Creating a framework of design principles to improve the effectiveness of interactive information visualisation systems in global health emergencies

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The candidate confirms that the work submitted is his own and that appropriate credit has been given where reference has been made to the work of other.

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Abstract

Interactive information visualisation dashboards have long been considered indispensable tools for data analysis in various industries such as finance and healthcare. These dashboards enable users to effectively examine data and make well-informed decisions that address specific challenges. Understanding complex information presented through interactive visualisation systems quickly and effectively presents an immense challenge to most members of society with limited data visualisation access. Recent years have witnessed an alarming escalation in global health crises that threaten public well-being and life, commanding immediate public attention during these emergencies. Through Internet technology, large quantities of information are rapidly disseminated through digital information systema to ensure accessibility of outbreak data for everyone involved in health emergencies worldwide. Preventing viral infections and managing panic are also of critical importance, where poor communications of information could result in misinformation and lead to further distress during pandemic outbreaks. Therefore, this study seeks to explore key design factors which affect the efficiency and efficacy of interactive information visualisation systems used for information dissemination. To meet this challenge, the goal of this framework is to provide users - visual designers and front-end engineers alike - a platform on which to improve interactive information visualisation system outputs from a public viewpoint.

Research began with an extensive literature review to provide the theoretical grounding necessary for further investigation, culminating in a framework of design principles for interactive information visualisation systems derived from this phase. Interviews followed, which were held with users experiencing epidemic scenarios to understand their information needs and suggestions before categorising all principles into seven user-centred dimensions. These included structural considerations, colour schemes, typography, design elements, information presentation, interactive features and visualisation components. This was followed by an exhaustive evaluation of previous visualisation examples disseminated during health crises to confirm the validity of the principles framework and to serve as a precursor to the direction setting of the subsequent experimental phase. User performance experiments, supplemented by interviews, were then conducted to identify key design constraints that impact on the user's reading and information comprehension processes.

The findings highlight the critical role of well-structured layouts in interactive information visualisation systems and the delivery of information through interaction in enhancing public information consumption and comprehension. Specifically, the use of interactive features to present information across multiple levels underscores the prominence of compact, mouse-swipe-free visualisation layouts. Such a layout facilitates quick retrieval and comparison of user information. In addition, the close juxtaposition of visualisation components with those interwoven with relevant information, such as maps, tables and bar charts, was emphasised to facilitate the effective observation of data links during the interaction. It is also important that the presentation of information after the interaction adheres to established information design principles without confusing the views of the original components.

These empirically based findings make a substantial contribution to the field of information presentation and visual design in interactive information visualisation systems (especially those aimed at the public). Adherence to a framework of principles can maximise the effectiveness of interactive information visualisation systems in information presentation, giving them the potential to support disease prevention initiatives and proactive public health.

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1 Introduction

1.1 Background

Interactive information visualisation can enhance people's visual cognition of information and facilitate their active engagement in exploring and understanding information presented to them (Mahyar et al., 2015). It works towards this end, by collecting relevant information, drawing a time-based visual chart, and sharing information with non-experts in an easy-to-understand graphic format (Keim et al., 2010; Raoufi et al., 2019; Meuschke et al., 2022). Since 1765, the utilisation of visual representations, such as bar charts, has emerged in diverse formats, signifying the commencement of employing visualisation techniques to depict condensed and abstract information (Beniger and Robyn, 1978). This marks the initiation of a transition away from the inundation of data towards a focal dependence on visually conveyed information. Within this paradigm, the conversion of substantial volumes of data into succinct visual summaries yields profound ramifications for societal advancement and significantly bolsters the progression of social development. (Yang, 2018). With the advancement of science and technology, people have been overwhelmed by large quantities of information, which further stimulates the improvement of information visualisation. More and more information is displayed in different visual forms, with the format gradually transitioning from paper to the Internet (Liao *et al.*, 2018). In 1987, Edward Tufte initiated the visual display of quantitative information by incorporating interactive manipulation of data into graphical systems, while Jason Dykes developed a visualisation toolkit in 1996 for the combination and exploration of information presentation. This process created in a new era of design for visual representation (Zhang, 2022). More and more visual diagrams are thus being presented in different forms, structures and visualisations (Landesberger et al., 2011; Cairo, 2019; Few, 2006; Ware, 2012). It is noteworthy that while visualisation has the capability to present a wide range of information, the incorporation of additional design elements, such as layout, colour, interaction, and graphics, plays a crucial role in shaping users' comprehension and utilisation of the information (Yang, 2018; Murray, 2019; Zhao *et al.*, 2022).

The visualisation system can be understood as a way of presenting information in a graphical format. In this system, the users need to define the category of information, and summarise the corresponding trends, outliers, content and patterns through the visual graphics. (Olavsrud, 2021). On this basis, effective interactivity in the operation interface can better convert information into visual graphics and present it to users (Gershon *et al.*, 1998). In other words, interactive information visualisation has been shown to provide users with a better way to communicate. This was exemplified in the study conducted by Srinivasan et al. (2018), in which they developed the Voder system that employed data visualisation and interactive components. A preliminary user study involving 12 participants with varying levels of experience in visualisation tools was conducted to evaluate the system. The findings of the study substantiate the efficacy of interactive data visualisation in facilitating information interpretation. Nowadays, in the process of information collection through the Internet, the design products of information visualisation become more intuitive for data exploration and reading, and people no longer need to understand complex mathematical functions or statistical algorithms in the process of data cognition (Keim, 2002). A vast sea of information in the digital society also brings various problems to the information presentation: what kind of information quantity and quality can meet the needs of users that view the information? What kind of visual layout can more effectively improve the user experience? How to simplify the process of users viewing information?

Since the 20th and 21st centuries, research efforts have been driven to investigate these questions in an attempt to improve visualisation design. Among the existing research on visualisation systems, there is a predominant focus on optimising programming languages to accommodate a greater variety of data and cater to professionals' needs. For instance, Taylor and Rodgers (2006) argue that the optimisation of programming languages can enhance graphic design techniques in visualisation, resulting in more visually rich information representations. Additionally, Fekete and Plaisant (2003) suggest that incorporating a wider range of data types within a visualisation system can enhance the diversity of information presented. Ren et al. (2010) developed a user interface toolkit based on a model of an interactive information visualisation system in order to facilitate the arrangement and combination of different data types. However, it is important to note that these studies lack post-model application design evaluations, and they do not adequately address considerations related to information comprehension and the association of data based on data arrangement. Tam and Ho (2006) conducted research on the correlation between website layout and user comprehension; however, their study did not specifically address user understanding of data visualisation presentation. In the existing research, most research interest is put in the visualisation in specific areas, such as helping medical professionals analyse millions of patient records through visualisation tools (Shneiderman *et al.*, 2013), or assisting business decision makers (Tegarden, 1999). These areas often have specialised audiences. For example, in the field of public health, Park et al. (2021) conducted a preference study on data use and data visualisation among public health professionals; Lee et al. (2021) specifically focused on nurses' views on the use of data visualisation in Omaha; Carroll et al. Al (2014) studied a systematic review of public health professionals using a visualisation tool designed for infectious epidemics. In specialised fields, professionals typically possess a certain level of experience in operating visualisations within their respective domains, and designers often create visualisation systems tailored to their specific audience's needs. For instance, Kennedy et al. (1996) established a comprehensive framework for the development of interactive information visualisation systems, focusing on developers in the 20th century. More recently, Matsui et al. (2011) proposed information visualisation frameworks primarily targeting web developers. However, there has been limited research and evaluation conducted on the design constructs that influence the utilisation of visualisation systems from the perspective of the general public, particularly for individuals who lack expertise and experience in interacting with complex data visualisations.

Apart from academic research, many emergencies in social development have made visualisation more present to members of the general public. In recent years, global health emergencies have occurred at an increasing rate, posing a significant threat to public health and life. A typical example is the coronavirus (Covid-19) pandemic that outbroke in 2019. Due to the extremely wide transmission rate and fatality of the new coronavirus, it is very easy to spread between people through physical contact and air transmission (Starkman and Ratini, 2022). Movement restrictions and isolation measures have become one of the main ways for people to prevent infection (Wilder-Smith and Freedman, 2020). This has hindered the dissemination of some traditional physical information (e.g., newspapers and magazines). During the quarantine triggered by the epidemic, the internet became an important means of accessing information (Brooks et al., 2020; McClain et al., 2021). As reported by Google, 2020's most popular word searched online was 'Coronavirus' (Thornton, 2020). According to the British Health Security Agency, hundreds of thousands of British users were updating relevant information daily (Flowers, 2021). As Covid-19 spread globally from one country to another, more and more visualisation systems have been made available to the public on the web in the form of dashboards (Schott, 2020). This unavoidably leads to the differences in developers' demand for public information, supply, layout and information presentation (Li *et al.*, 2022). Given the escalating frequency and severity of global health emergencies resulting from highly contagious epidemic diseases in recent times, it becomes imperative and consequential to undertake an exploration of the effective utilisation of visualisation systems during such outbreaks. This endeavour seeks to enhance the public's comprehension of information pertaining to the epidemics. By delving into the application of visualisation systems in this context, this research aims to contribute to the broader understanding and improved dissemination of epidemic-related information among the general population.

A well-designed dashboard, defined as a visual interface that presents a consolidated view of data and information in a concise and accessible manner, should be self-explanatory, conveying a dense collection of information efficiently and clearly and leading users to understand it quickly, without clutter (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.

Herein, the focus was laid on the application of information design, especially user-centred interactive information visualisation, in global health emergencies. Interactive technology, including the use of dashboards, plays an essential role in exploring and analysing information visualisation 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 Organisation (WHO) and the Centres 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, policymakers, and healthcare professionals.

The past decade has witnessed frequent international health emergencies. The Global Risks Report 2022 lists infectious diseases as one of the top ten risks for the next decade. Oxford Economics attributes the high incidence of global epidemics, especially in Asia and Africa, to the increase of global temperature by 2°C due to high emissions of greenhouse gases. Under this context, this research was carried out to develop an information visualisation design system based on global health emergencies and provide relevant design guidelines. By leveraging the principles of information design and interactive visualisation, the aim is to enhance the effectiveness and accessibility of dashboards in conveying critical information during global health emergencies, ultimately supporting decision-making and public understanding of epidemic-related data.

