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Evaluation of an Immersive COVID-19 Data Visualization

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Abstract—
COVID-19 restrictions have detrimental effects on the population, both socially and economically. However, these restrictions are necessary as they help reduce the spread of the virus. For the public to comply, easily comprehensible communication between decision-makers and the public is thus crucial. To address this, we propose a novel 3D visualization of COVID-19 data which could increase the awareness of COVID-19 trends in the general population. We conducted a user study and compared a conventional 2D visualization with the proposed method in an immersive environment. Results showed that the our 3D visualization approach facilitated understanding of the complexity of COVID-19. A majority of participants preferred to see the COVID-19 data with the 3D method. Moreover, individual results revealed that our method increases the engagement of users with the data. We hope that our method will help governments to improve their communication with the public in the future.

■ **TO REDUCE** the detrimental effects of COVID-19, the population of every country was encouraged by their respective governments to change their daily lifestyle significantly. Measures to control the spread of the virus included, for instance, wearing masks, limits on the numbers of people in gatherings, or even strict quarantine/lockdowns. Yet, communicating the need for such measures is a challenge as such control measures can have an enormous impact on people's lives. Thus, the public needs to be better informed why such measures are necessary. Increasing public awareness also increases willing compliance with such measures [1]. For this to happen, better and effective communication between researchers, governments, health authorities, and the public is the key [2].

Much of this communication centers around different trends in the spread of COVID-19. For example, this can involve comparisons with other jurisdictions, illustrations of how the number of cases has changed after measures have been implemented, and comparisons with previous pandemics. Yet, the rapid increase in COVID-19 cases makes it challenging to convey this message in a way that is easy to understand. The specific challenge in visualizing such data is that many of the trends are exponential in nature [3]. Researchers are familiar with such trends and know how to deal with them, e.g., through logarithmic plots.

The specific challenge is that explaining such trends to the general public is more challenging; people may not understand (or notice) the fundamental difference between linear and logarithmic visualizations to show the number of cases, or they might not interpret the data correctly [4]. Thus, there is a need for simple, effective, and easy-to-understand data visualization methods for COVID-19 trends, which would allow the public to more easily understand the severity of the situation.

Other work studied COVID-19 data visualization to improve the communication with the public [5], [6], [7], [8]. For instance, Wang et al. [3] studied different methods of visualizing COVID-19 data, including electronic posters, infographics, and videos. 3D data visualization has been used in various fields, including industrial engineering, construction, education, and medicine. Previous work also experimented with 3D visualization methods in Virtual Reality (VR) and Augmented Reality (AR) systems. For instance, targeting users wearing a VR headset, Sharma et al. [9] used bar graphs to present COVID-19 data and compared the user experience with desktop and tablet interaction. The results showed that participants preferred interacting with COVID-19 data in VR systems. Similar research was conducted for New York [10] and Poland [11]. In another study [12], WebXR was used to show COVID-19 data as line plots and bar graphs on geographic maps. The authors also investigated multi-user interaction with COVID-19 data in an immersive environment [12]. Their tool aimed to inform a wider public and to help people better understand government decisions about COVID-19.

In this immersive user study, we focus on visualizing daily new case data for COVID-19. Our main objective here is to improve the quality of the communication between authorities and the population by increasing the public awareness of the severity of the pandemic. To achieve this, we propose a 3D visualization of the COVID-19 data and then evaluate it in an immersive (virtual) environment as the first step. Currently, data on the spread of COVID-19 is shown almost always through 2D graphs. To identify which option is better for the communication of COVID-19 data, we thus compared our 3D visualization with conventional 2D graphs. In the process, we investigated the following research questions: *How do people respond to existing COVID-19 data visualization methods? How does their reaction change with unconventional visualization techniques in an immersive environment? Do people understand the severity of the problem better with the new method?*

MOTIVATION & HYPOTHESIS

Previous work has reported that in some scenarios, users tend to prefer 3D over 2D visualizations, especially when the data is sufficiently complex, e.g., [13]. COVID-19 case data can be fairly complex, if the vast differences between the low number of cases, e.g., during summer, and the steep peaks due to various “waves” are considered. In 2D graphs for such data, it can be challenging to observe changes in the periods with small numbers, since the scale on the axis needs to accommodate the large numbers to capture the peaks. However, these small variations play a crucial role for fighting against the pandemic, as any exponential trend initially starts (very) small.

