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Information Search in Interactive Information Visualization: Testing the COVID-19 Dashboard as a Case Study

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Abstract

This study explored the effectiveness of outbreak data dashboards in presenting relevant information during global health emergencies using mouse-tracking measures. Firstly, several problems in the visual design and information layout of the dashboard were identified by analyzing the path, mouse-movements and clicks made by users when using the dashboard. Secondly, suggestions on the process of how dashboards were used and their design were collected through user feedback and follow-up interviews during the experimental process.
The results of the study provide insights into user-centered design solutions for visual dashboards, which can guide the design of similar epidemiological dashboards in the future.

1 Introduction

1.1 Background

In recent years, global health emergencies have occurred at an increasing rate, posing a significant threat to public health and life (Faghy et al., 2022). A typical example is the coronavirus (COVID-19) pandemic with its outbreak taking place in 2019. The new coronavirus had/has a high transmission rate and is/was therefore very easy to spread between people through physical contact and air transmission (Starkman, 2022). Movement restrictions and isolation measures became one of the main ways to prevent infection (Wilder-Smith & Freedman, 2020). This hindered the dissemination of some traditional printed information (e.g., newspapers and magazines). As reported by Folkenflik (2020), the coronavirus pandemic has had a negative impact on the printed publications of many local news organizations. During the global quarantines triggered by the pandemic, the internet became a vital source to access information (Brooks et al., 2020; McClain, 2021). As reported by Google, 2020's most popular word searched online was 'Coronavirus' (Thornton, 2020), highlighting the global demand for information relating to the disease. According to the British Health Security Agency, hundreds of thousands of British users were updating outbreak-related information via the internet and other means daily (Flowers, 2021). As shown in Figure 1, the number of Google searches for "coronavirus" as a keyword increased by nearly seven times from 22 to 28 February 2020, related terms such as "coronavirus symptoms" displayed similar increases. In addition, the rapid growth of the searches for keywords such as "Lysol" (a popular disinfectant), "social distancing" and "contagion" also indicates the level of interest and concern among users regarding related topics.

However, it is important to recognize that not all information obtained through search on the internet is reliable, and information from both unofficial sources and even some government bodies can mislead users regarding self-prevention and isolation measures during the outbreak. As reported by the US Centers for Disease Control and Prevention (CDC) in an early summer 2020 study, 4% of the

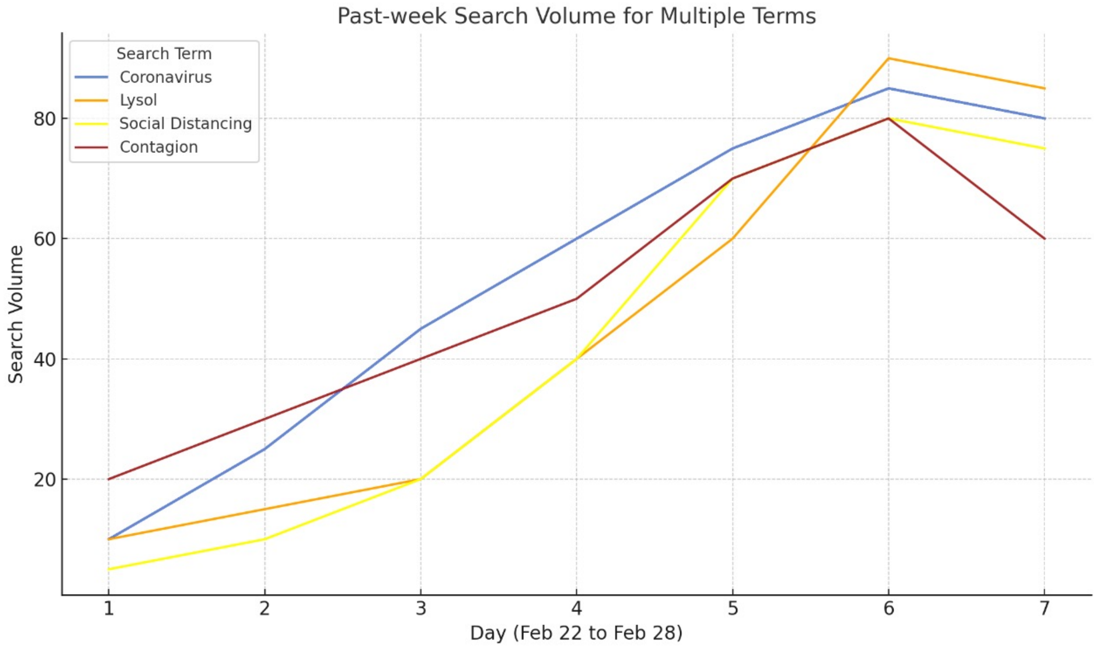

Figure 1. The number of Google searches for "Coronavirus", "Lysol", "Social Distancing" and "Contagion" as a keyword from 22 to 28 February 2020

502 respondents had used bleach as a preventive measure against COVID-19 (Reisdorf et al., 2021). These erroneous preventive measures originated from unverified information obtained through online sources. Incorrect or unproved information is more likely to cause new and erratic behavior (Rapp et al., 2018; Wang et al., 2019). Therefore, it is of vital importance to communicate reliable information to users, but also do it in an effective manner to mitigate public anxiety and encourage people to be active participants in a global health emergency, thus helping reduce pressure on society in general (Rubin, 2009). The latter can be achieved, for example, though the development of useful and understandable information visualizations based on users' needs and expectations.

A good example of this can be observed from Maxwell's (2003) research, who proposed an interactive emergency communications model to conduct studies on the West Nile virus outbreak in New York in 1999 and the anthrax release in 2001. This research aimed at exploring the significance of information communication within the context of emergency situations. The experimental findings provided valuable insights and recommendations on how governments and the public can enhance their practices and consumption of information in emergency telecommunications. Other visualization studies focusing on pandemic health have discussed the relationship and role of visual communication in relation to behavioral interventions. For example, Zhang et al.

(2022) investigated the impact of different types of information visualization on user behavior change, while Saltzman et al. (2021) assessed the effectiveness of visualization strategies through quantitative analysis and participant perception. Both studies highlight the positive impact of information visualization in aiding and influencing user behavior and perception.

Data dashboards have become a popular tool for data dissemination during widespread disease outbreaks. Dashboards are defined as a visual interface that presents a consolidated view of data and information in a concise and accessible format. They are therefore a powerful visual tool due to the straightforward presentation of complex data and able to convey a dense collection of information efficiently, clearly and without clutter, which consequently helps users to understand information quickly and clearly (Few, 2006). Dashboards have been widely used in various domains, including business analytics, project management, and public health, to provide real-time insights and facilitate decision-making.

Interactive technology, including the use of dashboards, plays an essential role in exploring and analyzing information visualization by reducing response time, handling complexity of large databases, and saving users' time (Godfrey et al., 2018). Dashboards, such as those implemented by the World Health Organization (WHO) and the Centers for Disease Control and Prevention (CDC), have been employed during previous health emergencies, such as the Ebola outbreak, COVID-19 pandemic, to provide timely and relevant information to the public. Consequently, the focus of this research centers on the application of information design practice in the design of dashboards, especially user-centered interactive information visualization in global health emergencies.

1.2 Aim and objectives

Epidemic dashboards used during global health emergencies serve as visual examples that provide a large number of investigative elements conducive to research development in the field of information visualization (Han et al., 2021). The aim is to enhance comprehension of visual representations by exploring the ideal configuration for a visual dashboard, concentrating on the correlation between information arrangement and design.

The study has three key objectives:
1. To assess the comprehensibility and efficacy of the current visualization systems concerning the representation of data, considering both the information framework and visual composition.

2. To identify the design limitations that influence the user's pace of comprehension and ability to use the system.
3. To examine the reading patterns of subjects and examine the user's requirements and information-seeking habits when using data dashboards.

In addition, the following research questions were investigated in the experimental testing:
a. How is the information on the dashboard, categorized by different types of data, located and accessed by the user?
b. Which designs on the dashboard (informative and interactive design) impede or enhance the user's search behavior for information?
c. How to improve the existing disease outbreak data dashboards and promote the development of informative data visualization techniques for data provision during global health emergencies?
d. What design solutions could be employed in the subsequent phase to address the design limitations identified from the existing maps?

To meet the objectives set and answer the research questions, screen recording was employed as a testing method to record the user's interactions when using the design, and frequency of clicks. This methodology was considered an essential approach to assess the legibility of the visualization system and monitor the participants' information search process.

2 Research method

Screen recording is established as a method for acquiring data associated with computer performance and interaction (Imler & Eichelberger, 2011). In the context of performance testing, the screen recording feature serves as a supplementary tool for the collection of human-computer interaction data. This approach was selected due to its capacity to provide a comprehensive analysis of the reading process and strategies employed by participants (Imler & Eichelberger, 2011). The researchers recorded and analyzed the total duration each participant spent on completing the task and correlated it with the trajectory of mouse movements and the position of interactive clicks to evaluate the average time is taken (Kirsh, 2022). This section will scrutinize the advantages of utilizing screen recording in performance testing and explore the user behavior and patterns that can be deduced from this research method.

Screen recording tools assume a crucial function in the experimental analysis since they facilitate the examination of the following three critical factors:

Scope of Interest: Screen recording tools furnish valuable evidence that reflects the extent of users' interest in a specific screen area (Christians, 2019). This constitutes a crucial aspect in the analysis of legibility and is often scrutinized by researchers.

Scanning Pattern: According to Rotolo's (2016) study, the movement of the mouse while reading can serve as an indication of the reading speed and habits of the user. Recent research conducted by Milisavljevic et al. (2021) has revealed a consistent correlation between mouse and eye movements when presented with frozen frames/fixed pages. In addition to this, the pattern of mouse movement can offer valuable insights into the reading strategy adopted by users when viewing data visualization charts.

Interaction Intensity: To examine the correlation between interface layout and user interaction clicks in an interactive information visualization system, it is necessary to analyze the limitations imposed by the layout. Recording the frequency and location of user clicks can effectively demonstrate the impact of the layout on the user's interaction process (Cheng, 2019).