1.2 Applied Information Design: Public Communication of Global Health Emergencies

1.2.1 Information Needs

In a global health emergency, the epidemic can restrict the common channels (such as newspapers and leaflets) through which people access information. As reported by Folkenflik (2020), the coronavirus pandemic has posed an adverse impact on the printed publications of many local news organisations. As people stayed at home, their chances to get newspapers, posters or leaflets are reduced. Compared with these conventional channels, the Internet has gradually become an essential way for people to obtain information. It is noteworthy that amidst the outbreak, home isolation has emerged as a prominent measure for preventing virus transmission. In this context, the visualisation of information disseminated through the Internet holds distinct advantages in terms of safety compared to traditional mediums such as newspapers and outdoor publicity posters. Consequently, it has garnered significant public interest and engagement. Moreover, web-based approaches can provide new and unique insights into the public's response to infectious disease outbreaks (Tausczik et al., 2012). As shown in Figure 8, the number of Google searches for "coronavirus" as a keyword increased by nearly seven times from February 22 to 28, 2020, and that of such terms as "coronavirus symptoms" had similar increments. Moreover, the rapid growth of the searches for keywords such as "Lysol (popular disinfectant)", "social distancing" and "contagion" indicates people's demand for knowledge on how to prevent the virus.

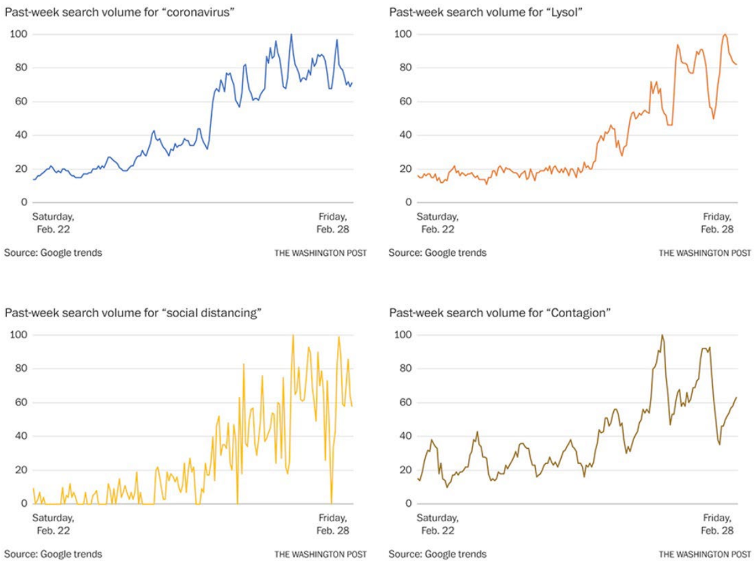


Figure 1.1 The number of Google searches for "Coronavirus", "Lysol", "Social Distancing" and "Contagion" as a keyword from February 22 to 28, 2020

However, it is important to recognise that not all information obtained through searches is beneficial or reliable for users. The increase in searches for certain keywords can reflect the level of interest and concern among users regarding related topics. It is noteworthy that information that has not been verified or confirmed by government or authoritative organisations can potentially mislead users regarding self-prevention and isolation measures during the outbreak. As reported by the US Centres for Disease Control and Prevention (CDC) in an early summer 2020 study, 4% of the 502 respondents had utilised bleach as a preventive measure against COVID-19 (Hardy, 2021). These erroneous preventive measures originated from unverified information obtained through web searches. Incorrect or unproved information is more likely to cause new and erratic behaviour (Rapp et al., 2018; Wang et al., 2019). Therefore, it is of vital importance to meet user needs for effective communication of information. To develop useful and understandable information visualisation based on users' needs and expectations is in urgent need. Proving useful information for users can mitigate public anxiety and encourage people to be active participants in a global health emergency, thus helping reduce pressure on society in general (Rubin et al., 2009). Kaye (1995) believes that high-quality and high-quantity information is critical to all aspects of operational decisions during a global health emergency; otherwise, people's judgment of everything will be influenced. According to the annual data report of Google Zeitgeist in 2012, search engine usage by individuals reached an astonishing 1.2 trillion times. More specifically, on a daily basis, 3.2 billion searches were conducted via the

Internet. These figures highlight the significant volume of information that is seamlessly delivered to users through digital information systems, a consequence of the rapid development and widespread adoption of the Internet. SARS (Severe Acute Respiratory Syndrome), recognised by the World Health Organisation as the first global infectious disease of the 21st century (Saleem, 2022), exhibited characteristics of extensive prevalence and rapid transmission, profoundly impacting society and individuals' daily lives. Consequently, during this period, people actively sought relevant information through the Internet and other channels distinct from traditional paper-based communication methods (Teo et al., 2005; Zhang, 2021).

In today's 24-hour news and digital media environment, people have access to multiple sources for continuous information gathering. During public health-related outbreaks, such as the COVID-19 pandemic, there is a strong desire to understand current developments and the impact on affected populations (Tumpey et al., 2018). This heightened concern reflects public concern about the severity of the outbreak and the need for effective information dissemination. Public health officials have a fundamental responsibility to facilitate the effective communication of information, especially via the Internet in emergencies. However, outbreaks due to epidemics pose serious challenges for society, during which the way information is disseminated may become more complex (Xu and Randall, 1996). Poor communication of information may lead to increased social instability, including weakened mass support, the creation of anxiety, and the burden of economic costs to society and government (Xu and Randall, 1996). Effective information communication during an epidemic, on the other hand, instead rallies social support, such as organising the masses, calming panic, and enhancing mass cooperation to save more lives (Xu and Randall, 1996). From the public's perspective, life-health oriented information communication during an outbreak is crucial for preventing the virus and addressing health risks (Zimmerman, 2016).

In the realm of emergency communications, Maxwell (2003) proposed an interactive emergency communications model and conducted studies on the West Nile virus outbreak in New York in 1999 and the anthrax release in 2001. This research aimed to explore 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 in emergency telecommunications. In addition, more visualisation studies focusing on pandemic health have discussed the relationship and role of visual communication in relation to behavioural interventions. Liang et al. (2020) investigated the impact of different types of information visualisation on user behaviour change. Their study highlighted the impact of information visualisation on user behaviour change, while Saltzman et al. (2021) assessed the effectiveness of visualisation strategies through quantitative analysis of experiments and incorporating participants' perceptions. These studies highlight the impact of information visualisation in aiding and influencing user behaviour and perceptions as a way of expressing the positive impact of information visualisation in driving behaviour change. Successful methods of information dissemination can be effective in helping the public to make timely adjustments and increase risk awareness of hazardous sources in the event of an emergency. On the other hand, inappropriate or ineffective information dissemination can intensify crowd conflict and accelerate the development of social and people hazards. These findings highlight the importance of using effective communication strategies to enhance public understanding, cooperation, and informed decision-making during emergencies, including the current COVID-19 pandemic.

Visualisation plays a vital role in promoting the transmission and understanding of information (Zhang *et al.*, 2022). To enable people to better understand information, designers should provide sufficient and valuable information and consider users' ability to learn and cooperate independently. The interactivity of information design provides users with the possibility of pre-learning, so that they can better absorb and understand the information they need (Tidwell, 2010). In terms of information communication in a global health emergency, interactive visualisation can be a route to accessible and effective communication. Due to the complexity of most health information, interactive visualisation can facilitate information processing and real-time data updating (Abecker, 1998). Among these considerations, the incorporation of interactive features facilitates the establishment of connections between data elements, thereby facilitating the management of logical relationships within extensive datasets and enabling a clearer comprehension of complex interrelationships among diverse data components (Van Dijck, 2014). Consequently, the amalgamation of visual graphics and textual elements, alongside a well-organised structure, user-friendly interface design, and a user-cantered interactive logic structure, holds significant potential in enabling users to efficiently assimilate substantial volumes of information within a limited timeframe (Lonsdale et al., 2019).

1.2.2 Means of Communication

As pointed out by Brenner et al. (2016), understanding the channels through which people obtain health information is necessary; even well-crafted messages can go unnoticed or even disappear if the way and manner in which they are distributed is not noticed. Since communication is a continuous process, a good platform or channel for communication is crucial for building continuous information exchange (Christof et al., 2019). The study conducted by Padgett (2016) explored areas experiencing disasters, despite the government's regular publicity, people's emergency response to disasters was still low because the previous experience might reduce their awareness of risk. Therefore, the increase in the quantity of information will not necessarily lead to changes in behaviour. And these populations need to be reached using more channels and methods. In addition, during the selection of means of communication, the community, culture and lifestyle of different classes of the public should be taken into account, so as to promote the design of a reasonable method of information communication. In some cases, compared to traditional paper-based forms of mass communication, the visual dissemination of information through the Internet and social media platforms has wider applicability.

Compared with newspapers, leaflets and other means of information dissemination, the Internet and media have gradually become the major means of modern information dissemination. In a report "The Impact of the Internet on Print", Dur (2014) pointed out that between 1999 and 2012, the demand for newsprint in the United States fell by 62% and print advertising fell by 60% as marketers turned to digital channels. As highlighted by the World Health Organisation guideline for emergency risk communication (ERC) emergencies policy and practice, social media may be used to "engage the public, facilitate peer-to-peer communication, create situational awareness, monitor and respond to rumours, public reactions and concerns during an emergency, and to facilitate local-level responses" (Christof et al., 2019). According to Ochoa (2018), 3.03 billion of the 3.5 billion Internet users are active on social media. Moreover, a new social media user appears about every 15 seconds, and the number of users shows an upward trend. Social media is a means of communication that most online users are involved in, making it a key theme for information visualisation in many ways. In addition, social media platforms, especially Twitter and Facebook, can also be used to spread true information and exclude whisper and wrong information during a public health crisis (Eckert et al., 2016). Broniatowski et al. (2022) conducted a comprehensive analysis of 325 million posts obtained from Twitter and Facebook during the COVID-19 outbreak to assess their credibility. Their findings revealed that the prevalence of COVID-19 content containing overtly false information was remarkably low. However, it is important to acknowledge that individuals are still susceptible to the pervasive spread of health-related misinformation on the Internet. In this regard, the adoption of visually appealing and professionally designed information visualisation can significantly enhance the credibility of data-driven information (Hofmann and Håkansson, 2021). This underscores the criticality of allocating adequate attention to the design aspects of charts, a factor that often goes underestimated.

Nowadays, access to online media is getting faster. People can quickly connect to the Internet and receive information through electronic devices such as TVs, computers and mobile phones. Pereira et al. (2022) found in a study that 87% of doctors in Brazil used WhatsApp to communicate with patients, and mobile phones and computers surpassed TVs to become the primary medium form. In West Africa, social media applications with lost costs were considered superior to short message services or SMS. Furthermore, social media gradually becomes a tool to monitor people's perceptions of public health issues (Savoia, 2015). For instance, the BBC and WhatsApp work together to make World Health Organisation news possible (WHO, 2009), the United Nations Children's Fund (UNICEF) and the US Centres for Disease Control and Prevention (CDC) to be directly disseminated to 20,000 subscribers. Most are in West Africa. In Sierra Leone, by the time of the Ebola outbreak in West Africa, the local version of the channel had 15,000 subscribers, who shared information about the epidemic through computers and smartphones (WHO, 2019). In the case of global health emergencies, information can also be transmitted to these people through more mainstream media via links or information maps.