In this work, we hypothesized that *our novel visualization method helps users to perceive COVID-19 data better than conventional 2D methods*. Given that our visualization illustrates variations across a wider range of values in an easily perceivable way, we expect users to prefer our visualization method over the 2D one. Thus, our approach could be used to increase the quality of the communication between researchers, decision makers, and the community.

THE 2D VISUALIZATION OF COVID-19 DATA

We collected data for daily COVID-19 cases from four different countries in Europe until November 30, 2021, from the respective official sources. We chose countries that had (roughly) similar numbers of inhabitants – France 67.30 million, Germany 83.24 million, Turkey 84.34 million, and United Kingdom 67.22 million. Due to the weekly cycles in the data, we smoothed the collected data on new daily cases with a 7-day averaging filter, similar to most other COVID-19 data visualizations. Then we normalized the COVID-19 incidence data to the number of cases per million inhabitants. This data was then directly presented in a 2D data visualization.

A NEW METHOD FOR 3D VISUALIZATION OF COVID-19 DATA

For the 3D visualization of the data, we designed an approach that makes it easier to see changes in areas with smaller values (see Figure 1). The classic answer to showing more detail in such ranges is a logarithmic data transform. However, this type of visualization is typically not usable outside of a scientific or medical domain, as the broad public does not understand such transformation of the data [4].

Consequently, we decided to investigate a visualization that used the *volume* of a 3D object to illustrate case numbers. In other words, in our 3D visualization method for daily COVID-19 cases, we use the third dimension to depict the data as a 3D volumetric object (see Figure 2) which is a rotationally symmetric, as though generated by a lathe. In the graph, time progresses on the horizontal axis, and the cross-sectional area of each slice of the volumetric object is a circular area representing the daily number of new COVID-19 cases. Since the area of the circle = $\pi \times r^2$, the radius r of the circle is proportional to the square root of the number of cases on that day and is used as the Y axis value. As a consequence, the overall volume of the object to the left of a given date then represents the cumulative number of COVID-19 cases up through that day. We also used a directional light in the scene to provide depth cues for the shape of the object. To differentiate data for each country, we used colors from Adobe Color (http://color.adobe.com) with a square color harmony rule on the color wheel.

PILOT STUDY

To understand the impact of our 3D visualization, we first conducted a pilot study. Although previous work had shown that participants can prefer to see visualizations in immersive environments [13] we decided to first analyze the impact of our 3D visualization method on a 2D screen to test if this visualization approach is easy to understand.

Our pilot study comprised 20 participants (8 female, 12 male) aged between 19-24 years (M = 21, SD = 1.4) with (corrected-to-)normal vision. They followed news about COVID-19 case numbers at different frequencies. Our prototype was built using Unity (http://unity.com) and enabled participants to move and select the created meshes for the 2D and 3D data as shown in Figure 3. We allowed users to zoom in/out, pan the camera, and to interact with the data for different countries through drag and drop with the mouse. We included two GUI buttons to place the plots either side-by-side or stacked on top of one another, to enable a direct comparison of the 2D and 3D plots.

In the pilot study, we first explained the difference between the 2D and 3D visualizations to participants. Then, participants were presented with an example question to be answered, first with a 2D visualization and then another with a 3D one. For each question, the software explained the correct answer step-by-step. The participants were encouraged to ask questions and the experimenter clarified accordingly.