Screen recording has emerged as a valuable tool for studying the reading processes, habits, and preferences of users, offering insights into their perceptions and underlying cognitive processes (Schoemann et al., 2021). Through recorded data, mouse movement trajectory can be analyzed to gain a comprehensive understanding of the user's interaction. Advancements in technology have made mouse tracking a widely accepted method for evaluating the legibility of reading materials or web pages (Cepeda et al., 2018). An expanding wealth of evidence implies that the utilization of mouse tracking can furnish essential information on the comprehension of intricate and novel model frameworks by individuals (Konovalov & Krajbich, 2020), thus serving as a fundamental basis for the blueprint of upcoming visual interfaces. The recurrent patterns of mouse behavior identified in the literature are subsequently synthesized, and the distinctive attributes that can be expounded upon for each archetype are explicated, drawing upon prior research findings.

Straight Pattern: According to a study by Griffiths and Chen (2007), users tend to trace the feature directly to the target area or point when seeking information. This pattern of behavior, termed "direct movement," is considered an immediate action taken by the user after deciding on the desired course of action and can indicate their certainty and task-oriented self-efficacy (Rodden et al., 2008). In the context of web applications, direct movement is described as a movement "without major pauses" (Ferreira et al., 2010). The analysis of mouse trajectories (e.g., straight lines) or selected targets (e.g., clicks) following direct movements can provide valuable insights into end-user self-efficacy levels and perceived ease of use when interacting with computer applications (Katerina & Nicolaos, 2018).

Hesitation Pattern: Mueller and Lockerd (2001) propose that when a user exhibits reluctance towards a specific hyperlink or text, it may suggest that the user is contemplating other pertinent information on the page. This pattern of hesitation is frequently demonstrated through the motion of the cursor hovering over a decision item (e.g., a clickable element) or traversing between multiple options while the user deliberates on which one to select (Ferreira et al., 2010). These hesitation patterns are commonly noticed in web forms, particularly during engagements with navigation menus (Atterer & Lorenzi, 2008). Usually, this hesitation indicates the user's uncertainty regarding the selected option. The more intricate the form, the more conspicuous these hesitation patterns become (Ferreira et al., 2010). Thus, the hesitation pattern can be utilized to deduce the user's perceived complexity and risk perception level (based on the user's evaluation of the cost-benefit of a process) and even offer insights into the system's usability based on the user's interactions.

Reading Patterns: Reading patterns can generally be categorized into two types: horizontal and vertical. The more prevalent horizontal reading pattern, as described by Rodden et al. (2008), involves the user moving the mouse from left to right, thereby facilitating visual reading. This model is characterized by lateral mouse movement within a paragraph (Ferreira et al., 2010). A comparative study utilizing eye-tracking technology revealed that the horizontal reading mode corresponds to following eye movements horizontally (Rodden et al., 2008). Conversely, the vertical reading mode is characterized by the mouse following a vertical trajectory with significant or small pauses in between (Rodden et al., 2008). This pattern, also known as "vertical eye-tracking" movements (Rodden et al., 2008), is often observed in vertical lists resembling menus. In visualization, it is frequently observed in the application of vertical data tables (Mueller & Lockerd, 2001).

Random and Fixed Patterns: Ferreira et al. (2010) elucidated that random patterns denote cursor movements that occur without a particular intention or purpose. These movements are merely the outcome of experimental actions or aimless play, frequently coupled with brief pauses or no pauses at all. The frequency of these arbitrary patterns is directly proportional to the level of difficulty experienced by users in comprehending the information. The interactive interface and visual aspects of the information design can also play a substantial role in shaping the user's interaction process. This indicates that the more challenging it is to grasp the information, the more arbitrary the cursor movements will be. Conversely, the fixed mode pertains to a scenario in which the user discontinues the use of the cursor (Katerina & Nicolaos, 2018). Ferreira et al. (2010) determined through their research that users often relocate the cursor to an empty space to prevent inadvertent clicks. Fixed patterns in "neutral" webpage regions can be characterized by long or short pauses. During this time, the user may contemplate the task at hand, read, or evaluate the pros and cons of performing a particular action or clicking. Thus, fixed patterns can offer insight into a user's perception of risk and utility.

Guide Pattern: The guide pattern, as defined by Griffiths and Chen (2007), is a behavior in which the cursor moves in a continuous manner with a "smooth" (i.e. slow) cursor movement to indicate horizontal or vertical reading. This pattern is thought to reflect the user's exploratory nature in using the mouse to navigate interface information and highlights the interplay between mouse and eye movements. Therefore, guided patterns may better represent user expectations of design elements. Furthermore, the mode of guidance may impact user acceptance, including perceived usefulness and ease of use, as well as the user's willingness to learn (Amin et al., 2014).

Through the integration of the above pattern, Table 1 presents potential interpretations for mouse behavior during mouse tracking, derived from previous experimental investigations into mouse tracking.

Mouse Movement Mode

Mouse Movement	Possible explanation
The mouse does not move for a long time (wheel moving process)	When users utilise the scroll wheel to navigate a webpage, they tend to preview the page roughly in accordance with the speed of the scrolling action (Williams, 2020).
The mouse stays in the same position for a long time	During this process, the user may momentarily cease operating the mouse or remove their hand from the mouse entirely. If this occurs while the user is reading, it may suggest that they are either interested or confused by the content at a specific point (Nielsen, 2011; Ferreira et al., 2010).
The mouse slowly follows the movement of the text from left to right	Users manipulate the mouse to aid in reading the content displayed on the screen (Milisavljevic et al., 2021; Rodden et al., 2008).
Irregular rotation of the mouse on the screen content	Within the range of rotation, the user may be contemplating the content or experiencing confusion (Meidenbauer et al., 2021).
The mouse moves back and forth between two objects	Additionally, users may utilise the mouse to compare targets or struggle with decision-making (Jaiswal et al., 2020).
Fast-moving	When users are seeking specific information, the mouse can be utilised as a tool for this purpose (Nielsen, 2011).
First move location	Elements that are particularly attention-grabbing may also capture the user's focus (Jaiswal et al., 2020).
Last move location	Less engaging, difficult to locate, or irrelevant information may be overlooked (Jaiswal et al., 2020).
Point to the same location on different pages	Represents the user's habitual interaction with a specific area, reflecting intrusive design (Rotolo, 2016; Katerina & Nicolaos, 2018).

Table 1. Mouse movement data and possible interpretations

Analyzing the behavioral patterns of mouse usage within user data yields significant insights into the reading process and the design challenges that have the potential to impede readability. The critical element in usability testing, mouse movement data, affords a more profound understanding of users' cognitive processes by exposing the underlying connections between their cogitations and behavioral patterns (Rotolo, 2016; Kortum and Acemyan, 2016; Katerina & Nicolaos, 2018; Leiva & Arapakis, 2020). Such information is pivotal for assessing overall usability.

3 User performance test

3.1 Participants

During the study period, due to the global impact of the COVID-19 pandemic, searches for outbreak-related information transcended geographic boundaries, necessitating a wider range of information retrieval. Alexander et al. (2021) found that users' cultural preferences can greatly influence the usability of a website. Therefore, unlike the online questionnaire in the previous chapter, which was based on a single focus country, this experiment adopted a more inclusive approach by recruiting a diverse group of participants for the user performance evaluation, aiming to ensure cultural equity in the experimental process and subsequent experimental feedback. Specifically, 30 participants were recruited for this study from five different countries (i.e., the UK, the US, China, Germany, and Japan), which represent the three continents of the Americas, Europe, and Asia. The selection of these countries was deliberate and based on the following factors: 1) these countries have experienced large-scale outbreaks during health emergencies; 2) these countries have different levels of control over outbreaks during health emergencies; and 3) the usability of the experimental samples would differ significantly between participants from different cultural backgrounds, which would be more conducive to identifying the visual design that affects user usability elements.

Regarding the age of the participants, the vast majority of the participants were from the age group of 25-34 (53.3%), while the remaining participants were from the age groups of 18-24 (30%), 35-44 (10%) and 45-54 (6.7%). Based on the National Bureau of Statistics (Fordham and Charnock, 2022), the number of coronavirus infections in the age groups of 12-24 years old and 25-34 years old has increased to 3.5% and 1.6% respectively during the period of a stable and sustained global outbreak of the virus since 2021. Furthermore, BBC (Meredith, 2021) stated that as the Delta and other variants rapidly spread, the number of COVID-19 cases among young people is rising exponentially. This indicates the virus's was spreading rapidly among the younger population. With regards to "dashboard usage," 44% of participants reported prior experiences using similar dashboards, while 56% stated that they had only heard of similar dashboards. Prior to the experiment, it was ensured that all participants possessed basic computer skills and passed the Ishihara color vision test (Hardy et al., 1945) to guarantee that all participants had a normal color vision.

3.2 Test Environment, Materials and Test Settings

The experiment took place indoors to prevent the impact of external natural illumination on the color of the instrument panel. The task was performed by the participants utilizing a computer system with a display resolution of 1920 x 1080 pixels. The dashboard utilized in the experiment employed Google Chrome as its internet browser, with the user interface scaled to 100% of the display size to ensure homogeneity of the display's dimensions. In accordance with Rempel et al.'s (2007) research on the optimal distance for screen usage, every participant sat at a distance ranging from 52 to 73 cm from the screen. Throughout the testing phase, the EV screen recording tool captured the user-generated usage data that transpires during the experimental sessions. Additionally, participants were queried about their operational behaviors as they executed each task within the course of the study. In this investigation, the mouse motion data was examined, utilizing the motion frequency chart produced by the EV screen recording tool. Additionally, paired-sample t-tests for comparison between diverse variables were used to analyze the collected data.

In order to comprehensively evaluate the design efficacy of dashboards (employed for the presentation and dissemination of interactive information visualization data in the context of a global health crisis) the participants were systematically engaged in the execution of four distinct tasks, each aligning with a precise research objective. During the assessment, participants' interactions and information retrieval processes were asked to be systematically documented using a "think-aloud" process. The tasks encompassed the retrieval of targeted data from the dashboards of the World Health Organization (WHO) and Johns Hopkins University (JHU). To mitigate any potential sources of bias or learning-related influences on data collection, the presentation sequence of the dashboards was randomized. The specific tasks and their corresponding research objectives can be found in Table 2.