1.3 Aim and Objectives

The primary aim of this research is to examine the impact of information design and interaction design, including visual elements, typography, and interaction, on the public's ability to comprehend information within interactive information visualisation systems. This investigation will cover factors such as user habits, reading efficiency and accuracy to assess the effectiveness of these designs in enhancing information comprehension. The second objective is to develop practical solutions that prioritise user-centred information visualisation in order to optimise the role of interactive information visualisation in disseminating information. These solutions will focus on improving the overall functionality of the interactive information visualisation system while ensuring seamless connectivity and consistency between the different components of the system. By achieving these goals, this research aims to advance the field of interactive information visualisation and contribute to the effective dissemination of information to the public.

To achieve the research aims, the main objectives were set as below:

Objective 1: to investigate the theory applicable to information and interaction design based on a literature review in visualisation systems and explore its past applications in global health emergencies.

Objective 2: to identify the design factor constraints affecting the legibility of interactive information visualisation systems and examine how they affect people's reading strategies, speed, and accuracy.

Objective 3: to explore effective design options to improve the usability and aesthetics of information visualisation.

Objective 4: to examine the effectiveness of visualisation based on research findings, and hence provide design recommendations for future visualisation systems in the context of global health emergencies.

1.4 Research Questions

The research question of this thesis is: How can the design and construction of interactive information visualisation systems be enhanced to improve users' ability to comprehend and employ reading strategies, thereby assisting them in effectively acquiring and utilising information during emergency situations like epidemics? It was divided into the following seven sub-questions for further detailed study:

Sub-question 1: What are the prevailing design theories influencing the development of interactive information visualisation systems? Can these principles be effectively applied to support the implementation and creation of interactive information visualisation systems during epidemics?

Sub-question 2: What reading strategies do inexperienced individuals employ when utilising interactive information visualisation systems to comprehend global epidemics? Specifically, how do they engage with visualisation components comprising professional data?

Sub-question 3: To what extent can existing principles be applied to interactive information visualisation systems, taking into account the public's reading strategies and requirements?

Sub-question 4: Do the macro-design structures and visualisation layouts of public-facing interactive information visualisation systems hinder the public's ability to locate relevant information regarding global pandemics?

Sub-question 5: How do microscopic visual design elements and typographical design influence user comfort during the process of information retrieval?

Sub-question 6: What effective design approaches can be employed to improve the legibility of data visualisations in systems through information and interaction?

Sub-question 7: Can the framework of interactive information visualisation design principles, formulated based on epidemic situations, offer valuable information design guidance for future emergency scenarios?

1.5 Research Significance and Strategy

The significance of this study lies in trying to enhance the effective impact of visualisation on data dissemination through design. In today's rapidly developing society, the dissemination of data is becoming more and more important due to the abundance of information. Interactive information visualisation systems, especially dashboard-based systems, have become popular communication mediums and play a vital role in contemporary global health emergencies. To achieve the goals and address the issues outlined in the previous sections, this research will adopt a user-cantered approach. The theoretical underpinnings of the survey were drawn from benchmark studies combined with user feedback obtained through experimental results. In previous design practices, designers often focused on functional requirements and made assumptions, resulting in a lack of coherence and proper organisation of information design materials, thus hindering users' reading and operating experience (Kouprie and Visser, 2009). To alleviate this problem, performance tests will be conducted based on users' actual route planning to objectively evaluate map readability and understand users' needs and reading difficulties (Roberts, 2012; Wu et al., 2020). On this basis, this study explores the impact of information and interaction design on the user's own perceived reading efficiency and user behaviour in an interactive information visualisation system. This check includes aspects such as reading speed, accuracy of information search and reading habits.

2 Methodology

2.1 Introduction

In the preceding chapter, the significance of information communication, demand, and presentation in the context of contemporary digital advancements was underscored. Furthermore, in recent years, information visualisation has emerged as a crucial means for individuals to comprehend epidemic-related information, particularly in the context of global health emergencies such as the COVID pandemic. Accordingly, this study aims to investigate expedited design approaches that enable the general public to comprehend data-driven information effectively, while also developing guidelines for design professionals to effectively convey such information. This chapter provides a concise overview of the principal methodologies employed in each phase of the research, which are instrumental in accomplishing the research objectives outlined in the previous chapter.

A well-designed methodology is crucial for ensuring the reliability of research findings (McCombes, 2019). In scientific inquiry, research design refers to a carefully planned approach aimed at addressing specific research questions. It encompasses effective data management strategies and incorporates various components, strategies, and methods for data collection and analysis (Saunders et al., 2012). Based on the research objectives and questions outlined in Chapter 1, this study adopts a user-centred research methodology.

Taking a user-cantered approach in the research process allows for a better understanding of users' actual needs, goals, and feedback (De Troyer & Leune, 1998; Silva da Silva et al., 2012; Babich, 2019). Experimental research, however, runs the risk of researcher bias, which can undermine the quantity and quality of information gathered (Shuttleworth, 2022). To mitigate this potential issue, a performance test based on user interaction was conducted to objectively evaluate users' reading comprehension and understanding of information from a visualisation perspective (Steichen et al., 2014). In this study, the research combines users' information search accuracy, search time, and visualisation usage habits to explore the impact of information design and interaction design on the behaviour of the public when using interactive information visualisation systems. This approach allows for an examination of how these design factors influence users' interaction with the systems.

The first part of this research was mainly to understand the design theory affecting the visualisation system. The literature review established the theoretical foundation and design principle framework for the interactive information visualisation system from the aspects of information frame, visual communication and dashboard structure design. Notably, the visualisation system was evaluated and investigated as a whole design material instead of discrete element modules. The first part consists of two chapters: Chapter 3 (in which the theoretical knowledge of visualisation systems and information design are illustrated and a framework of design principles applicable to interactive information visualisation systems is collected and constructed on this basis) and Chapter 4 (in which the effectiveness of the framework as applied emergencies is explored). In detail, a literature review of interactive information visualisation was firstly performed, and questionnaires and visual surveys were used to narrow the research scope and check whether the real-life situation was consistent with the literature review. Then in the second stage, based on the principle framework and visual survey assessment provided in the first stage, efforts were made to determine how the public can effectively access information on the visualisation system and what design constraints may affect the dashboard's legibility. According to Macdonald and Waller (1998), the process of information design involves the transformation of complex information into clear and comprehensible forms. This process necessitates a thorough comprehension of users' information requirements, as well as their methods of accessing and utilising information. For this purpose, user-generated data in the process of using the visual dashboard were collected and compared through usability experiments, as illustrated in Chapter 5. In the third stage, the information communication and design layout of the system were analysed according to the main design limitations of the previously developed visualisation system. On this basis, various design schemes were realised to improve the design of interactive visualisation systems according to the literature review and empirical theory.

2.2 Methods in Study of Design Principles

2.2.1 Literature Review

The literature on the information design, interaction design and the overall information framework of the dashboard involved in the visualisation system was reviewed. A literature review is a systematic review of scholarly resources on a specific topic, designed to provide an overview of current knowledge on the topic and to identify relevant theories, methods, and research gaps in the existing literature (McCombes, 2022), but also lays a theoretical basis for the present research and offers comprehensive insights into the research field. Moreover, it can also expose researchers to new and previous discoveries and guarantee the timeliness of the research by offering a valuable framework (Randolph, 2009). In order to construct a design theory for interactive information visualisation systems, the literature reviewed in this thesis include books, chapters, journal papers, conference papers, doctoral theses, official papers, and related websites. The keyword-inclusive search method (Levy & Ellis, 2006) was used strictly centred on the design elements of the visualisation system, including information visualisation, interaction design, dashboard, information structure, data visualisation, *etc*.

Design is a practical subject, while the literature review is an effective way to summarise the results and weaknesses obtained in practice (Zheng, 2015). In the research by Baer and Vacarra (2008), more than 30 cases of information design patterns were summed up and a detailed description of graphical methods, solutions, and inspirations was given. Notwithstanding, little attention was paid to the design principles. According to Gregor et al. (2007), design principles can provide a design basis for the redesign. Thus, a summary of design principles is described in this paper in order to contribute to the usability of the design in later stages.

In this stage, to investigate whether the application of these guidelines can optimise interactive information visualisation, such research work as exploring the database, summarising relevant design theories and principles, and identifying and recording gaps in existing literature were carried out, so as to create the interactive infographic design frameworks at 'good', 'medium and 'poor' levels. First, the theories and principles of information design were collected, together with the examples in the structure, clarity, fluency, aesthetics and other aspects. Afterwards, the scope of information visualisation was narrowed to interactive infographics and the applications of usability and user experience principles were examined. In addition, the principles of information design and interactive information visualisation based on user experience were used as the evaluation criteria of the principle framework. The frameworks designed by corresponding principles were then applied to a case study (described in the next chapter) to survey the weaknesses of existing applications.

The literature review as the first stage of this research is of considerable significance, laying a solid foundation for later research stages. The literature of this research mainly covers the importance of deadly virus prevention, user-centred design, information design, information visualisation, and interactive infographic for information communication during global health emergencies. To be more specific, the design theory and principles of information design and interactive information visualisation were summarised, and related to the research objectives. Books, excerpts, and peer-reviewed papers were taken as the primary sources of the review. Published doctoral dissertations, official documents, websites, and academic books and chapters in related interactive visualisation or dashboard design were also reviewed to build theoretical knowledge for this research.

2.2.2 Visual Survey

A case study was performed to identify the current functions of interactive information visualisation design in a global health emergency. As concluded by Baxter and Jack (2015), a case study as a research tool is conducive to developing theories, evaluating programs, and formulating intervention measures, which promotes the analysis of complex phenomena in different backgrounds. With the continuous progress in technology, the characteristics of cases in various contexts usually reflect the development trend and user needs.

Here, study using health emergencies published by World Health Organisation in three different periods of the 21st century were taken as examples and main information visualisation systems were surveyed. These cases were compared from the perspective of information design principles, usability and user needs. The principle framework formulated previously was applied to the study case for the purpose of learning the development trend, advantages and potential limitations of information visualisation design. The evaluation of the cases was expected to lay a foundation for the redesign of existing infographics in the next stage of the project.

Then, a design-related content analysis was performed after the selection of an existing case. In this stage, whether the framework of design principles created based on the literature review can be applied to current interactive information visualisation cases was determined. The design principles contained in the framework were compared among these actual cases, and the standards were strictly divided. Content analysis and application of the framework can provide evidence on whether existing cases meet the framework criteria of the principles. Moreover, whether the literature review was consistent with the existing cases was discussed.