Our pilot study consisted of 3 main parts, each of which involved a set of questions. Participants first answered 10 questions about the data, where they used the 2D visualizations, followed by another 10 questions based on the 3D visualizations. In the third part, we showed both 2D and 3D visualizations for the same data to the participants and asked them to report which data visualization they used to answer the question.

The questions were not the same for both

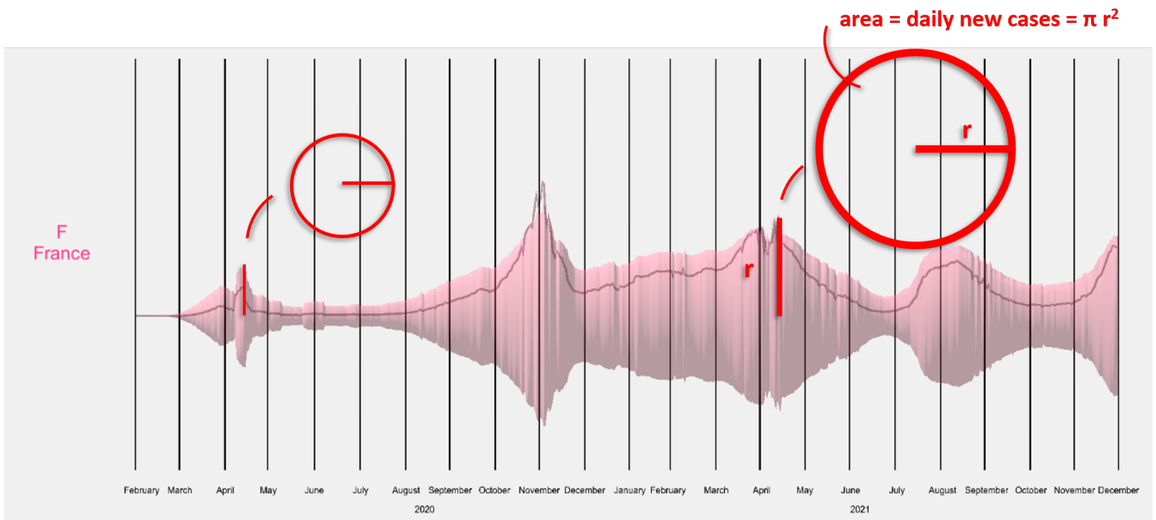


Figure 1. Magnitude comparison of 2D vs 3D visualization of COVID-19 data for France. The differences between the visualizations are visible when comparing areas with low numbers such as in June-August 2020, where little detail is visible in the 2D data, and, e.g., the time between October 2020 and December 2020, when the COVID-19 numbers were high.