During these tasks, the examination of information layout, graphic presentation, colors, fonts, and interaction flow is further scrutinized and discussed. In the course of testing, participants are asked about their user experience and their interpretation of the purpose of specific actions in the experiment, which

Task Detail and Research Aim

Task	Task details	Research aim
Task1	Find the current number of confirmed cases and deaths in China on the dashboard	To assess the reading techniques employed by participants when searching for basic information and investigate potential layout issues regarding information type and/or search processes.
Task2	Find the total number of confirmed cases worldwide on November 1st, 2020 on the dashboard	To test the legibility of visualisation, with particular emphasis on the layout structure and visual design of crucial information (including design principle elements such as colour and typography).
Task3	Find the current number of confirmed cases in the UK on November 1st, 8th and 15th on the dashboard	To evaluate the impact of various interfaces on information search in the context of further interactive operations, as well as the reading strategies used by users when viewing infographics under more interactive conditions.
Task4	Use the dashboard to understand the current epidemic situation in India or Germany and makes a rough summary	To test the participants' systematic reading routes and strategies in planning to comprehend and summarise information. The researchers also aim to gain insight into the user's overall understanding of information and the information design structure of the entire dashboard.

Table 2. Task details and corresponding research aims

contributes to a better comprehension of the users' reading behavior and the purpose of the interaction, augmenting objectivity in the results. For instance, when users utilize the mouse to explore and view information, the mouse remains in a particular area for a prolonged period compared to other spaces, signifying that certain elements of this area draw the attention of users. Various explanations can account for this phenomenon: 1) the content, structure, and complexity of the information in that specific area are confusing, leading the user to read it multiple times (Nielsen, 2011); 2) the area encompasses several interactive features with ambiguous intentions, causing the user to have to think before taking action (Lockton et al., 2010); 3) some elements of the area are more novel and appealing compared to others, attracting the user's attention (Richardson et al., 2009). It is possible that many of these interpretations could be applicable so further data collection is required to investigate which factor may have caused increased attention. Consequently, various studies employed test duration as an index and metric to measure the obstacles faced by users in comprehending and locating information. In such instances, explaining the objectives of the respondents (e.g., via interviews) can develop the knowledge of user behavior before arriving at conclusions. Ultimately, to gather supplementary data concerning user experience, the participants were required to complete a short questionnaire on their experience of locating information on the dashboard.

3.3 Test Results and Analysis

The participants exhibited an average completion time of 105.9 seconds for the combined execution of the designated tasks involving the dashboards. Notably, the average time spent by participants in accomplishing all tasks within the ambit of the WHO dashboard was recorded at 88.3 seconds, whereas a higher average completion time of 123.5 seconds was observed for the JHU dashboard.

3.3.1 Task 1 Results and Analysis

Task 1 requires participants to conduct a comprehensive search for fundamental pandemic information pertaining to a specific country (China) across two distinct dashboards. The requirements of this task includes the retrieval of data on the number of confirmed cases and fatalities. The objective was to examine the reading strategies utilized by participants when searching for fundamental information and to uncover potential issues related to information retrieval due to the layout during the process.

Average time spent for T1

World Health Organization dashboard

		n	M	SD	t	p	
T1	World Health Organization	30	50.2	12.3	-27.557	.000	P<0.05

Johns Hopkins University dashboard

		n	M	SD	t	p	
T1	Johns Hopkins University	30	176.3	27.3	-27.557	.000	P<0.05

Figure 2. Average usage time of the two dashboards in Task 1

In Figure 2, the mean time spent on the first task by participants on both dashboards is presented. It is apparent that the information search process took considerably more time on the JHU dashboard (M=176.3, SD=27.3) compared to the WHO dashboard (M=50.2, SD=12.3) ($p < 0.05$). The primary reason for this difference can be explained by the use of different search strategies by participants while locating the correct answer on each dashboard. In the WHO dashboard, the majority of participants (80%) directly utilized the map tool to identify the relevant country or region. Conversely, the remaining 20% of participants utilized the search box to enter keywords such as "China," "China data," or "China pandemic" to locate the information within the dashboard system. Only two participants (6%) failed to locate the correct answer. On the other hand, 76.6% of participants on the JHU dashboard employed the country list provided by the dashboard to locate the answer. Of these, 17.3% failed to identify the correct answer. The remaining 23.3% of participants used the search box provided by JHU to locate the answer. However, dissimilar to the WHO dashboard, the search function is for the entire JHU website rather than solely for the dashboard, thereby displaying interface details that were unrelated to the dashboard. Consequently, users experienced confusion and frequently had to retrace their steps during the search process.

The mouse movement chart of a single participant was chosen as a representative example to explore the reading strategies employed by participants and identify the design elements or features within the dashboard layout that influence the user search process. This behavior also accounts for the reading patterns observed in most of the participants.

In Figure 3, the primary reading strategies and processes employed by participants for Test 1 on the WHO and JHU dashboards are depicted. The mouse trajectory on the left-hand side of the figure indicates that the reading strategies employed by participants on the WHO dashboard mainly focused on two aspects. Firstly, adjusting the map size through steps one to three to locate the target information on the map. Secondly, moving the mouse to the left-hand side numbers to check for any changes and to obtain detailed information before returning to the map for a second check. In contrast, the reading strategies adopted by participants on the JHU dashboard, as demonstrated on the right-hand side of Figure 3, were more intricate and involved five distinct stages:

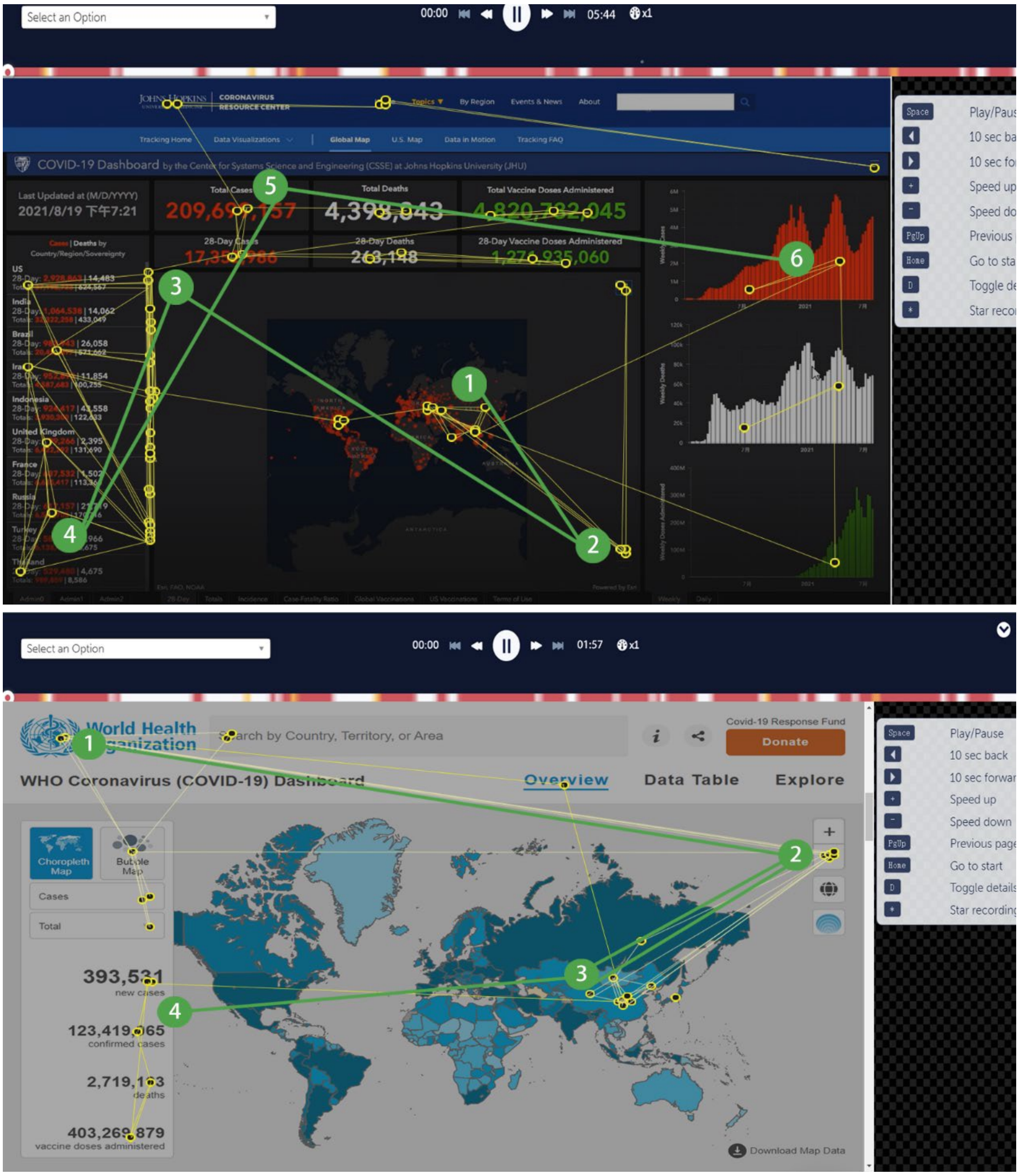

Figure 3. Representative reading behaviors for both JHU and WHO dashboards in sequential order in Task 1

• Steps 1 & 2: Participants scrolled through the map to pinpoint the geographical location of "China" while simultaneously modifying the size of the legend to enhance visibility.

• Step 3: Participants attempted to click the interactive slider located on the left-hand side of the list by dragging it upwards and downwards.

• Step 4: Participants used mouse movements to assist in their visual search for information and repeated the process of adjusting the interactive slider (as in Step 3) until they retrieved the pertinent information.

• Step 5: Participants checked for updates in the data and compared it with the information available in the list.