In conclusion, which underlying design theories can improve the use of interactive information visualisation systems together with the reasons were identified through the literature review and a framework of design principles was built on this basis. The status, application and impact of visualisation systems in three global health emergencies were surveyed, so as to identify the gap between theory and practice in the design of information visualisation systems.

2.3 Methods in Experimental Studies of Finding Design Limitations in Interactive Information Visualisation

2.3.1 User-centric Performance Testing

To investigate the actual use of interactive information visualisation systems by the public during the pandemic, user-centred performance testing and observation were first conducted to identify design constraints (*e.g.*, information design structure, interaction, typography and visual elements) affecting the speed, process, and accuracy of information search by the public in the use of pandemic-related dashboards. User-centred performance testing is considered a crucial way for understanding and improving web-based user experience (Walton, 2022). Observation is a strategy to approach people involved in this research activity, which is often used as a complementary method (Patton, 2002; Crouch & Pearce, 2013). According to the analysis results of the users' mouse movement track and the number of clicks, the visual parts that users stayed or surrounded for a long time were observed and recorded. This user-centred performance testing can reveal the main design limitations of current visualisation systems (information exchange, overall layout, and data presentation), so as to help improve these problems in later research based on theoretical principles and practical solutions.

2.3.2 Questionnaire

"The core of a survey is its questionnaire." (Krosnick, 2018) Questionnaires can be collected through Google forms on the Internet and questionnaire analysis is an effective way to understand users' opinions and attitudes (Muratovski, 2021). The questionnaire in this research was divided into two stages. The first stage was designed to understand the users' needs, get feedback on information dissemination during the selected global health emergencies, and clarify the importance of the information to users. The second was to understand and collect the design elements influencing the use of visual dashboards. For high information validity, the online questionnaire was considered to be the most feasible method for collecting participant information during the Covid-19 pandemic.

The first stage of the questionnaire was mainly composed of two parts. One is about user demand for information types during global health emergencies. The other is focused on the user preference for different types of information communication and the role of interactive information visualisation in the research context. A total of 330 participants with varying educational backgrounds and who experienced the health emergency caused by Covid-19 were recruited to complete the questionnaire for this stage of the survey. Most of them had study or work experience in the field of data analysis or visual design.

In the second stage, the elements influencing users' cognitive decisions and usage processes of dashboards were investigated. Participants' answers were based on experiences and feedback on the dashboards after performance testing. Then, a design suggestion was given based on the public's point of view. The questionnaire survey in this stage was focused more on the obstacles to users' cognition and use due to practical problems.

In the context that the Covid-19 pandemic poses an immeasurable influence on all parts of the world (Allain-Dupré, 2020), the questionnaire survey can help understand not only the users' acceptance, usage, and reading habits of the information model during the pandemic but also the frequency, status and user feedback of the interactive information visualisation systems during the pandemic. It further demonstrates the feasibility of the research direction.

2.4 Research Data

In design research, the collection and analysis of research data play a crucial role in establishing a robust scientific foundation for research findings (Tenny et al., 2022). Data types in research can be broadly classified as qualitative and quantitative. Qualitative data, primarily consisting of language-based information, is used to interpret and understand the underlying reasons and motivations behind behaviours through techniques such as explanation and description. On the other hand, quantitative data focuses on numerical information, enabling statistical analysis of frequencies, durations, and other quantitative measures (Mcleod, 2023).

According to the purpose and objectives of the research, this research process used a variety of qualitative and quantitative mixed data methods for data collection. This method can more comprehensively analyse the research topic and purpose, so as to clearly explain various situations and phenomena based on experiments during the research process. By combining different data types (qualitative and quantitative), research can better observe user behaviour in experiments, as well as the differences between different behaviours and analyse their complexity. At the same time, the generated data (numeric patterns and statistical trends) can be analysed more systematically. This method not only enhances the richness of the data, but also enables more in-depth analysis and research.

2.4.1 Data Collection

Table 2.1 summarises the data collection methods used in this study and describes each method. Further elaboration and details on the data collection methods will be provided in subsequent relevant chapters. These sections will provide a comprehensive understanding of each data collection method, including the specific procedures, instruments, and techniques used to collect the data required for the study.

Data collection methods	Brief explanation
Information visualisation case study in public health emergencies (Chapter 4)	A total of 12 application cases of information visualisation were collected, focusing on their utilisation during different periods of global health emergencies, namely, SARS, H1N1, and COVID-19. These cases were carefully evaluated based on a comprehensive framework comprising 56 design principles, categorised into 7 distinct directions.
Online questionnaire (Chapter 4)	A total of 366 participants from Wuhan, China, who experienced the initial outbreak of the COVID-19 virus, were recruited to participate in an online questionnaire survey.
Scoping testing (Chapter 5)	Designers (N=5) with Internet and design professional experience participated in the evaluation of the dashboard by the framework of design principles
User performance test (Chapter 5)	A total of 30 participants were recruited to partake in a rigorous performance test aimed at assessing the effectiveness of two prominent dashboards, namely the World Health Organisation (WHO) and Johns Hopkins University (JHU) dashboards, which were utilised during the global health emergency triggered by the COVID-19 pandemic. Each participant was tasked with answering four questions specific to each dashboard, allowing for a comprehensive evaluation of their comprehension and utilisation of the provided information.
The follow-up interview (Chapter 5)	A total of 30 participants were engaged in the performance test of the dashboards, during which they provided valuable feedback regarding their experience. This feedback encompassed both positive and negative aspects encountered during the experiment, along with constructive suggestions pertaining to the design of the dashboards.

Table2.1 The data methods collection used in this study and a brief description.

2.4.2 Data Analysis

In mixed research experiments, the analysis of data collected through both qualitative and quantitative methods necessitates the use of distinct analytical approaches (Sandelowski, 2000). Qualitative data will be classified and normalised using the template method (Maxwell, 2010), facilitating the systematic organisation and interpretation of the data. On the other hand, quantitative data will be examined using t-tests and mean-difference calculations to explore relationships among variables in closed-ended questions (Jansen and Warren, 2020). Additionally, visual data comparisons will be employed to represent responses to open-ended questions. Table

2.2 provides an overview of the data analysis methods employed in this study, along with a concise explanation of their respective purposes.

Data Analysis	Brief explanation
Template method analysis (Chapter3, 4 and 5)	Template evaluation and analysis of visualisation cases applied to health emergencies in different periods. Analysis of qualitative data from interviews, online questionnaires, usability testing and scope testing surveys.
Descriptive summary (Chapter 4 and 5)	Determine why users prefer information. Determine the most preferred tools and data types. Explore the influence of information layout on the process of users exploring information. Explore design elements that affect how users understand information. Gather user-cantered design suggestions.
Average Threshold Interval (Chapter 4)	Reasonable classification of three levels of visualisation cases based on the framework of design principles
Data visualisation (Chapter 4 and 5)	In order to identify the different differences that the two dashboards evaluate in the principles framework. In order to show the different comparisons in 7 design principles in 12 cases.
Paired sample t test (Chapter 5)	In order to test whether there is a significant difference in the average time when users search for the same information under different design elements.

Table2.2 The data methods analysis used in this study and a brief description.

3 Principles of Interactive Information Visualisation Design

3.1 Introduction

This chapter presents a thorough introduction to information design and interactive information visualisation, with particular attention paid to design structure, visual elements, user experience goals, usability concerns and goals of usability goals. Through an exhaustive literature review, this chapter investigates how these principles impact users' comprehension of visual information. Literature Review. To begin this analysis, this literature review comprises basic design theories required for this project such as information design and interactive information visualisation. It identifies gaps in existing research as well as deficiencies with regards to theoretical and design principles applicable for this investigation. Based on these findings, this chapter proposes a framework of information visualisation design principles applicable specifically to global health emergencies. By outlining a series of design rules which can easily be applied in future case studies, this chapter offers practical guidance for designers attempting to increase effectiveness of information visualisation during emergency situations.

Pettersson (2019) provided an in-depth framework of information design principles while Shneiderman and Nielsen (1992) explored interactive information visualisation from an experience/usability viewpoint. These design principles have become prevalent in interactive visualisation applications today, though COVID-19's global health emergency has led to widespread usage of information visualisation charts as an aid in comprehending severity and status of epidemic. Therefore, this research endeavour will concentrate on frameworks which impact reading comprehension - this underscores the necessity of clear standards defining suitability principles which influence user reading comprehension.

3.1.1 Limitations of Existing Research

Several studies have begun seeking to establish guidelines for relevant visualisation design principles. Watzman (2003) outlines the various visual design disciplines and principles used in creating high-quality design solutions. However, the practical application of these principles is difficult to explore through experimental research due to the wide range of disciplines applied. An example of practical data visualisation principles is based on scientific research led by Midway (2020), who describes ten fundamental principles for creating compelling data visualisations to represent data about data in scientific experiments. Those principles are well researched and simplified where appropriate, as the publication's intended audience is scientific researchers applicable to all disciplines. However, more nuanced principles and guidelines are more conducive to further improving the visualisation design. Moreover, Midway's explanation of each principle contains many assumptions based on the application of scientists, and this explanation is complicated and applied to general guidelines for information visualisation principles. Engelbrecht et al. (2014) collected a set of principles and guidelines to guide the design of information visualisation views. Among them, 30 principle guidelines based on user interaction and system framework are included. These principles defined functionality for designers that met primary interaction conditions. However, it did not effectively apply other design principles. Khajouei et al. (2013) conducted a usability evaluation of a hospital emergency information system using Nielsen's ten usability principles. The findings reveal multiple usability issues related to the identification of healthcare systems in emergencies. The study authors concluded that by optimising usability principles, efficiencies can be achieved, such as saving patient and user time, reducing errors, and improving data quality. In the study by Naleef et al. (2021), experts reviewed the content, functionality, and visual design of public dashboards used by U.S. state governments to respond to COVID-19. Study results revealed that dashboards had varied appearances due to inadequate design guidance. While all four featured similar interactive features and visualisations, their authors failed to offer comprehensive instructions for effectively comprehending all information presented.

Due to an increasing frequency and severity of global epidemics in this century, studies relating to emergency situations are being undertaken at an increasing pace. Against this background, Cheng et al. (2011) proposed a digital dashboard framework for influenza surveillance that can be customised on various platforms. However, the framework lacks detailed design guidelines and does not fully explain its design principles. To fill this gap, Jin et al. (2021) conducted research on the design of information visualisation for public health security emergencies. They defined three key elements of user-themed visual design: users, user cognition, and user behaviour, which can improve the effectiveness of information visualisation in the era of big data. However, these elements need to be further codified based on applicability principles guidelines. Lechner and Fruhling (2014) identified eight aspects of the principle applicability of existing dashboards in the United States and suggested new guidance for user cognition and time trend functions. While these guidelines are useful for improving dashboard design, there is a need for further usability experiments to validate their efficacy.