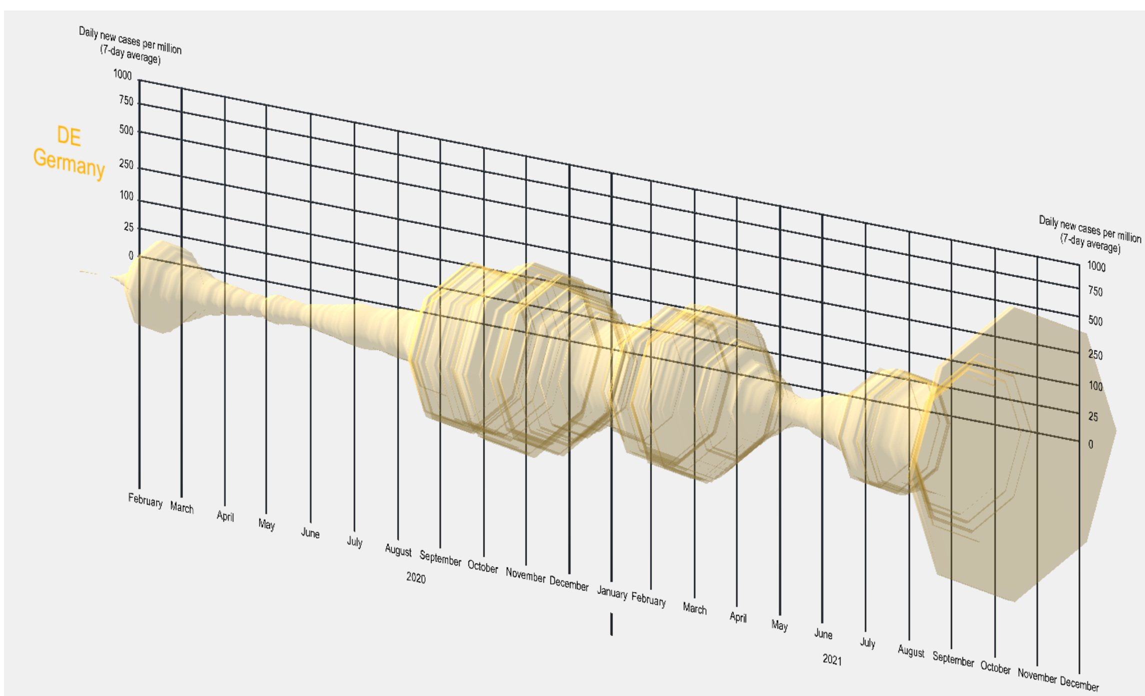
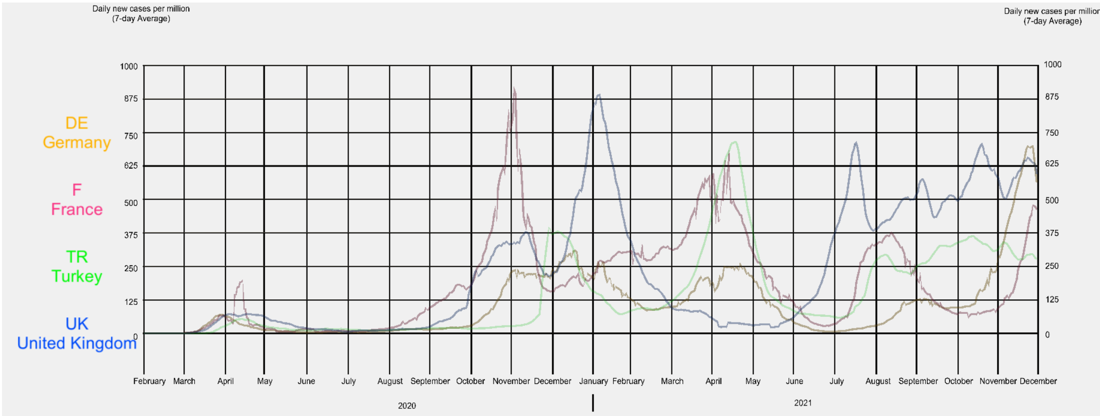
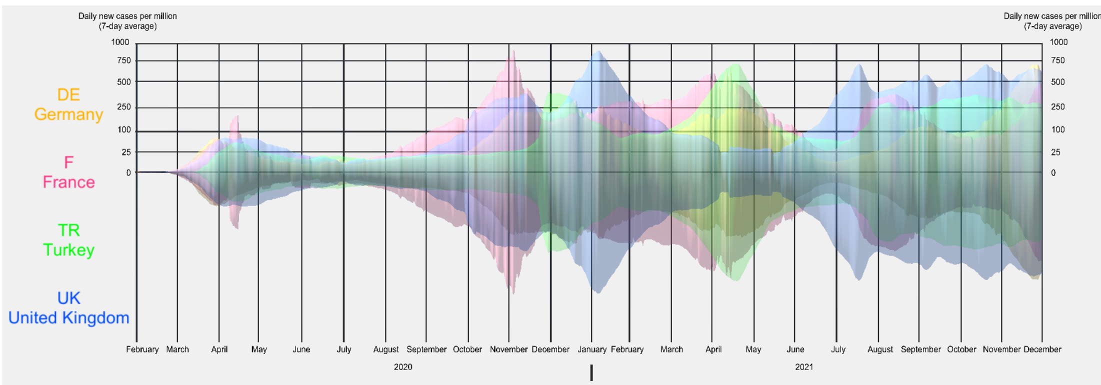


Figure 2. Side-view of the 3D data visualization of COVID-19 data for Germany.