Through examination of participants' mouse trajectory on the JHU dashboard (Figure 3), it was observed that the layout of data information had an impact on the usability of the dashboard. The frequent scrolling within the list highlighted the difficulty of information retrieval and emphasized the considerable amount of time required for this process. Additionally, prolonged reading of black text against a red background can impede reading efficiency when viewed on a screen (Zhang et al., 2007). Text that is too small or crowded can also hinder text legibility on the screen (Rello et al., 2016; Dobres et al., 2018). It is worth noting that on the JHU dashboard, participants initially endeavored to locate information on the map (Step 1 and Step 2) and resorted to listing searching only after unsuccessful attempts at identifying the correct answer.

3.3.2 Task 2 Results and Analysis

During Task 2, participants were tasked with locating the global confirmed case increment for 1 November 2021, from the dashboard. This task aimed to assess the readability of the data visualization, which includes the interactive display structure of critical information and the visual presentation of these statistics. In the WHO dashboard, 24 participants (80%) found the correct answer. Of those, 83.3% utilized the "optimal" reading strategy, which involved searching by sliding the mouse wheel for interfaces not shown first on the dashboard. The remaining 16.6% found the answer through other means, such as using the search box or exploring other pages of the dashboard. On the other hand, the relevant data visualization was directly displayed on the right side of the JHU dashboard. However, only 16 participants (53.3%) found the correct answer. The errors in both dashboards may have been attributed to certain design limitations in the data display of the visualization, resulting in user confusion.

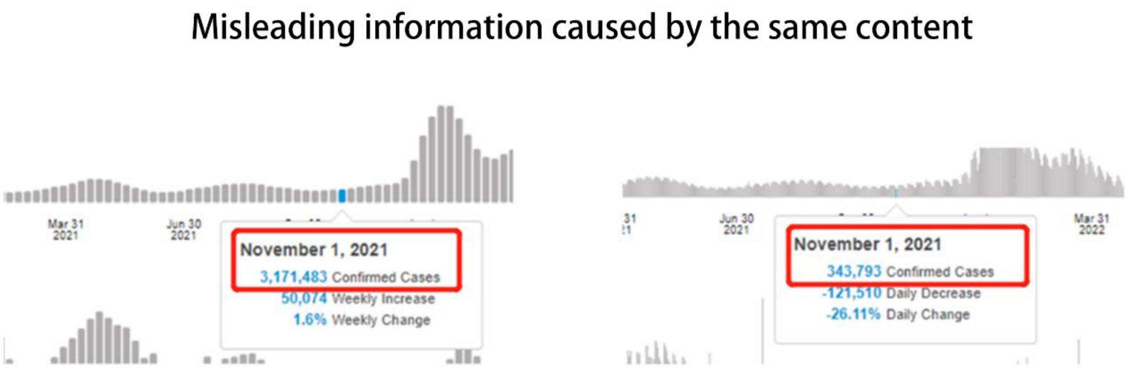

Figure 4. Misleading information present in the WHO dashboard in mission two

In Figure 4, the reading errors of the participants on the WHO dashboard were predominantly caused by a failure to discriminate between the temporal units of the data display (week/day). Figure 4 shows that the participant mainly relied on the interactive display of the date titles when placing the mouse on the visualization chart to select an answer, scarcely inspecting the text and data content of the smaller titles. Additionally, the absence of additional temporal unit labels for "Confirmed Cases" could also misguide users in selecting information. In light of this, the sole method that the participant employed to differentiate between the time units was to compare the dates before and after and make inferences. Although the chart allowed an interactive function to switch the temporal units, the primary reason for the participant's reading errors was the small font size and interactive buttons.

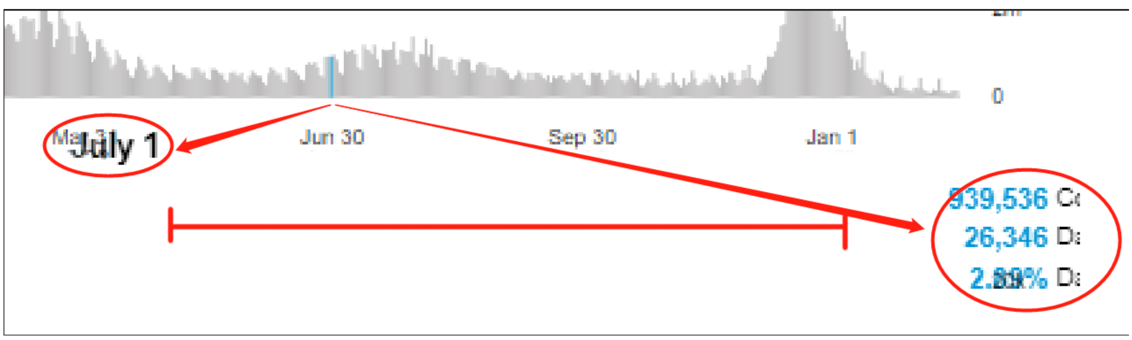

Figure 5. The poor impact of information design structure on users' reading strategies is shown in the WHO dashboard in Task 2

Throughout the experiment, the instability of the dashboard system caused user difficulties, which negatively affected 13.3% of the participants (four individuals). Figure 5 outlines the various predicaments related to information presentation encountered by users while using the WHO visualization. As depicted in the figure, the highlighted blue bar on the chart displays the data information for July 1st. However, the date display overlaps with the unit scale, and is at a notable distance from the related blue bar. When a user wants to view precise data, the information is located further away on the right side, and the data units become cut off. These flaws in the display of the data requires more effort from the user to correctly understand the information. This indirectly verifies that a well-structured visual design influences users' understanding of information.

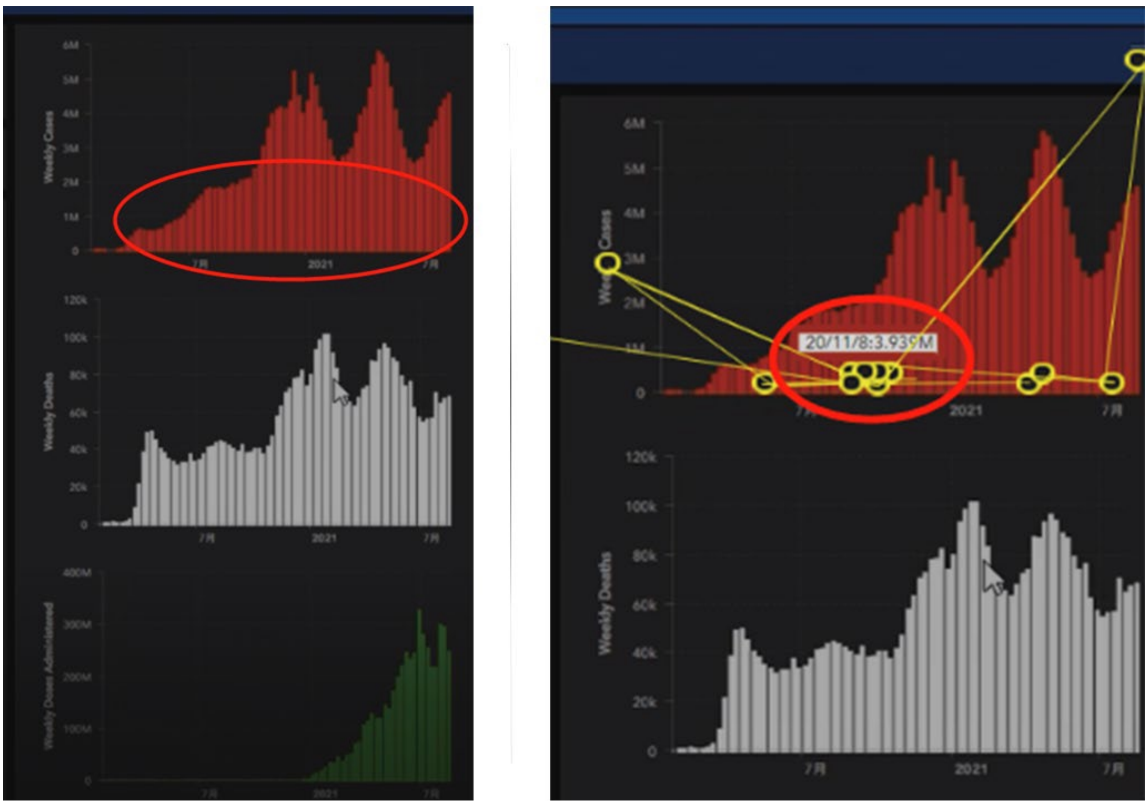

Figure 6. Representative mouse traces of the JHU dashboard in Task 2

In Figure 6, an example of a participant's mouse movement trajectory in the JHU dashboard illustrates a representative reading strategy for most participants. Firstly, the participant inspected the JHU dashboard to verify that the displayed data pertained to global statistics (as the interface layout remained unchanged when users viewed data for a specific country or region). Next, the participant examined the relevant information by activating the interactive features through placing the mouse pointer over the visualizations. Subsequently, the participant engaged in a prolonged period of reading and searching before ultimately identifying the critical date and retrieving the corresponding data. Uncertain about whether the retrieved information matched the target answer, the participant repeated the process of moving the mouse to display information. However, after prolonged repetitive cross-checking and reading, the participant exhibited impatience and provided an incorrect answer. They noted that the legend of the visualizations was too small, and the interactive response was excessively slow, causing confusion and contributing to the error.

The reading behavior suggests that the visualization's design structure and information display are ambiguous, making it challenging for participants to locate the desired information quickly. Notably, in comparison to JHU, the WHO dashboard employs more space to present the visualization and introduces a date/period-based viewing mode to expedite users in finding information promptly. Furthermore, JHU provides a design feature for users to zoom in on data visualization; however, only 20% of the participants (6 individuals) attempted to click and use it due to the button's small size and unclear meaning. Additionally, JHU fails to offer any other design features to assist users in quickly locating information.