As Kimball (2013) states, it is challenging to determine consistency even with the many books, designers and design educators talking about visual design principles under the same domain. In contrast to the above studies, this literature review is more specific to the visual design impact of interactive-based information visualisation systems on the presentation of information as users explore data, and the impact of the interaction experience when using and exploring data.

Interactive information visualisation systems, including dashboards, have published much evidence in support of the use of user perception principles when optimising visualisation design (Sedrakyan et al., 2019). Interactive information visualisation systems include dashboards as a component that well accommodates multiple information and graphic presentations through interactive means. The design of the test was developed without considering application information and following design principles, which may lead to the need for further improvements in the design of the dashboard system. Similar situations have occurred in many other dashboard designs (Fuller et al., 2020; Nadj et al., 2020; Faiola et al., 2015; Chen et al., 2020; Ahn et al., 2019).

3.1.2 Focus of Literature Review

The following literature review will focus on defining those design principles applicable to interactive information visualisation since only certain applicable principles are well represented and applied in future evaluations. The literature review is an extensive process. Due to the breadth of visualisation applications and the limited number of experiments exploring the principles of interactive information visualisation within a single domain, this chapter attempts to consider relevant research from multiple domains. The literature review also consults and references other appropriate domains.

The literature review in this chapter will start with the information design theory to understand the necessary design factors in the effective transmission of information. During this process, design principles that affect human perception of information based on visualisation research will be studied, including Gestalt theory based on human visual perception patterns. Related elements that affect information and vision are studied. This chapter will study the impact of information exploration-based interaction design on information presentation and user experience. Furthermore, conduct a comparative study with static visualisation to explore the impact of user interaction on the ability to understand information. Finally, it studies the application of relevant design theories in the layout framework and media presentation of the dashboard as a visual overall layout component at this stage to understand the impact for information capabilities. The search for relevant literature was conducted by using keywords such as "visualisation", "information visualisation", "interactive design", "visual representation in visualisation", "dashboard framework", "user perception", and "information". The search was performed in academic databases and combined with principles, design, and guidance. The Reference lists of relevant publications were also consulted for additional research information. Relevant materials with a focus on public health and global emergency, particularly in light of the COVID outbreak, were given priority. Given that the project took place during the outbreak and spread of COVID, literature related to visualisation systems developed for COVID was also included. Research also consulted other fields, including health care and information communication. Coupled with the frequency and severity of epidemics in the current information age, people's demand for knowledge about their health has deepened. These fields have also begun to frequently study the help of related visualisation in disseminating health information in disciplines, so it is effective for the principle framework of this study. Finally, this study divided the principle framework into seven specific core themes based on the established guidelines, including layout, typeface, colours, elements, interactive functions, display components and content.

3.2 Information Communication Design Theory

Information design is the art and science of preparing information so that humans can use it efficiently. The unique value of information design is to increase the efficiency and effectiveness of communication objectives, which is different from other types of design. (Pettersson, 2002). The primary goal of effective information design is therefore to achieve clear communication. To achieve this objective, all info has to be carefully made, generated as well as distributed before it can be appropriately interpreted as well as understood by the target market. These procedures are directed by concepts, implemented making use of devices and influenced by the social context (Pettersson, 2019). In the communication of information, an essential part is visualisation methods. As defined by Card (1999), information visualisation refers to the use of computer-assisted and interactive visual representation of large amounts of information to enhance cognition. In other words, it is a good way to more vividly present massive information to users. As concluded by Kuosa et al. (2013), visualisation has such advantages as promoting communication, enhancing people's cognition, memory and recall, and facilitating search and navigation of information.

These advantages are even more critical in a global health emergency. For the general public lacking professional medical knowledge, information visualisation can provide them with accessible and understandable content regardless of their communication skills, language, as well as education and cultural backgrounds (Franconeri et al., 2021). Specifically, information on infectious diseases can be understood more effectively after being transformed into graphical and visual forms. Fagerlin et al. (2017) further argue that excellent communication is conducive to alleviating the economic and social pressures caused by an epidemic and even preventing its sudden outbreak.

3.2.1 Gestalt

Gestalt theory was proposed by German psychologists Max Wertheimer, Kurt Koffka and Wolfgang Köhler in the 1920s. Its purpose was to study the role of human visual perception in the process of information acquisition (Ash, 1998). This theory can simplify and organise complex images or design problems composed of many elements (Chapman, 2018). Gestalt principles can be used to explain the problems people encounter when dealing with text and graphics (Moore and Fitz, 1993). Some experimental evidence also exists in support of Gestalt principles. Lemon et al. (2007) experimentally documented a positive linear increase in the accuracy and efficiency of people's chart comprehension under the influence of Gestalt principles, thereby validating the effectiveness of these principles for single graph comprehension. Peterson and Berryhill (2013) demonstrated the effectiveness of the three basic principles of Gestalt in aiding visual working memory. In the preliminary results, Tse and Bačić (2022) also documented the impact of the design of tables, charts and graphs present in visualisation information systems on the physiological responses of users and unveiled the prominent influence of Gestalt principles in their design process. Even so, the lack of context and the variety of feature impedes the applicability of Gestalt principles. Considering that interactive information visualisation systems are based on complex structures composed of multiple elements, six applicable principles were selected in the present research.

3.2.1.1. Proximity

The proximity principle refers to the objects that are closer to each other and are more relevant than those farther away (Vinney, 2022). The closer the objects are to each other, the more related they will be to each other, and this is true even if the objects are of different colours, sizes or shapes (Oppermann, 2022). In visualisation systems, this principle can help differentiate visual elements to reduce visual clutter and make designs easier to understand (Gleicher et al., 2011). Proximity has an impact on the principles of balance and hierarchy, based on the manipulation of white space in the background in the typography of graphics and text, and it is used as a means of clearly delineating different groups of information elements.

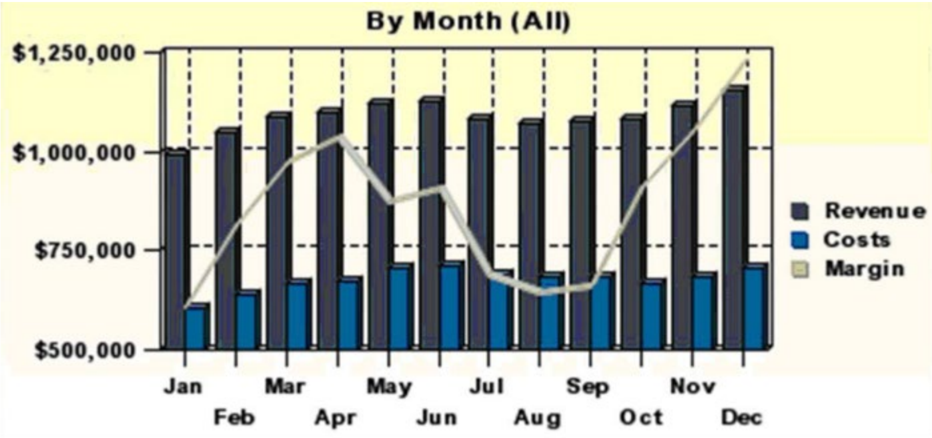


Figure 3.1 A poor practice in applying the proximity principle (Ramotion, 2021)

The proximity principle has wide applications in visualisation systems. Based on the findings in Figure 3.1, it can be concluded that the lack of adherence to the proximity principle between certain months and the visual graph can significantly impact the accuracy of data transmission. Specifically, users may struggle to discern the differences in data that are positioned at a distance from the visual graph. The arrangement of the months far from the data plot also creates ambiguity regarding the specific data categories each month represents, such as whether they correspond to black, blue, or all data points. Figure 3.2 makes good use of the principle of proximity, even though it has many different types of data information. The designer placed relevant information and charts close together so the user could understand the data diagram through the textual information. Each section has appropriate and clever dotted lines to divide the areas. The components within the areas are redefined by white space to allow the user to distinguish between the individual areas. This design approach gives the user reasonable space to understand the information.

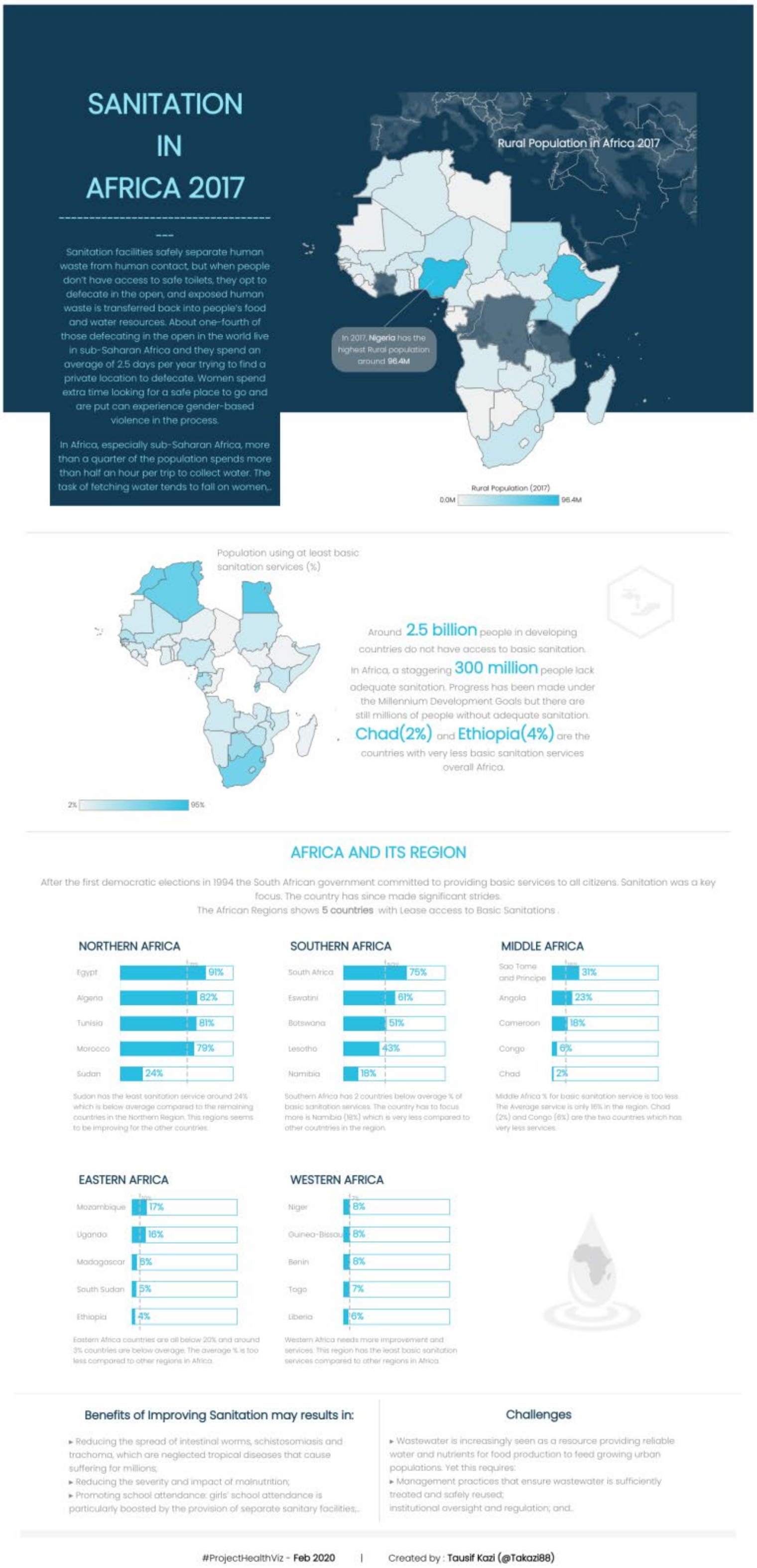


Figure 3.2 A good practice in applying the proximity principle (Betzendahl, 2020)