(a)



(b)

Figure 3. a) Conventional 2D graph with a linear Y axis and b) our 3D visualization with its square root transformed Y axis.

visualizations, but similar in nature, such as *Between France and Germany, which country had the fewest COVID-19 cases on July 2020?; Where was the highest number of COVID-19 cases observed at the beginning of April 2020?; Rank the countries by the number of cases of COVID-19 at the beginning of June 2020, from largest to smallest;* and *Between Turkey and the United Kingdom, how many times did the COVID-19 cases in Turkey exceed those in the United Kingdom?*

In the third part, where participants were presented with both 2D and 3D visualizations, we asked questions such as *Which country had the most cases in January 2021?; In which country was the first COVID-19 wave seen?;* and *Which country had the fewest cases of COVID-19 in November 2021?* To conclude the experiment, we gathered additional comments and insights about the experiment from participants through a semi-structured interview.

Pilot Study Results and Discussion

According to the quantitative results for the first set of questions for the 2D visualization, participants correctly answered 63.5% of them. In the second set with the 3D visualization method, they correctly answered 65.5% of the questions, only a slight improvement. For the third set, which involved direct comparison between 2D and 3D, participants chose the 3D visualization method 133 out of 200 times (66.5%) to answer the questions.

The questionnaire results indicate that while there was no preference to use the 3D visualizations to answer questions in general, 18 out of 20 participants preferred the 3D method when the data visualization was difficult to interpret, e.g., because case amounts in May 2020 are small and relatively similar (see Figure 3).

The experimenter observed that, at the beginning of the experiment, and because participants were not used to 3D visualizations, the majority of the participants found the 3D visualizations to be more difficult to comprehend. But once they learned to interpret the 3D graphs, they found them to be very practical. Still, 15 out of 20 participants tended to choose the 2D visualization to identify obvious peaks in the data. Participants stated that the 2D visualization made it simpler to identify peaks, but that it was more difficult to interpret the data when the values were small as it was difficult to see differences between the data in the grid.

The results support our initial hypothesis to a certain extent, in that our 3D visualization method helps participants to perceive the complex aspects of COVID-19 data more easily than the conventional 2D method that is typically used to communicate with the public. Seven participants who had prior experience analyzing 2D graphs on other platforms stated that, once they experienced our 3D visualization method, they did not prefer to use 2D as much. However, as mentioned above, at the start of the experiment 3D was perceived to be more challenging. We posit that such 3D visualizations are still unusual in people's everyday life which mostly involves 2D environments.

IMMERSIVE USER STUDY

The results of the pilot study showed that the majority of participants preferred our 3D visualization method when the data was complex and hard to understand. These results motivated us to test our visualization method in an immersive environment, i.e., would users better grasp our 3D visualization if they could experience and manipulate our 3D volumetric object in 3D using an immersive VR display?