3.3.3 *Task 3 Results and Analysis.*

Task 3 required the participants to determine the number of confirmed cases in the United States on 1, 8, and 15 November 2020, using the dashboard. The objective of the task was to observe the participants' "optimal" reading approach employed throughout the search process. Additionally, the aim was to assess the user experience of the participants as they explored the information, and to investigate the visual components that influenced the search experience. Comparable to the prior tasks, the majority of participants initiated their search with the map tool; nevertheless, the map tool lacked specific information regarding the target dates. This reading behavior infers that the participants placed greater reliance on the map legend than on other interactive tools provided on the dashboard and that they lacked certainty about the information that should be included in the interactive map tool.

Expanding upon the knowledge acquired from the antecedent task, in the third task, the individuals attained a greater level of accomplishment in discovering the accurate solution in both interfaces (93.3% for the WHO dashboard and 70% for the JHU dashboard), albeit both dashboards have relatively longer average search times. Nevertheless, owing to the preference for the map tool by participants, the investigation recognized a problem with the composition of information and interactive capacity of the dashboard maps, which may have resulted in confusion and depletion of users' time.

In Figure 7, the JHU dashboard's map display is showcased in various scales, categorized into three stages: initial, intermediate, and detailed. The "red dots" on the map can be clicked by users to obtain important information about specific regions. During practice, a vast majority of users opt to adjust the map legend to the "intermediate" or "detailed" stage before commencing their reading activity. This occurs due to the hindrance caused by the black areas on both sides of the map during the "initial" stage, which obstructs the complete display of the map's extent and restricts the user's ability to locate information. Furthermore, during the "preliminary" stage, the dimensions of certain "crimson dots" impede the user's comprehension of the map, and in certain regions, the "crimson dots" may obscure the primary country names exhibited on the map owing to their secluded location and negligible territorial range. This is due to the fact that the size of the "crimson dots" on the map does not adjust proportionately with the map's legend. This confusion prompts the participants to bypass the "preliminary" stage and expend more time exploring and locating the map during the "intermediate" and "detailed" stages.

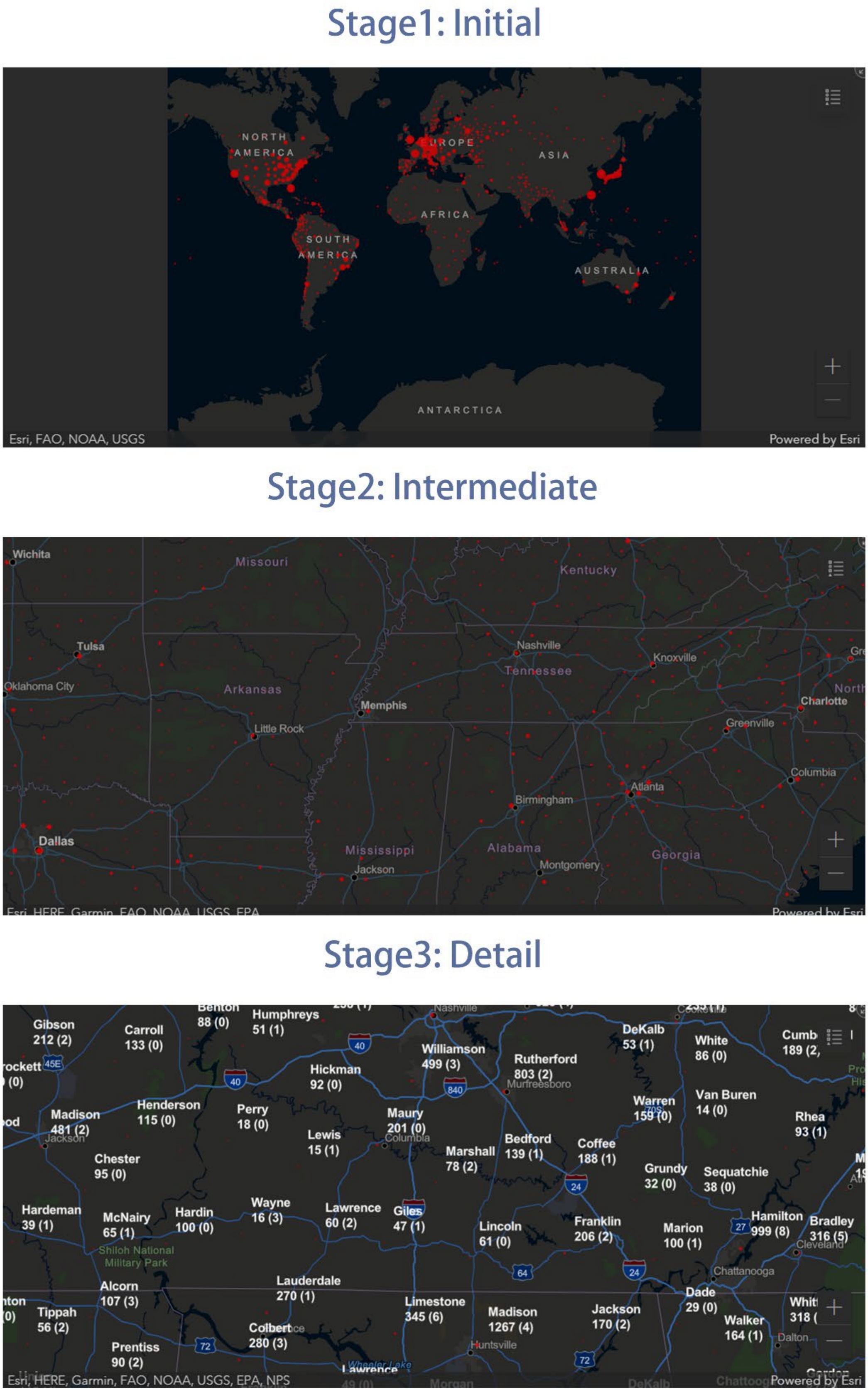

Figure 7. Three stages of JHU dashboard map display

Figure 8. Design limitations in the map in the JHU dashboard

Furthermore, the map does not provide clear explanations regarding the information the "red dots" conveys, resulting in some areas/countries exhibiting numerous "red dots." In contrast, others have only one or none, presenting a confusing data display for participants. Figure 8 demonstrates the contrast between the United States and China's display in the intermediate stage of the JHU dashboard map. During the detailed phase, participants most often criticized the depiction of the crowded road network on the map, which did not help them to obtain relevant pandemic information. On the contrary, the color contrast made it difficult for them to concentrate on finding information. Furthermore, this stage's "red dots" are too small and easy to overlook. Figure 8 displays the obscurity of the "red dots" in the detailed stage of the map.

Figure 9 further investigates the impact of design constraints on user experience. Analyze participants' timing and interaction clicks while using the map on the JHU dashboard. It was found that the mean duration of use for the JHU dashboard (170.5 seconds) significantly exceeded that of the WHO dashboard (100.1 seconds). Moreover, the number of clicks made by participants using the JHU dashboard (15.7) was notably higher than for the WHO dashboard (5.3). These findings demonstrate how the design limitations apparent within the JHU dashboard map not only waste users' time but also have a detrimental impact on their overall user experience.

Average time and number of hits for T3

The interative operation

		n	M	Valid	Invalid
T3	World Health Organization Johns Hopkins University	30	80.1 170.5	3.2 4.6	2.1 11.1

Time spent to find information

		n	M	SD	t	p	
T3	World Health Organization Johns Hopkins University	30	80.1 170.5	19.9 13.8	-21.449	.000	P<0.05

Figure 9. Comparison of the time and number of clicks for the two dashboards in Task 3

3.3.4 *Task 4 Results and Analysis*

Task 4 required the participants to gather data related to the present COVID-19 scenario in India and Germany. The individuals were also asked to describe their reading and search strategies. The task requires navigation and interpretation an extensive volume of data through many different segments of the design; highlighting the users' navigation decisions while accessing different areas of information, and the dashboard configuration and design impacts on such preferences.

The significant increase in average usage time (121.8 seconds) of the WHO dashboard is notable in this task compared to the previous three tasks. This result can be attributed to a variety of factors, with the primary reason likely being the unengaging flow created by the structural layout and the lack of annotations within the data visualization. Figure 10 portrays the structure of the WHO dashboard homepage, where 36.6% of participants (11 individuals) opted to utilize the "cases by country, territory, or area" feature. As a result, each time participants switched to a new country, they were forced to return to the homepage, ultimately leading to a greater amount of time spent searching for and locating information. Moreover, the absence of basic axis labelling within certain charts could also contribute to user confusion when attempting to view data.

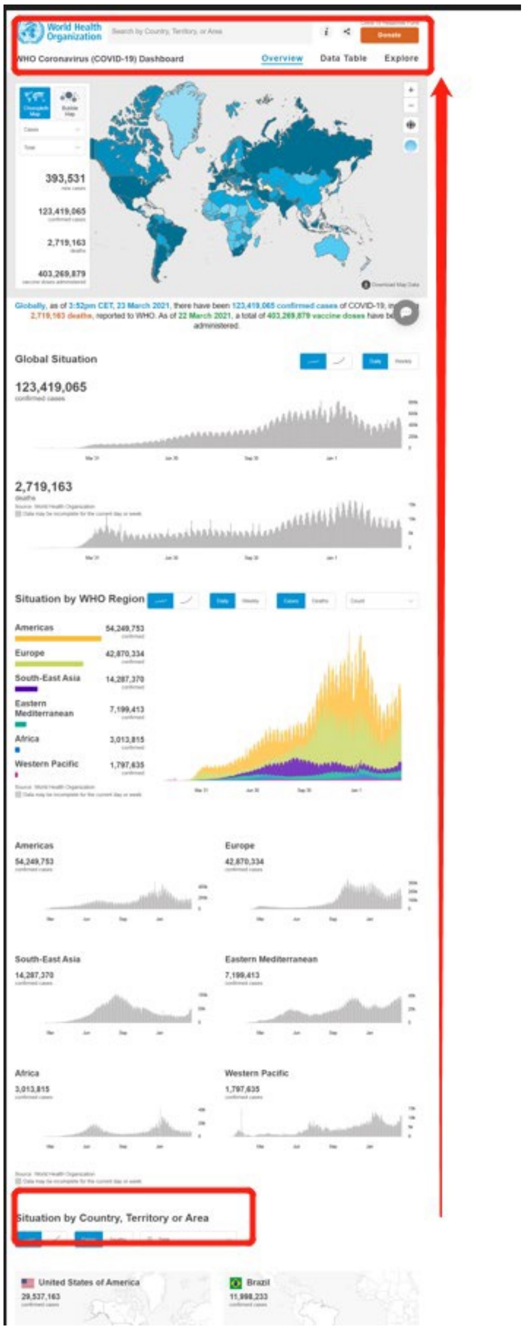

Figure 10. How far participants were able to find and compare information in the WHO dashboard pages

3.4 User Perspective

Following the completion of the task, separate interviews were carried out to assess basic feedback from users who had utilized both dashboards. The obtained results provided insight into the users' feelings toward the respective dashboard.