3.2.1.2. Similarity

The Gestalt principle of similarity states that objects with the same visual characteristics are considered more relevant than objects that are not similar (Harley, 2020). The design elements that influence visualisation designs include such features as colour, shape and size (Guthrie, 2022). When viewing dashboards or graphics, users can use the principle of similarity to establish connections between the same elements in their brains more quickly and thus perceive their relationships more easily (Soegaard, 2015). This is where colour takes precedence over other elements and thus becomes the preferred means of connecting information (Eiseman, 2017). In graphs or data visualisations, colours are more intuitive in dividing and connecting related information (Engebretsen and Weber, 2017). Even if the data in the visualisation is represented in the same form (meaning the same shape and size), different colours can allow users to quickly understand the division of information.

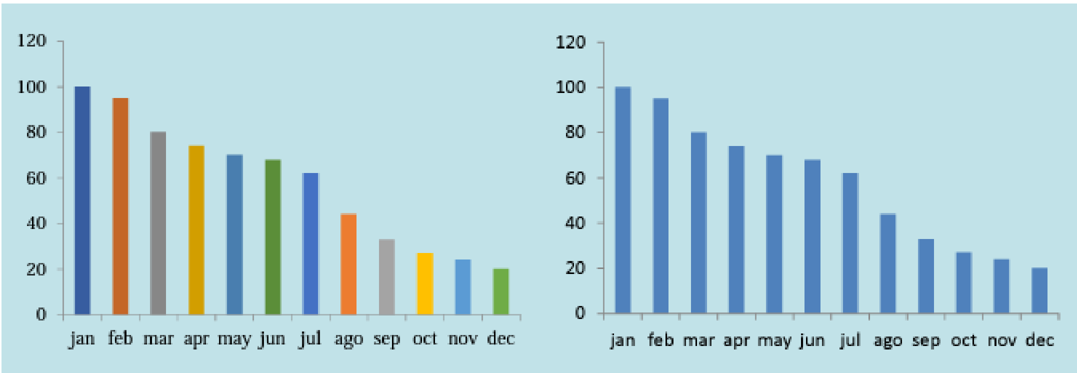


Figure 3.3 The diagram on the left shows poor practice in applying the similarity principle (Moura, 2018)

Diagramming tools are typical examples of applying the similarity principle in visualisation systems. As shown in Figure 3.3, the two bar charts show the same data content. It is worth noting that the only difference between them is the colour for each month displayed. The relevance of the data in the chart can be determined by the month at the bottom. However, the bar on the left uses 12 different colours to represent it, which not only makes it easy for the user to misunderstand whether there is any other information in it but also confuses the user's memory of the information. In contrast, the way the charts in Figure 3.4 are designed better applies the principle of similarity (both in terms of colour and other visual shapes). In the pie chart, the different colours represent the three main categories, and the user can automatically categorise the information according to the colour. In addition, each section is represented by a specific shade of colour, which not only divides the area but also helps the user better understand each section's details.

Figure 3.4 A good practice in applying the similarity principle (Moura, 2018)

3.2.1.3. Enclosure

The Gestalt principle of enclosure states that objects surrounded by a visual boundary (*e.g.*, a line or a common colour field) are more likely to be considered to belong together in the view of users (Harley, 2020). The same group under enclosure is not necessarily the same component or design element, but more often presents the same group of information (Few, 2013). This principle can help to organise information and define different structure levels, which is particularly important in visualisation systems that contain design elements with great quantity and variety.

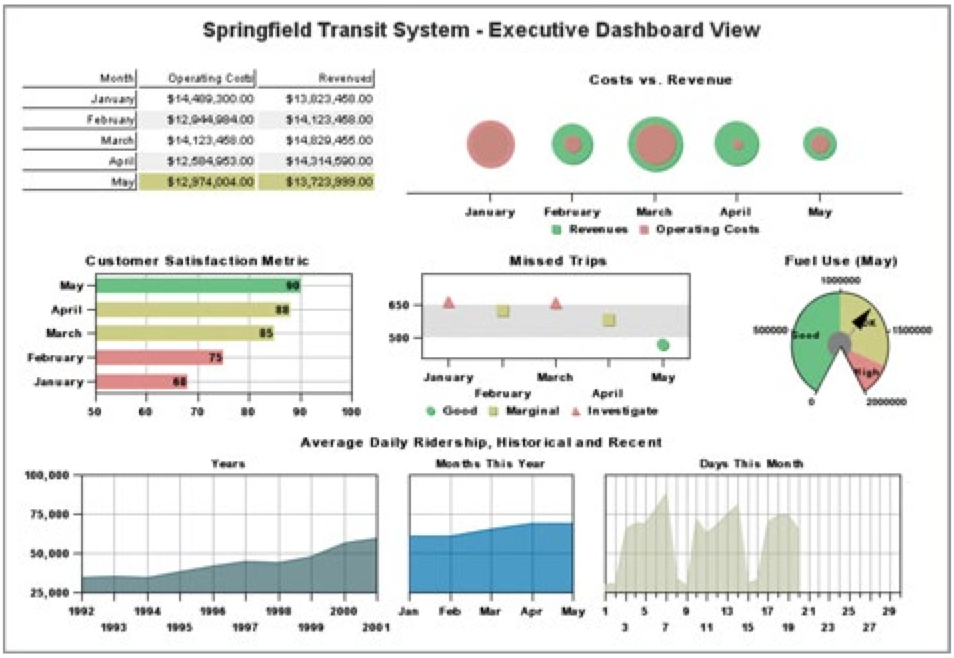


Figure 3.5 A poor practice in applying the enclosure principle (Few, 2013)

The enclosure is more about dividing groups of information into different types and has an impact on the overall layout and structure. In Figure 3.5, boxes are not effectively used to define each component and chart in the visual dashboard. Most of the components blend in with the background and white space without clearly delineating the areas. On the one hand, the charts are not aligned, making the appearance less appealing. On the other hand, it also leads to confusion as each component cannot be separated from the background, especially the values below the chart. A better solution is to reflect the fence through aligned content and faded wireframes and to demonstrate good layout discipline. In Figure 3.6, the designer cleverly differentiated each area from the background by using the background colour and effectively dividing the layout in this way. The division makes the enclosures less abrupt and does not distract the user by grabbing the colour, but also allows for a logical layout of the entire design framework.

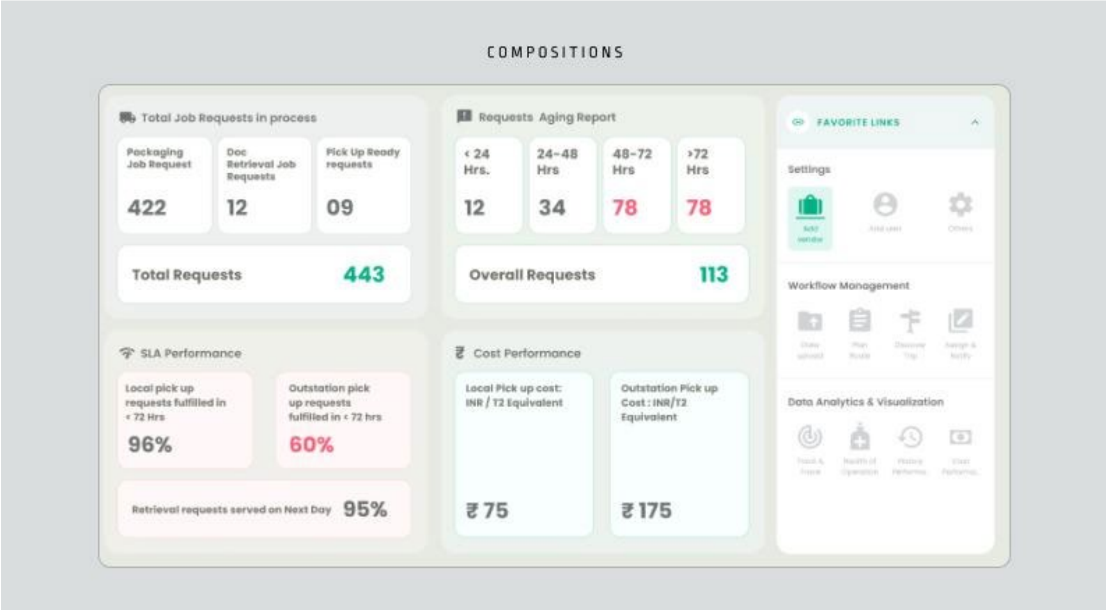


Figure 3.6 A good practice in applying the enclosure principle (Sharma, 2021)

3.2.1.4. Closure

The Closure principle refers to the fact that people will fill in the gaps to perceive the complete object by matching external stimuli to parts of that object (Joyce, 2021). By adopting a closed design, the number of elements required to convey a visual message can be reduced, resulting in less complexity and a more attractive design (Hensley, 2016). Importantly, this principle influences the structural layout of a visual system more on the basis of individual design elements or components compared with the enclosure principle.