Participants

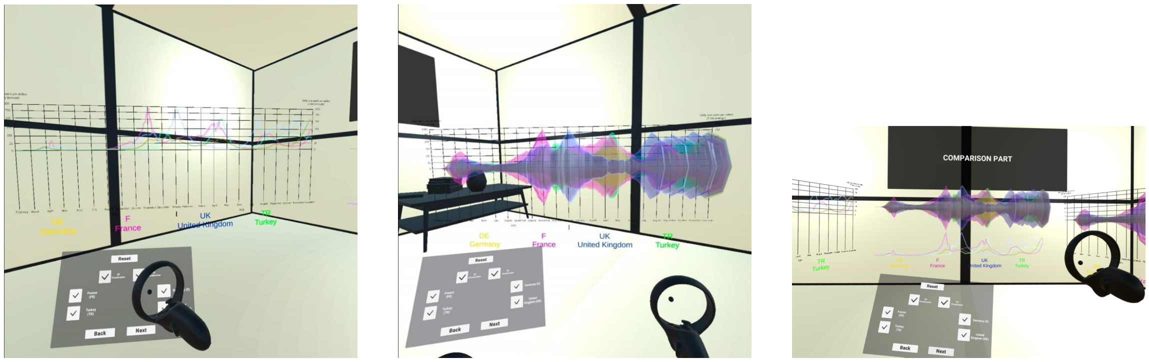
We recruited 20 different participants (11 female, 9 male) aged 19-24 years (M = 21, SD = 1.36). Our study was approved by the Ethics committee of Kadir Has University. All participants had normal or corrected-to-normal vision, i.e., none of the participants had color blindness or other visual disorders. 7 participants did not follow the news about COVID-19 cases, 6 followed once or more in a month, 1 participant followed only once in six months, and the remaining 6 checked once or twice a week. None of the participants followed COVID-19 case counts on a daily basis. 13 participants followed COVID-19 case counts through social media, while the remaining 7 participants followed COVID-19 news via TV and/or through other people. None of the participants followed COVID-19 new cases through official government websites.

Procedure

We designed our software so that participants could interact directly with the visualizations, e.g., they could grab and move the objects in 3D. The intent was to enable direct interaction with the graphs and more importantly, to make the content more engaging for the participants. We built our system with Unity and visualized 2D and 3D data as shown in Figure 4. We used a Oculus Quest 2 in our experiments, and a Samsung Galaxy Tab S7 FE for sharing instructions, demonstrating the differences between the visualization methods, and for having participants complete the final questionnaire. We also added a virtual panel above the left controller, which participants could use to enable and disable the 2D and 3D objects with the right controller. This panel had the same function as the GUI in our pilot study and can be seen in Figure 4.

In the lead-up to the experiment, we verified that all content was clearly visible to participants in the virtual environment. We (again) used the palette from Adobe Color to identify appropriately distinguishable colors for the visualizations, used a light color for the walls to ensure discriminability, and placed point lights in the room corners to create highlights on the visualizations. We scaled all user interface elements, including the visualizations, so that it was easy to interact with them within the virtual environment.

At the beginning of the experiment, the experimenter first explained the procedure step-by-step to the participants. Then, participants were asked to fill out the consent form and a demographic questionnaire. Afterwards, the experimenter showed participants how to use the Oculus Quest 2 and the software, explained how to grab objects, click the virtual buttons, and how to enable or disable the 2D and 3D graphs



(a) (b) (c)

Figure 4. Virtual environment used in the study. a) 2D data visualization used as the benchmark condition. While some of the lines may not be clearly visible in the image due to capture resolution limits, we made sure that participants were able to see the lines clearly in the VR HMD (Head-Mounted Display). b) Our 3D visualization algorithm evaluated in the study. c) Juxtaposition of 2D and 3D visualization used in the study.

by interacting with the panel (see Figure 4). Subsequently, the participants were allowed to try out the VR system until they felt comfortable. The system then showed an image comprising both 2D and 3D visualizations of a country, such as Figure 4, to highlight the difference between the visualization methods.

We used the same experimental method as in the pilot study, i.e., we first asked participants to answer questions with 2D visualizations, then with 3D visualizations, and then showed both versions simultaneously and asked them which version they preferred for a given task. Task questions were shown to the participants on the wall of the immersive environment, and participants advanced to the next question through the buttons on the virtual panel attached to the controller. When the participants had determined their answers, the experimenter recorded them on a tablet. During the study, the experimenter also observed the interaction of the participants with the 2D and 3D visualizations. After the experimental tasks, we gathered insights and comments about the experiment in a semi-structured interview.