3.4.1 Usage and Information Understanding about Dashboards

First, the interview process commenced with the gathering of information relating to the overall usability of both dashboards by the participants of the experiment. This encompassed factors such as the ease of use and the clarity of the information presented within the dashboards. The aim is to understand the impact of different dashboard designs on the user's information comprehension and usage process while keeping the content the same.

Figure 11 depicts the feedback obtained from participants regarding the usability and information comprehension of the two dashboards. As shown in the figure, the "ease of use" and "ease of understanding information" for both dashboards were graded on a scale of five levels, ranging from 1 (indicating very difficult to use/understand) to 5 (indicating the high level of ease of use/understanding). The WHO dashboard received positive feedback, with 80% of participants selecting grades 4 and 5 in "ease of use", signifying that they found the dashboard to be user-friendly. Similarly, 66.7% of participants selected grades 4 and 5 in "ease of understanding information", indicating that they found it relatively easy and straightforward to comprehend the information presented in the dashboard. Notably, for the JHU dashboard, half of the participants selected grades 1 and 2 in "ease of use", with only 13.3% of them finding it user-friendly. Concerning information comprehension, nearly 46.7% of participants remained neutral, while 43.3% of participants found it relatively clear.

Initial feedback on the ease of use and information comprehension of the dashboard

Number of respondents:30

How easy is it to **Find** COVID data information with the dashboard	Very hard	Hard	Netural	Easy	Very easy
JHU	1(3.3%)	14(46.7%)	11(36.7%)	3(10%)	1(3.3%)
	15(50%)			4(13.3%)	
WHO	0(0%)	3(10%)	3(10%)	18(60%)	6(20%)
	3(10%)			24(80%)	
How easy is it to **Understand** COVID data information with the dashboard					
JHU	0(0%)	3(10%)	14(46.7%)	10(33.3%)	3(10%)
	3(10%)			13(43.3%)	
WHO	0(0%)	0(0%)	10(33.3%)	14(46.7%)	6(20%)
	0(0%)			20(66.7%)	

Figure 11. Participants' initial feedback on the two dashboards

3.4.2 *Feelings and Preferences about Dashboards*

The experiment incorporated 20 descriptive words (10 positive and 10 negatives) derived from the "Microsoft Desirability Toolkit to Test Visual Appeal" (Meyer, 2016), verifying the correlation between users' perceived experience and the information presentation and interaction functions during the dashboard usage process. Participants were requested to assess both dashboards based on their experience during the experiment and select five words to encapsulate their depiction of each dashboard. Subsequently, an interview was conducted based on the positive/negative aspects of the dashboards to obtain detailed feedback and evaluations.

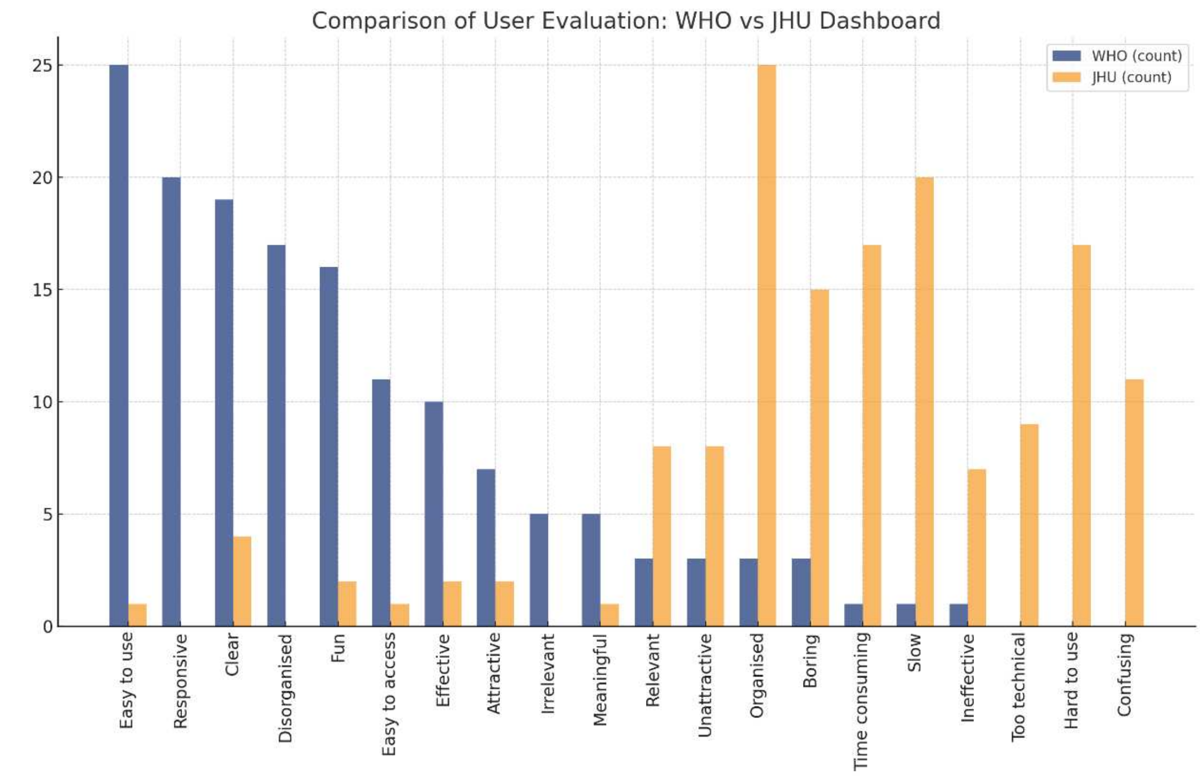

Figure 12. Choices of five words after using the WHO and JHU dashboards

Figure 12 illustrates the feedback provided by the participants concerning the two dashboards based on keywords following their use of the respective dashboards. The top 5 keywords for each dashboard were compared and analyzed in the experiment. As shown in the figure in the WHO dashboard, the majority of participants (83.3%) perceived the dashboard to be "Easy to use". Additionally, many participants rated the dashboard as "Responsive" (66.7%) and "Clear" (63.3%). Although half of participants (56.7%) found the dashboard "Disorganized" but "Fun" (53.3%). In contrast, for the JHU dashboard keywords, 83.3% of participants acknowledged the dashboard to be "Organized". Nevertheless, many participants (66.7%) experienced the dashboard as "Slow", which left a lasting impression on them. Simultaneously, half of the participants regarded "Time-consuming" (56.7%), "Hard to use" (56.7%), and "Boring" (50%) as the primary experiences while using the JHU dashboard.

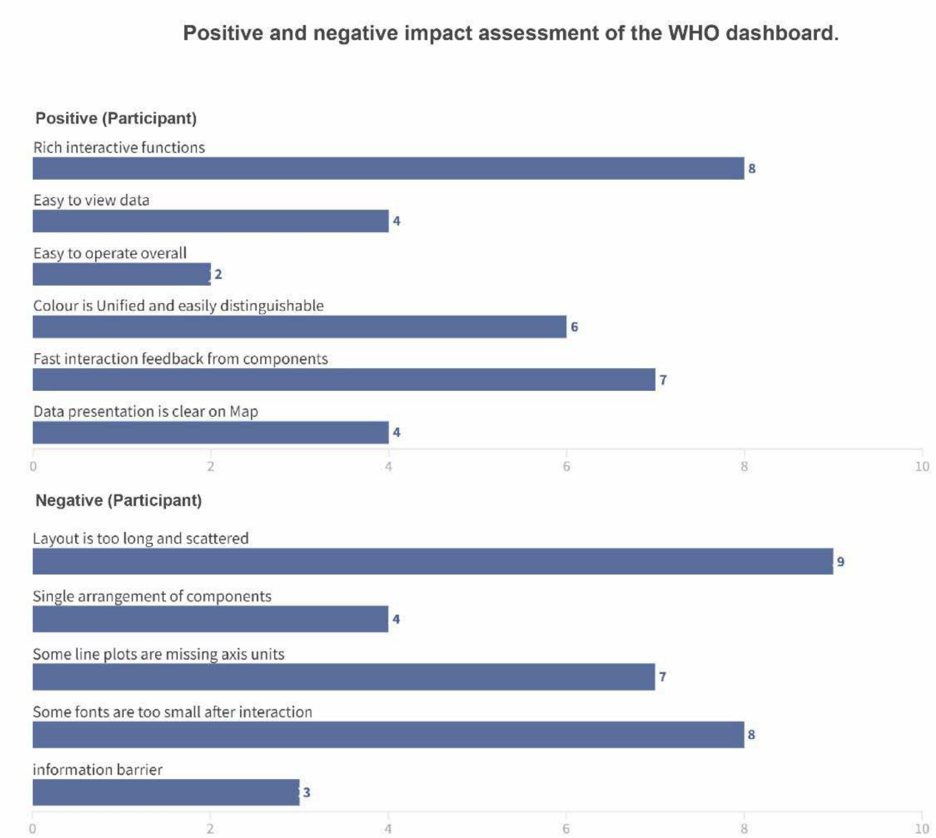

Figure 13. Users evaluate the positive and negative effects of the WHO dashboard during use

