using the right mouse click. The only other change is how an "Area Sphere" is activated; the desktop version activates the sphere with the laser pointer.

V. User Study

We conducted a user study to evaluate the effectiveness of the developed narrative visualisations and the presence of the VR environment compared to that of a desktop display. The primary goal of the study was to determine if the use of virtual reality technology would enhance a narrative visualisation based experience compared to that of a standard desktop display. The secondary goal was to evaluate the effectiveness of narrative visualisations to persuade or inform a user through both of these mediums.

The study was a between groups design: *Desktop* (standard screen display) and *Virtual Reality* (HTC Vive). Both groups experience the study in the same quiet indoors room. The participants filled out a questionnaire when they finished the experiment. The first part of the questionnaire focused on the participant's entire experience being convinced of a particular opinion. The second half of the questionnaire is a subset of the B. Witmer and M. Singer presence questionnaire [3] and Slater version [19]. The application was instrumented to record each participant's total time, the number of clicks, time spent using the laser pointer, and time spent within each visualisation all recorded in seconds.

A. Demographic

Specific demographics of age was not recorded excluding a requirement of being between the ages of 18 and 40. A majority of the participants had high computer experience, and over half had experience with virtual reality technology in the past. The study included a total of 30 (26 males and 4 females) participants with 15 being chosen for each group.

B. Study Methodology

For each participant, they were guided into one of two areas of the room. A divider was placed between the two areas to help create a sense of privacy for the user during the study. Creating this safe area was a priority particularly for the virtual reality group of the study, as the combination of headphones and headset left the user isolated from the real world around them. At this stage, the context around the study was described. The participant was told to consider themselves a person of interest in an upcoming vote to introduce stricter gun laws in the United States; users were asked if they were aware of gun control and its significance in the U.S. After this, the user was placed into the headset, if in the Virtual Reality group, or asked to sit by a computer with a set of headphones on. The participants then worked their way through the task. Following the end of the experience, the user was asked a series of questions relating to their experience and levels of presence throughout. The user was able to add comments.

C. Visualisations

For this study, six separate visualisations were developed using the techniques described earlier in this paper. Visualisation 1 compares accidental deaths using guns in the United States compared to other countries. Visualisation 2 is focused on comparing statistics in the United States regarding gun control with other countries that are generally deemed to be dangerous or war-torn, see Fig. 7. Visualisation 3 discusses poverty and uses symbolism to compare wealth and gun violence, see Fig 6. Visualisation 4 is designed to be similar to the visualisation that showed statistics rapidly. However, this one focuses its visualisations around the state of Louisiana. Visualisation 5 focuses on the connections between gun control, specifically gun permit requirements and burglary rates, see Fig. 5. The final visualisation is focused on comparing the success rate of suicide attempts when guns are used compared to other methods, see Figs. 1 and 2.

TABLE I
DESCRIPTIVE STATISTICS OF THE RESULTS

	Group	Mean	SD	SE Mean
Num. of Clicks	Desktop	10.53	3.796	0.98
	VR	12.93	10.32	2.67
Time in All Vis	Desktop	360.1	101.64	26.24
(sec)	VR	379.18	136.94	35.35
Time in States	Desktop	119.7	73.15	18.89
(sec)	VR	112.99	70.13	18.74
Time in Laser	Desktop	172	101.34	26.16
(sec)	VR	102.32	69.75	18
Total Time	Desktop	555.19	169.75	43.75
(sec)	VR	589.88	227.02	58.6

VI. RESULTS

A. Quantitative Results

We performed an SPSS independent t-test on each of these variables: total time, the number of clicks, time spent using the laser pointer, and time spent within each visualisation. For total time, participants spent longer in the virtual reality condition ($M = 590\ sec, SE = 58.6$) than those in desktop ($M = 555\ sec, SE = 42.8$). This difference of 35 seconds was not significant $t(28) = -0.47, p = 0.32$. The number of clicks for VR ($M = 12.9, SE = 2.7$) compared to desktop ($M = 10.5, SE = 0.98$) showed minimal difference, 2.4 clicks. This difference was not significant, $t(28) = -0.85, p = 0.2$. Participants spent less time using the laser pointer in VR ($M = 102.3\ sec, SE = 18$) compared with desktop ($M = 172.08\ sec, SE = 26.1$) at an average of 69 seconds less time. This difference is significant, t(28) = 2.2, p = 0.02, and showed a medium-sized effect, d = 0.38. Full results can be seen in Table I. These results suggest a minimal difference in behaviour for users in both VR and desktop. The only major difference that is significant is that desktop users tended to use the laser pointer for longer than those in VR (see Discussion).