Results

Quantitative Results. In the first section involving the 2D visualization method, participants correctly answered 61% of the questions. In the second part, where the participants experienced the 3D visualization method, they answered 75% of the questions correctly, a noticeable improvement compared to the 2D method. In the third section, where the participants were given the option of using either 2D or 3D visualizations, 66% of the answers were given using the 3D plots.

Preference Results. All of the participants found 3D graphs easy to use for evaluating COVID-19 data, and 13 out of 20 participants felt they learned something new about the COVID-19 trends from the 3D visualizations, unlike the 2D graphs. In the end, 19 out of 20 participants stated that they wanted to see COVID-19 data with the 3D visualization method.

Qualitative Results. All participants found the 2D visualizations challenging to interpret. Further, in the first section of the experiment all participants struggled to comprehend the (in their words) "complex" 2D graphs, which then prevented them from, e.g., making correct decisions around data in areas where the lines in the graphs were superimposed on each other. Participants commented "*it was difficult to read the data*", "*I had a hard time understanding the values when two lines superimposed*", and "*it was complex*."

The participants stated that the 3D visualization method made it easier to see variations of the data in areas with both small and large absolute values. Further, the immersive presentation also seems to have made the 3D visualization more attractive, which improved engagement with the data. Reading and understanding the 3D data proved to be easier and more interesting for the participants. At the end of the experiment, participants commented: "*The 3D graph was more informative*", "*it is new for me but it was easy to understand*", "*it was fun*", "*I had a different experience*", "*I enjoyed a lot*", "*It was easy to read and understand*", and "*it was easy to process visually*". One participant commented: "*[the proposed visualization] must be disseminated immediately. It makes it even more clear to see the number of COVID-19 cases and ratios.*"

Based on our observations during the study, in the part of the experiment that allowed participants to use either the 2D or 3D visualization, several of the participants first tended to gaze at the 2D visualizations because of their familiarity with 2D graphs from previous experiences. In spite of that, all the participants adapted to use 3D graphs by the end of the experiment. Participants mentioned "*3D was easier to read because the variation in it makes it easy to detect the right answer for each question*", "*I think it was easier to use 3D because you can see the differences whether they were small or large*", "*in 2D graphs, when lines overlap, it was very difficult to read them*", and "*at the beginning, I chose 2D graphs because I am used to them. After I got used to 3D graphs, I started using the [3D visualizations].*"

DISCUSSION

In this paper, we proposed a 3D visualization method to represent the number of new, confirmed COVID-19 cases daily from official sources and – to assess user preferences – compared it with more conventional 2D graphs being used for the same data. We first conducted a pilot study to analyze our visualization algorithm on a 2D monitor in comparison with a conventional 2D plot. These results showed some preference for our 3D visualization method, particularly for complex, hard-to-interpret data. But then in our immersive user study, users stated a clear preference for our 3D visualization when viewed using a 3D VR display, finding them easier to understand. Indeed, 19 out of 20 participants stated that they preferred seeing COVID-19 data visualized as 3D representations. This also supports and extends outcomes from previous research [13]. At the start of the experiment, all participants needed some time to understand the 3D visualization, but once they did, they found it to be very useful.

One of the limitations of this study is that we used university students as participants, generally between 19 and 24 years old. In a general population, we would expect people with a wider range of ages and also a greater range of VR and computer display experience. Also, people who have specific medical conditions, such as asthma or weakened immune systems, may be even more interested in the data. We also acknowledge that the colors in the figures may not be fully representative of what participants saw, since the colors shown on screens, printouts, or in the VR system are not guaranteed to be the same. Still, we ensured that the colors of each object were easily distinguishable on the monitor and headset we used.