Figure 13 presents a summary of the effects of using the WHO dashboard on participants, both positive and negative. According to the data, 46.6% of participants believed that the positive effects of the dashboard primarily derive from its various visualization tools, which enable users to view data in multiple ways. Specifically, feedback from eight people indicated a "diversity of interaction functions," four people mentioned "convenient viewing," and two people appreciated its "ease of use." Additionally, 30% of participants evaluated the color combination positively, noting that the dashboard utilizes fixed colors (blue for newly added data and functions, orange for death-related data and functions) in a representative data scenario, and applies them consistently throughout the system, making the colors "uniform" and "easy to distinguish". Moreover, 36.6% of participants found that the presentation area of the visualization tools (charts and maps) in the system provided "clear data" and "timely interaction feedback", thereby reducing the time required for users to view the data. On the negative aspect, it was noted that 30% of the respondents espoused the belief that the "dispersed layout" and "single" were principally attributable to the elongated design structure, which results in extended visual movement for users whilst navigating through the information. According to

Few (2013), when information cannot be displayed on a single screen, it disrupts user cognition, thus impeding the speed of identification of information within the structure. Moreover, 26.6% of the participants stated that there were certain “font sizes not suitable for reading” while interacting with visualization tools. 6% of participants further argued that, in certain circumstances, the information generated via mouse interaction with visualization tools could obscure the original interface content. As can be seen from the above analysis, participants generally felt that the WHO dashboard had good usability because it performed well in terms of information recognition. This capability is largely due to the dashboard’s ability to effectively and intuitively present data through visual design and interactivity that provides rapid feedback on component usage. These strategies collectively facilitate users’ capacity to differentiate and interact with specific data during their engagement with the dashboard. This effectiveness is consistent with the successful integration of information design elements, including color and typography, as defined within the dashboard’s overarching principle framework. Conversely, participants’ feedback regarding the dashboard’s layout points to concerns related to its perceived fragmentation. This assessment predominantly arises due to the dashboard’s extended layout structure, which lacks cohesiveness in terms of information interaction and interlinkage across distinct visual components.

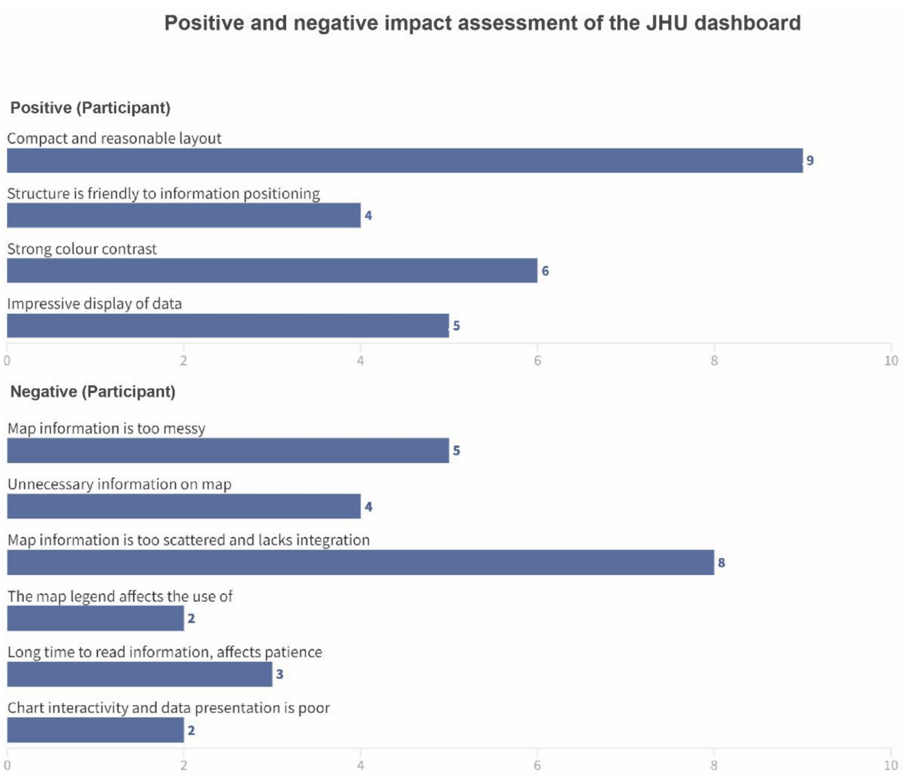

Figure 14. Users evaluate the positive and negative effects of the JHU dashboard during use

Figure 14 illustrates a synopsis of the positive and negative effects of the JHU dashboard, as encountered by the respondents. Specifically, the configuration arrangement of the dashboard was favorably perceived by the participants. Of them, 43.3% of participants perceived the dashboard to possess a "rigorous layout," whereas the time to locate the type of information was "relatively short" (4 participants). Additionally, 36.6% of participants (6 participants) found the contrast amid the data and the background color to be "robust," rendering the data "impressive" to users (5 participants). Nonetheless, on the negative aspect, 19 participants (63.3% of participants) found the usability of the visualization tool (the map) to be inadequate. Among them, 9 participants (30% of participants) believed that the information on the map was "too messy" (5 participants), comprising "unnecessary information" (4 participants). Moreover, 26.6% of the participants (8 participants) felt that the information on the map was "dispersed" (5 participants), with a "lack of information integration" (3 participants). In addition, 6% of the participants (2 participants) deemed the map legend to be "inferior," hindering its use.

Besides, 10% of the participants (3 participants) claimed that searching for specific information consumed a considerable amount of time, testing their patience. Additionally, 6% participants expressed their dissatisfaction with the charts' interactivity and data presentation, hampering their ability to review individual data. To summarize, the participants' keyword selections and feedback underscored their favorable response to the layout of the Johns Hopkins University (JHU) dashboard. Specifically, the JHU dashboard's layout was praised for its ability to diminish the necessity of swiping through pages to access information, thereby enabling participants to rapidly orient themselves toward the general information flow based on the layout. Conversely, participants' less-than-ideal experiences with the JHU dashboard stemmed primarily from the visual design aspects of the information presented in the visualization components. Notable shortcomings included the dispersion of information within the map tool and the suboptimal arrangement of information within the lists. As a result, while participants could swiftly locate the sections presenting relevant information on the dashboard, more time was required to locate detailed information and comprehend it thoroughly.

3.4.3 Design Suggestions

The design suggestions provided by the participants for both dashboards with regards to their impact on the information search process and information viewing were noted. Overall, it was observed that some of the design suggestions complemented each other in both dashboards. Concerning information search, it was found that the majority of participants (14 of participants) recommended a concise design structure for the dashboards.

They argued that such a design would be effective in improving the use of space in the dashboard and reducing time cost caused by overly complex interface layouts. Furthermore, interactive features (3 participants) or design layout (6 participants) were proposed to assist users in filtering and searching for specific information. Twenty participants suggested modifications to the map tool in the dashboard because it represented the "best" choice for users in the experiment. Some of these modifications came primarily from feedback on the JHU dashboard and included defining different countries and regions by color rather than individual red dots (8 participants), minimizing the impact of unnecessary information on the map such as detailed highways (6 participants), providing explanations of the map legend (2 participants), and increasing the transparency of information generated by interactions in order to reduce information blocking (4 participants). Additionally, for the WHO dashboard, some participants (2) suggested increasing the font size of the interaction-generated font to help users view specific information in the visualization charts. Two participants also suggested that data units and measurements, such as the x-axis and y-axis, be clearly identified in the visualization charts. On the other hand, some common suggestions came from the map tool of both dashboards. 7 participants suggested using fixed colors for important types of information, which would increase their representativeness and reduce user-defined information. Additionally, 3 participants suggested reducing the saturation of colors, as high saturation creates strong contrasts and makes the dashboard "impressive" but also makes the user susceptible to visual fatigue during use. Figure 15 shows the design suggestions for the dashboard.

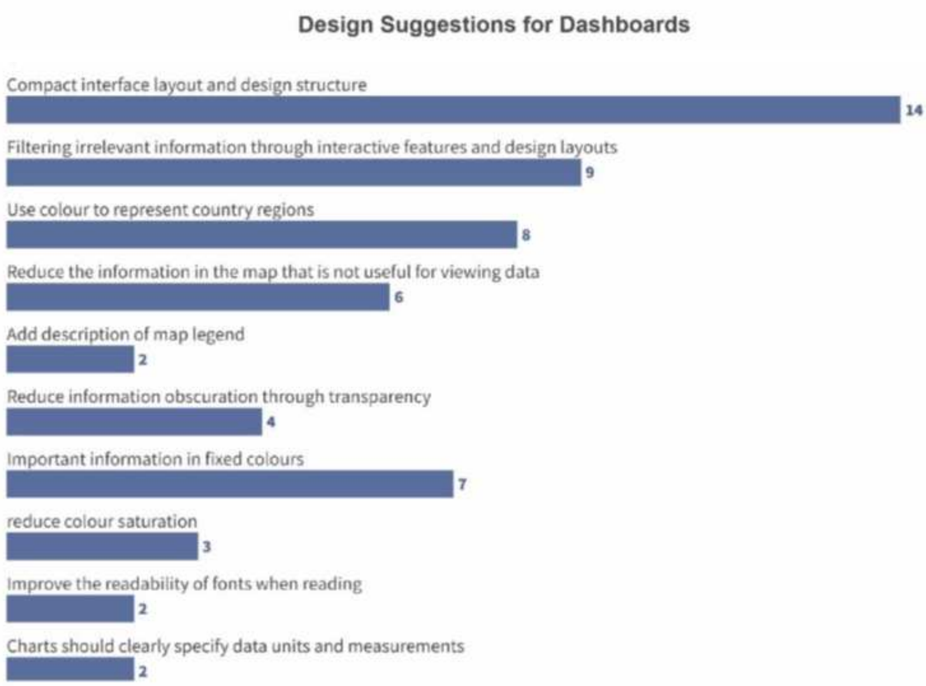

Figure 15. Design Suggestions for Dashboards from Participants

4 Summary and discussion

To determine the design factors that affect reading strategies and legibility in dashboards, an experimental study was conducted to measure the reading performance of participants in two different types of dashboards through various tasks; recording performance metrics such as reading time and interaction clicks. Screen recording and mouse movements were also used more extensively to determine the limitations of the design and analyze users' information search behavior, thereby gaining a deeper understanding of the issues related to the navigation of the information and understanding of visual elements. Additionally, the design suggestions provided by participants regarding aspects of the dashboard that affect information search, and the design proposals themselves can, provide valuable insights for improving the dashboard. This section will further discuss the design limitations found regarding the information structure and visual design of the dashboards from the testing.