Comparing time spent looking at the six visualisations only one of the visualisations has a difference of means that is considered significant, ($p < 0.05$). Participants spent longer looking at the sixth visualisation in VR ($M = 79.75\ sec, SE = 12.14$) than in desktop ($M = 46.73\ sec, SE = 4.74$). This difference of the means, 33.02, is significant with $t(26) = -2.53, p = 0.01$; showed a large effect size, ($d = 0.52$). This result is counter-intuitive as it can be fairly assumed that any behaviours exhibited on one visualisation would be similar for others. The result of Levenes test for equality of variance seems to confirm this finding ($F(16.9, 26) = 11.4, p = 0.002$); therefore failing the Levenes test. A possible cause of this discrepancy of behaviour may be found in the ad hoc discussions with the participants in the study. Multiple participants of the VR study reported audio issues on this visualisation that made it appear as if it had crashed. As such, many users reported watching the visualisation again to see the end of it. This issue with the project could account for the extended time spent in this visualisation and its significant difference of means.

B. Qualitative Results

The questionnaire given to the participants contained two sections. The first were a set of 5 questions designed to gauge whether the user felt the experience was improved by the specific technology they used. The second set of questions (based on the subset of the Witmer and Singer questionnaire [3] and Slater version [19]) were designed to gauge the levels of presence experienced by the users throughout the visualisations.

Each questionnaire was marked on a Likert Scale of 1 to 5 with the anchors of "Strongly Disagree - Not Sure - Strongly Agree". These results were analysed with the Mann-Whitney U test. Out of the 15 questions asked only three returned a significant result: *Vis Q1: You felt that the medium you used (Desktop or VR) added to the overall experience?*, *Vis Q2: You found the use of audio increased the overall experience?*, and *Pres Q7: How aware were you of events occurring in the real world around you?*.

For the Vis Q1, users in VR answered more positively than those who used a desktop display, ($U = 54.5, z = -2.65, p = 0.004$) and displayed a medium-sized effect, ($r = -0.48$). Vis Q2 had a similar positive VR result with ($U = 74.5, z = -2.65, p = 0.034$), and ($r = -0.33$). Finally Pres Q7 had ($U = 70.5, z = -1.82, p = 0.0345$) and a medium effect size of ($r = -0.33$). Pres Q7 is a negatively worded question, and this indicates an increased sense of presence within VR.

VII. DISCUSSION

Time spent looking at each visualisation returned no significant difference. Comparing the means for each visualisation with the runtime of the attached data video show very similar durations. From this comparison, it can be inferred that most users watch each visualisation once, with slight variations most likely arising from users reselecting a visualisation to add it to the favourites board. The questionnaires returned results more in line with expectations with users who participated in the VR experience recording that the medium of VR did, in fact, enhance the experience, as did the inclusion of audio components. It is worth noting that the addition of audio components returned a more positive result in VR further adding to the conjecture that audio is a key component in immersive VR experiences. The more positive results towards awareness of surroundings, while using the desktop display further add to the possible immersive qualities of VR.

Ad hoc remarks from the users suggested that most enjoyed or found interest within the narrative visualisation data videos. Interestingly some users found the one data visualisation, an interactive map of the United States of America, to be the most engaging, as it allowed them to discover trends or interesting facts independently. Of the narrative visualisations, one user claimed that the suicide statistic visualisation supplied the most impact, as they felt an emotional response to the data. Multiple users suggested removing the text-to-speech voice and replacing it with a real human voice actor. The users also felt that matching the music to be more closely correlated with

the visualisations could have been used to build tension and strengthen the narrative of some of the visualisations.

A majority of the users forgot to favourite visualisations at all. This trend was noticed in both desktop and VR environments and suggests that users were not clear on the goal of the task. This problem could be avoided through a short introduction where a narrator could inform the user to favourite visualisations for comparison at the end.

VIII. Conclusion

This paper presents contributions to multiple research fields. In regards to visualisations and big data analysis, this paper contributes a set of design techniques and steps to create narrative visualisations for the intended goal of generating an emotional response or expressing an opinion. For the research area of virtual reality, this paper contributes designs for implementing narrative visualisations in an interactive 3D environment. As a result of the user study and following analysis of its results to test the advantages of virtual reality in conjunction with narrative visualisations, the visualisations are presented as being successful while the advantages of the virtual environment are inconclusive. Anecdotal evidence suggests virtual reality to be an engaging method of presenting the narrative visualisations.

This paper originally proposed two research questions: *Q1: Is a narrative visualisation enhanced by the inclusion of Virtual Reality technology?* and *Q2: What are a set of suitable techniques to develop narrative visualisations in virtual space?*

From the results of the user study performed it can be concluded that no significant result could be recorded to substantiate the claims of the first research question. However, a few significant results suggest a possible correlation between a more positively viewed experience by the user and the virtual reality medium offered. These results suggest further research is worth conducting to more thoroughly discuss the answer to this research question.

The second contribution was a strategy for placing the narrative visualisations created into a 3D virtual space that a user can explore and interact with at will. The virtual space developed was designed with an abstract theme to allow the visualisations to be the focal points of the experience.

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