The purpose of our study was to understand if our 3D visualization method conveys COVID-19 trends better to the general population. Our work is still in the "preliminary study" stage, and we are working towards a more comprehensive evaluation where we will address the aforementioned limitations. Also, in future research, we plan to use the 3D visualization method in AR, where users can interact with the virtual 3D data within the real environment, as previous work [16] identified that interacting with 3D AR visualizations is preferred over 2D ones within virtual environments. Further, Herring et al. [17] showed that interacting with 3D data on immersive interactive maps can allow for greater appreciation of its impact. We also want to test our 3D visualization approach with real-life 3D printed versions, where the user can directly "feel" the data further, based on the premise that people readily understand the comparative volumes of different containers in real life, and show them on our 3D visualization object at the appropriate points in time. We believe that our 3D volumetric visualization technique can be useful in communicating many types of growth data.

REFERENCES

1. B. V. Reddy and A. Gupta, "Importance of effective communication during Covid-19 infodemic," Journal of Family Medicine and Primary Care, vol. 9, no. 8, p. 3793, 2020.
2. J. Oh and A. H.-C. Hwang, "Interactive data visualization enhances preventive intentions in COVID-19 news stories: The mediating role of fear and the moderating

role of political orientation," Journal of Broadcasting & Electronic Media, pp. 1–26, 2021.

3. Y. Wang, et al, "COVID-19 data visualization public welfare activity," Visual Informatics vol. 4, no. 3, pp. 51–54, 2020.
4. E. Bowe, et al., "Learning from lines: Critical COVID data visualizations and the quarantine quotidian," Big data & society, vol. 7, no. 2, , pp. 1–13, 2020.
5. Y. Zhang, Y., et al., and A. G. Parker, "Mapping the landscape of COVID-19 crisis visualizations," in Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems, pp. 1–23, 2021.
6. D. Mercatelli, et al., "Web tools to fight pandemics: the covid-19 experience," Briefings in Bioinformatics, vol. 22, no. 2, pp. 690–700, 2021.
7. S. V. H. V. G. Somisetty, et al., "A comparative study of various data visualization techniques using COVID-19 data," International Research Journal of Engineering and Technology (IRJET), vol. 8, pp. 1306-1328, 2021.
8. C. K. Leung, et al., "Big data visualization and visual analytics of covid-19 data," in 2020 24th International 10 IEEE Computer Graphics and Applications Conference Information Visualisation (IV), pp. 415–420, IEEE, 2020.
9. S. Sharma, et al., "Real-time data visualization to enhance situational awareness of COVID pandemic," in 2020 International Conference on Computational Science and Computational Intelligence (CSCI), pp. 352–357, IEEE, 2020.
10. E. Goetschel, et al., "Coviz: Visualization of effects of covid-19 on new york city through socially impactful virtual reality," in 2021 IEEE Conference on Virtual Reality and 3D User Interfaces Abstracts and Workshops (VRW), pp. 703–704, IEEE, 2021.
11. P. Regulski, et al., "Advanced methods of visual analysis and visualization of various aspects of the COVID-19 outbreak in Poland," Procedia Computer Science, vol. 192, pp. 4194–4199, 2021.
12. M. DiBenigno, et al., "Flow immersive: A multiuser, multidimensional, multiplatform interactive COVID-19 data visualization tool," Frontiers in Psychology, vol. 12, pp. 1–9, 2021.
13. J. A. Wagner Filho, et al., "Evaluating an immersive space-time cube geovisualization for intuitive trajectory data exploration," Transactions on Visualization and Computer Graphics, vol. 26, pp. 514–524, Oct 2019. VIS '19.
14. R. Williams, et al., "Immersive visualization of COVID-19 UK travel and US happiness data," in IEEE Conference in Visualization (VIS): Information Visualization, pp. 1–1, 2020.
15. C. A. Donnelly, et al., "Four principles to make evidence synthesis more useful for policy," Nature 558, pp. 361-364, 2018.
16. M. Mendez-Lopez, et al., "Evaluation of an augmented reality application for learning neuroanatomy in psychology)," Anatomical Sciences Education, vol. 15, no. 3, pp. 535–551, 2022
17. J. Herring, et al., "Communicating local climate risks online through an interactive data visualization," Environmental Communication, vol. 11, no. 1, pp. 90–105, 2017.

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