The structure and layout of a dashboard can have an impact on the ability of a user to promptly locate information. The layout of a dashboard involves the integration of all visual components and the interconnected information generated through interaction to guide the user's understanding of all the functions within the dashboard, economizing the user's time (Bach et al., 2022). At present, the structure of dashboards provided to the public during health emergencies lacks a clearly defined framework. For example, in Task 4, it was discovered by the participants that the vertically structured layout of the WHO dashboard made the entire interface lengthy. Moreover, owing to the absence of fixed navigation at the top, participants had to spend a significant amount of time searching for the page. Whereas another group of participants solely relied on the map component at the top of the interface to explore the information, which also led to lower utilization of the components below the interface in the WHO dashboard (only approximately 36.6% of participants were willing to use). In comparison to the WHO dashboard, participants were more inclined to the layout structure of the JHU dashboard, which not only reduced the cost of moving the page but also had clear utilization of the components in the dashboard. As mentioned by Abd-Elfattah et al. (2014), dashboards with decision support systems are generally suited for displaying crucial information on a single screen. For the general public, reducing page scrolling and panning is vital in helping the user's memory and locating key information (Few, 2006).

Another observation made during the experiment study regarding the design relates to the difficulty in promptly locating information due to the arrangement of the country list in the JHU dashboard. It was noted by participants that the list was arranged based on the total data of the country's pandemic situation. However, some participants questioned the feasibility of this arrangement, stating that the data list should be designed based on the quick identification of a country or region. Unfortunately, the current arrangement made it cumbersome for them to promptly locate the data of their desired country. Moreover, it was pointed out that organizing the list based on total data does not accurately reflect the current stage of the pandemic situation in the country. Whisner (2004) discussed the possibility of simplifying the system by arranging the information in alphabetical order. Shedroff (2000), on the other hand, believed that information should be organized, presented, and arranged in various ways to cater to the needs of individuals. Therefore, it is possible to arrange the list of information in an interactive way by adding information filters with interactive features to meet the different needs of the participants. The principle of information design enriched by interaction should also be upheld in future enhancements of the dashboard.

In Task 3, despite the map component in the JHU dashboard lacking any relevant information, the individuals still opted to dedicate a substantial amount of time searching for information in the map legends. This observation shows that users are motivated to interact with the map component when accessing dashboard data and expect to locate the information they require here, rather than exploring other aspects of the system. This user behavior emphasizes the significance of well-designed functionality and visual elements in the map, as the quality of the map design will impact the comprehensibility of the entire dashboard (Buard & Ruas, 2009). In the JHU dashboard map component, the design elements in the map mainly influence the participants' capacity to find information. This is evident in Task 3, where the JHU dashboard failed to precisely summarize the data for users through the "red dots" in the map component. Moreover, participants also reported that the explanation of the "red dots" in the map legend was unclear, which led to the need for repeated comparisons to the legend. Fareed et al. (2020) suggests that the design elements in the map ought to be clear, straightforward, and effortless to comprehend. Meirelles (2013) recommends that when designing the map legend, information categories should be defined, and information should be grouped into different categories to reduce the frequency of information comparison.

One design aspect that influences the placement and comprehension of users' information often arises from the interaction between components and users. In tasks 2 and 3, nearly all the participants pointed out that the information produced through mouse interaction frequently covers the original content, requiring users to reposition the mouse. The issue of information overlap refers to the transient information produced during interaction but not overlapping (Hunt & Cavanagh, 2011), and this problem is also widespread in many existing visualizations. The briefly appearing information during interaction is far from the object indicated by the mouse cursor, potentially causing the two to appear disconnected and disordered. This untested design approach might cause confusion for users during actual use, as they are unaware of the reasons before and after the interaction. Hence, it is advisable for designers to refrain from presuming that users will accurately use an untested design scheme as intended, instead testing of the design is highly recommended to investigate if the interaction is functioning as intended (Deleu et al., 2003). According to the recommendations provided by the respondents, enhancing the user experience could be achieved by means of visual design, including but not limited to transparency of information, color schemes, display styles, etc.

Another aspect of visual design quality arises from the implementation of color in the visualization of data in dashboards. In the course of the experiment, positive feedback was obtained from participants regarding the use of color and its fixed correlation with significant data in the WHO dashboard. Nevertheless, participants still reported encountering issues with the color scheme while attempting to locate information. During Task 2, participants reported that the contrast of colors had a detrimental effect on their ability to perceive certain graphs. Holtze (2006) and Coles-Brennan et al. (2019) proffered evidence in their investigations regarding the influence of colors on the digital viewing experience. In the context of dashboards, users typically require heightened attention for data retrieval and exploration, and a well-calibrated saturation and brightness of color can augment their concentration and help avoid ocular strain (Sleeper, 2019).

In summary, this experimental study comprehensively examined users' performance in different types of dashboards, including behavioral processes such as reading time and dashboard interactions. This inquiry is further enriched through the meticulous analysis of users' information-seeking behavior, facilitated by the use of screen recordings and mouse movements. This multi-faceted approach allows for a comprehensive identification of design limitations and an enhanced understanding of issues pertaining to information structure and visual elements. Participants' approach to using the dashboard to acquire information can be distilled into two principal stages. The initial step involves identifying the specific visual display format of the desired information and its corresponding location within the dashboard. Subsequently, participants engage in a meticulous process of locating and comparing information by carefully scrutinizing the visual components. Notably, the experiment underscores the substantial impact of design on users' information retrieval behavior. Elements encompassing dashboard structure, layout, arrangement of information lists, map components, interactive features, and more, collectively influence users' ability to quickly locate data while potentially introducing challenges in the information search process.

Observations gleaned from the experimental process reveal the interplay between design and user behavior. Aspects such as structure, layout, the arrangement of information, and interactive components significantly impact the speed and accuracy with which users locate information. Participant feedback and observed design limitations provided valuable insights into dashboard improvements. Among other things, a thorough analysis of users' information-seeking behavior allowed for optimization of the design to better match users' habits and preferences. Among the salient design limitations observed are the role of map components in dashboards, the extent of interactivity, and the efficacy of color schemes. Recommendations from participants suggest enhancing the user experience by refining visual design attributes, encompassing aspects like transparency, color schemes, and display styles. Additionally, the issue of color application in data visualization is emphasized, highlighting the significance of considering color saturation and brightness in design to enhance user attention and mitigate visual strain.

4.1 Conclusion

This study comprehensively assessed the impact of the legibility of a representative global dashboard in the context of the epidemic through user performance tests and interviews in different countries and cultures, while analyzing different layout and visual design elements in the dashboard. Dashboard designs that limit users' information-seeking behavior were identified by recording their screen movements, as well as their mouse trajectories. This approach provided reliable evidence to clarify which dashboard design constraints hindered users' ability to read quickly and search for information accurately. In addition, the user feedback and suggestions obtained through interviews provided a valuable and diverse contextual perspective for improving dashboard design.

In this investigation, diverse limitations in terms of design were identified relating to visual design elements that impact the location of information. Based on the findings of all tasks, the layout structure of the dashboard is one of the factors that influence users' cognitive categorization of the overall information. Taking the layout of the information structure in the WHO dashboard as an example, the visual elements resulted in an extended interface length in the absence of interaction, and the location of user information required frequent page scrolling. Similarly, in the JHU dashboard, the arrangement of the information lists appeared to cause distress and confusion to users searching for targeted information. Its lists often make it difficult for users to quickly find the pattern of information arrangement, thus wasting time. This does not meet the user's need for quick access to information. The utilization of visualization as an alternative approach to presenting information on the dashboard was insufficient in assisting the user in locating detailed information. Inadequate explanations in the map legend, subpar font quality in visualization interactions, and data overlays incorporated into the design led to unproductive reading time for the user and multiple misunderstandings. These findings support the need to the need to enhance the layout structure and information design that affects users' ability to locate information. Additionally, during testing, another visual design problem was discovered regarding the impact of the color scheme on the user's ability to view information. In Tasks 2 and 3 of the JHU dashboard, the intense color saturation and brightness of the visual components negatively influenced the user's viewing experience of the data. As suggested by participants, the color system requires redesign, particularly with respect to adjusting the contrast between hue and brightness. Furthermore, the map, which is a visual element given precedence by the user, significantly impacts the effectiveness and swiftness of information retrieval, as well as its integration and visual design. Consequently, the usability of the interactive map on a data dashboard should be prioritized, ideally a focus of testing to ensure functional usability.

Broadly, this study represents a significant stride in elucidating information design and interactive display principles. Specifically, the actual impact of the dashboard on the global public health crisis that was occurring at the time was explored through the hands-on behavior of participants in the experiment during the outbreak phase and, in turn, the actual impact of the dashboard on the global public health crisis that was occurring at the time. This design feedback gathered through user performance can be applied to other similar emergencies, such as natural disasters, major accidents, etc., to help the public better understand and respond to crises. On the other hand, participants from different countries, ages and cultural backgrounds were recruited, and through their experimental manipulations and user feedback, factors such as information arrangement, user understanding, interaction design and various visual elements were examined from a global perspective. This also somewhat enhances the commonality of the experimental results across specific countries and different cultural contexts, as the interpretation and communication of data usually involves cross-cultural and cross-geographical audiences. While recognizing the existing limitations of public dashboards based on pandemic data through performance testing, this investigation also conducted post-experiment interviews with users based on their actual feedback on the usability of the dashboards during the course of the experiments, thereby summarizing the limitations affecting the readability and visual presentation of the information, and in doing so, laying the groundwork for future improvements to the overall design and layout structure of such dashboards. This systematic approach can provide valuable lessons for the design of data dashboards in other domains, be it health, future outbreak prediction, other disease surveillance, or other data domains. By understanding user needs and feedback, designers can better optimize the usability and effectiveness of dashboards.

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