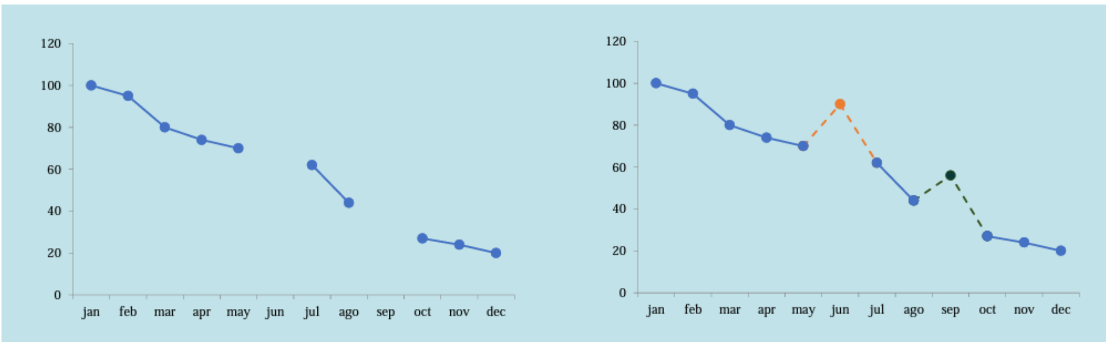


Figure 3.7 A poor practice in applying the closure principle (Moura, 2018)

The complex arrangement of visual elements tends to drive the users to look for a single, recognisable pattern. In Figure 3.7, the graph on the left shows the amount of data for each month of the year. However, the blank points do not help the user to determine the amount of data for the blank months through some supporting information (including significant numbers and visual features, colours, etc.), which also makes data transfer ambiguous. However, the association of the gaps in between becomes difficult if there is a large gap in values or distances between the blank points. Furthermore, this is improved in Figure 3.8. Although the data is left blank in the chart, the user can still see the information through several visual elements and design approaches, such as the numbers near the breakpoints, the bars below and the data support on the left side where the numbers are seen.

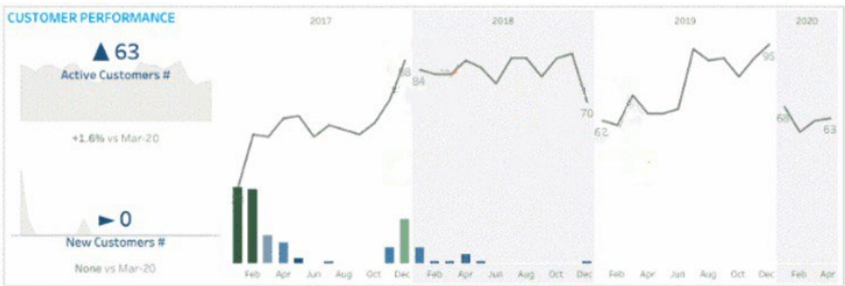


Figure 3.8 A good practice in applying the closure principle (Camoes, 2011)

3.2.1.5. *Continuity*

The principle of continuity in Gestalt theory mainly focuses on highlighting the continuity and fluidity of lines rather than discontinuity. This makes it easier for people to notice (Spielman et al., 2021). This principle can help to guide the viewers' movement through the design, allowing them to easily navigate through the composition while establishing relationships between different groupings. In some cases, it can even override colour-based similarity, as the eye will first follow the smoothest direction all the time.

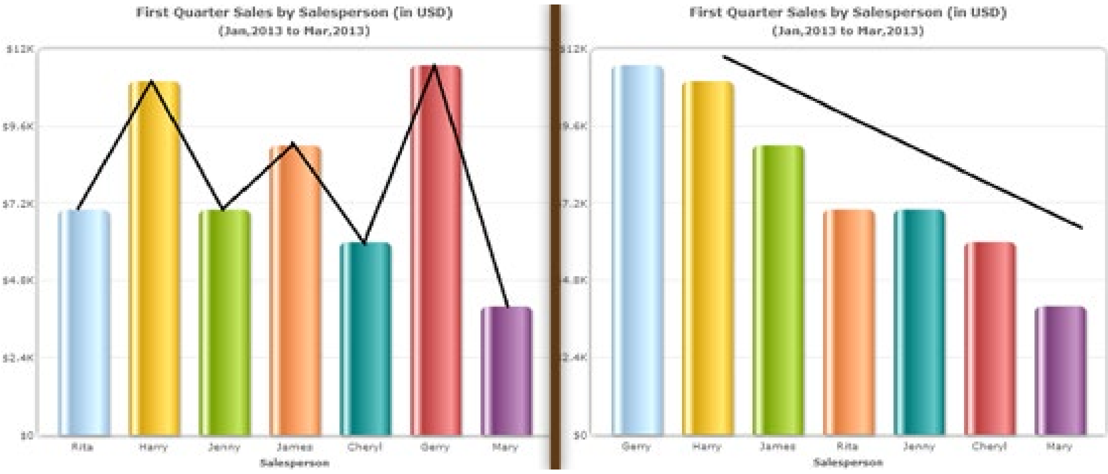


Figure 3.9 The comparative practice of applying the continuity principle (Craig, 2022)

In data visualisation, continuity helps sequence the data to drive the user's visual movement through the data visualisation. In Figure 3.9, the histogram on the left will cause the user's visual movement to move up and down as the data fluctuates, which cannot bring effective continuous visual movement to the user. In contrast, the chart on the right is more able to guide the user's visual movement, slowing the user's sight down with the chart data. This not only improves the chart's readability but also helps users summarise the data. Another example of continuity in visualisation is shown in Figure 3.10. Although the designers used different colours for each node to represent different stages, the smooth lines transitioning between nodes make it easy for users to track data visually.

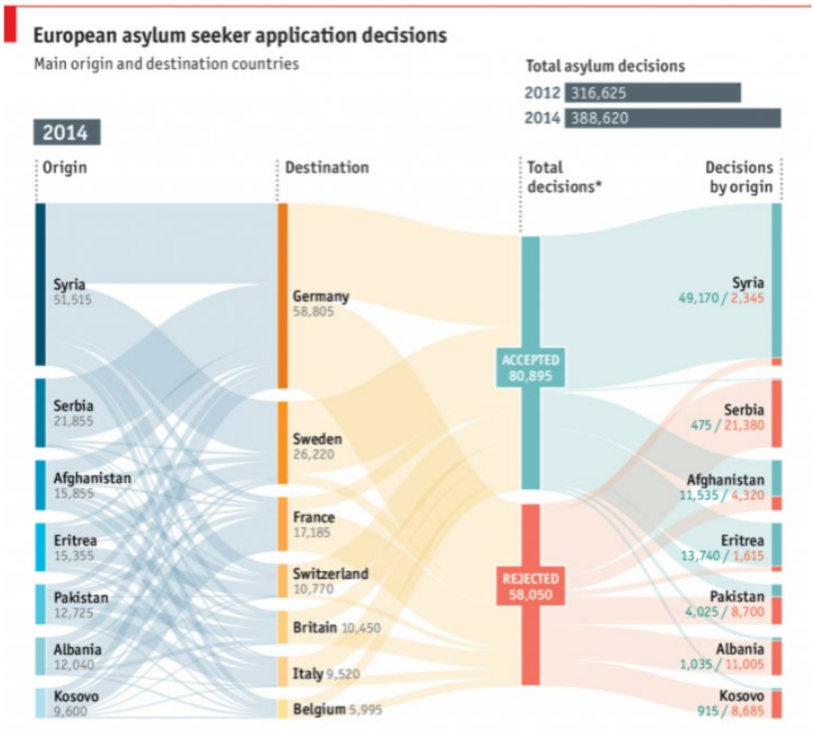


Figure 3.10 A good practice in applying the continuity principle (Baglin, 2020)

3.2.1.6. Unified Connectedness

This principle proposes that elements connected using colour, lines, frames, or other shapes are considered a single unit compared to other elements that are not connected in the same way (Graham, 2008). It can help and guide users to effectively divide the numerous elements in the area. In the visualisation generated by data, the data types are often not single, and following the principle of unified connection can better help users classify and summarise data sets visually (Han et al., 1999; Yablonski, 2023).

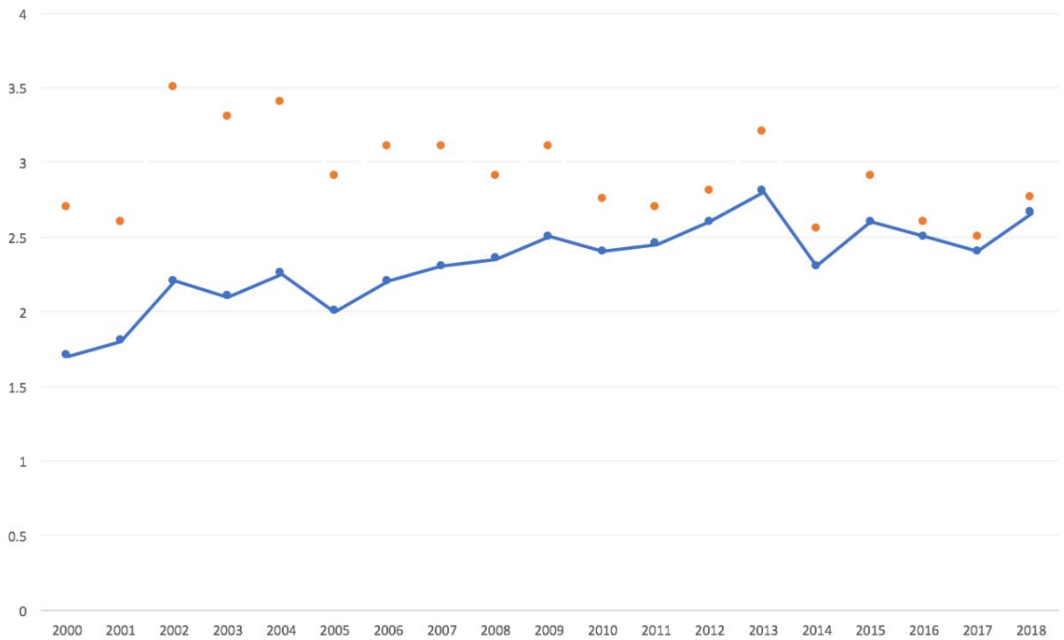


Figure 3.11 The comparative practice of applying the unified connection principle (Vidya, 2018)

In Figure 3.11, the unified connectedness principle becomes a data connection comparison. The dots in the figure are divided into two categories by different colours. In this case, the scattered blue dots are connected into lines. Compared to the orange scattered dots, the line segments formed by the blue dots are more representative of the trends generated by the data and lead the user to discover patterns in the data. In addition, the principle of unified connectedness has the advantage of optimising the overall structural layout and connecting the relationships between elements. In Figure 3.12, for example, the elements of the left-hand graph are more related to each other than the right-hand graph, and the overall structure is more coherent than the right-hand graph.

Figure 3.12 The comparative practice of applying the unified connection principle (Williams, 2021)

3.2.2 Typographic Design

Text is one of the ultimate means and ways of communicating and spreading information. People can learn most of the information intuitively with text and form their understanding in the fastest way (Babin, 2018). Nowadays, the growth and popularity of digital society have made text not only limited to paper, but expanded to computers, mobile phones or any communication device with a screen. This has also made typographies important for the presentation of text (Andrew, 2013).

In screen reading, the factor most likely to affect a user's comprehension of information comes from the image quality of characters produced by screen resolution (Gould et al., 1978). However, with the progress of the times and the evolution of related technologies, Hermena et al. (2017) have been able to prove in recent research that the reading speed of modern screens is not significantly different from that of traditional paper media. In terms of reading comprehension, Singer and Alexander (2017) proved through 36 studies that there was no significant difference in information comprehension tests after users used these two media. Numerous studies have proven that screen reading can be an appropriate way of communicating text in today's modern age. In this study, the suddenness and isolation measures of global health emergencies lead people to rely more on convenient and fast network information. This provides an efficient possibility for screen-based visual text communication.

In interactive information visualisation systems, text is generally used to guide the readers in interpreting the information contained in a graphic, table or graph - telling them what the graphic or table conveys and the importance it possesses (In and Lee, 2017). To date, extensive research on the design of typographies for print and paper documents has been carried out, while relatively little research attention is paid to screen-based presentation, particularly for typefaces presented in interactive information visualisation systems, even though both apply equally to reading speed and comprehension (Singer and Alexander, 2017; Hermena et al., 2017). However, it is undeniable that due to the wide application of typefaces on screen displays such as mobile phones and computers in modern society, research on digital typography is becoming more and more common. While there is a large body of research that examines the application of typography in print to web and screen in recent years, it is undeniable that the results are not necessarily transferable to visualisation (Prieto, 2015; Vladimirova, 2017; McGinley, 2018). The research focus of this thesis is to focus on the content information in the screen. Thus, in the absence of visualisation studies, both print and digital type studies were referenced in this paper, and more recent studies in digital typography will be given preference.

3.2.2.1. Type Attributes

The first section will explore and enumerate the different attributes that affect the visual variation of typeface. According to Piolat et al. (1997), typeface attributes are inherent attributes of a typeface during its design. Users cannot adjust the fixed typeface attributes by means of parameters or Settings. In fact, these properties are manipulated by the designer in the process of creating the typeface. Although nowadays, users have been able to change and customise the display of typeface under different attributes under the pre-set conditions of the system. According to Readability Matters (2019), tweaking these text formats can significantly improve accurate reading speeds for adult readers, boosting speeds by as much as 20% or more. Shaver-Troup et al. (2017) also noted that by adjusting font families, character spacing, and line spacing, the reading ability of school-aged children can be significantly improved. These evidence show that the display of typeface with different attributes has certain influences and preferences on users' reading and comprehension. Among typefaces attributes, some intrinsic properties apply to all characters in a typeface (e.g. contrast and X-height of lowercase letters), while others apply to only a few specific characters. X-height is literal in its definition, referring to the height of the letter "x" in the typeface. Poulton (1972) argued that X-height determines typeface size better than any other feature. Today, X-height is commonly used as a relative measure of typeface height for lowercase letters (Lonsdale, 2014). The figure below shows the meaning of x-height in typeface design. The figure below shows what x-height means in typeface design.

Figure3.7 Shows the meaning of "x-height" mentioned in typography design (Wikipedia contributors, 2022).

Nowadays, despite the fact that many typeface attributes (such as weight, italic, capitalisation, and underline) have been applied to digital media, the typeface attributes available to designers have changed over time. Michael Twyman (1981) distinguished typeface attributes into intrinsic and extrinsic attributes. The former refers to features that are predetermined by the designer in the process of composing the interface, while the latter means the features that can be controlled and manipulated by the user. For instance, in mechanical typewriters, due to the absence of external bold typefaces and italics, underlining and capitalisation become one of the means of highlighting and emphasising content. Even today, some computer technologies still limit the role typefaces can play in typography (Bloomer, 2014). Parametric-like typefaces and some variable typefaces, on the other hand, provide visualisation designers with additional typefaces properties (Brath, 2017). Cheng (2020) summarised the definitions of widely used typeface attributes (Table 3.1). Wallace et al. (2022) defined in detail the typeface attributes that affect users' reading speed and preferences through practical application experiments of typefaces in digital media: serif, type size, type weight, and type spacing.

Typeface attributes	Definitions
X-height	The height of lowercase letters as a percentage of the height of the upper case letters, with the range of 50-75%. The larger the X-height, the larger the surface size of letters.
Serifs	Short strokes at the end of horizontal and vertical strokes, the shapes and sizes of which can vary greatly (or do not exist in sans serif typefaces).
Contrast	The difference in thickness between the thinnest and thickest strokes in each glyph.
Axis	The angle at which the thinnest part of the letter appears, usually visible in round characters. The angle of stress has nothing to do with that of italic characters.

Table 3.1 Definitions of widely used typeface attributes.

3.2.2.2. Type Serif

Serifs in typography pertain to ornamental lines added to the terminal ends of letters to enhance their visual appeal (Bosler, 2012). Typeface with serifs has been traditionally regarded as a classic style of typography, largely owing to the prevalence of serif typefaces such as 'Garamond' and 'Caslon' in the printing industry (Silvertant, 2018). Consequently, the use of serif typography has been more prevalent in literature, and it has become familiar to the public eye. However, in contemporary social development, sans serif typography has gained popularity as a practical tool for various purposes such as road signs, license plates, TV advertisements, and brand logos (Yardemli, 2019). Unlike serif typography, sans serif typeface lacks decorative lines, giving it a simpler and more modern appearance (Tselentis et al., 2012). Despite the fact that sans serif typeface has a long history that can be traced back several millennia, its widespread use in modern society, particularly in the realm of screen typography, is undeniable. Figure 3.8 illustrates the contrast between serif and sans serif typography.

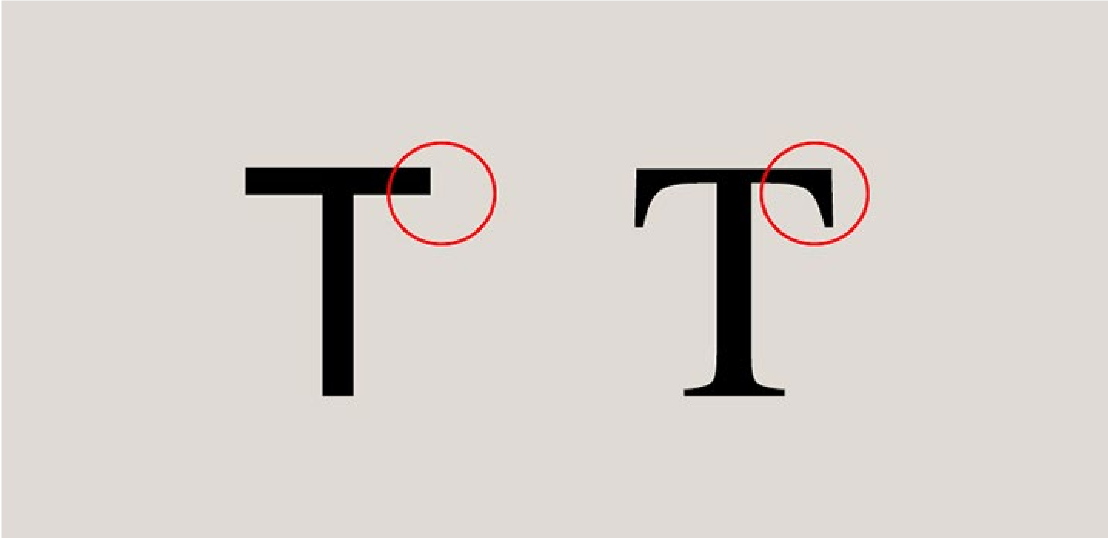


Figure3.8 Shows the difference between serif and sans serif (Todd and DeCotes, 2019)

Historically, early usability guidelines for online typography recommended the use of sans serif typefaces due to the limitations of computer screens in rendering serif fonts, which resulted in blurred shapes and reduced legibility at smaller sizes (Nielsen, 2012). However, technological advancements in screen resolution have since eliminated this potential issue, allowing for the full rendering of serif fonts on screens (Weinzierl, 2019). Contemporary research examining the readability of serif and sans serif typefaces on screens has produced inconsistent findings.

Studies on screen typography suggest sans serif fonts may be superior for reading on screens, according to research using eye tracking technology (Dogusoy et al. 2016). An experiment using these two fonts for screen reading had different outcomes (Times New Roman and Arial respectively) (Dogusoy et al.). Bernard et al.'s results of their research indicated that sans serif fonts (Arial) performed better in terms of reading accuracy; however, due to a small sample size and insignificant variations among results. Furthermore, Bernard et al. Researchers conducted a text usability study, which tested the legibility of Times New Roman and Arial for on-screen use when considering font size, formatting and legibility issues. According to their findings, Times New Roman outperformed Arial when font size was 12, showing higher legibility scores with its legible font face than Arial. The authors of the study suggested that Arial may be to blame due to its larger x-height, which usually results in it being displayed with smaller font sizes such as 10 pixels. It should be noted however, that their analysis only considered native English speakers without taking into account potential legibility differences among international students.

Josephson (2008) conducted an experiment that examined participant preferences for fonts used on screens. As part of their usability test, participants preferred the sans serif font Verdana over Times New Roman in terms of performance - perhaps reflecting its prominence due to small sample size of participants compared with Josephson's 8 participants for this experiment; however these results cannot be taken as absolute due to limited sample size of participants involved in testing the comparison; Chaparro et al (2010) performed experiments comparing legibility performance between Verdana and Times New Roman and found Verdana performed better when used when using numbers and symbols while Bernard (2002) concluded Verdana was the more popular font while Times New Roman was least preferred font.

Contrarily, evidence also exists to support the use of serif fonts on-screen contexts. Perea (2013) and Kaspar et al. (2015) recommend their usage when publishing American Psychological Association (APA) abstracts or texts and scientific e-scientific abstracts and texts respectively. Hashim and Majid (2015) observe that serif fonts offer greater legibility over sans-serif fonts, although they did not specify its specific aspects. Bernard et al. (2013) provide further explanation. Beier and Dyson (2014) have highlighted that legibility considerations when it comes to serif fonts must take other elements such as font size and formatting into account when considering readability (Beier and Dyson 2003). Furthermore, research shows that serifs do not impact readability (Beier and Dyson 2014). Wallace (2022) conducted experiments exploring more subtle variations when it came to font comparison, noting how serif and sans serif fonts were being employed differently on screen - with serif fonts more frequently utilised for PDF documents while sans serif fonts were being preferred in web design projects.

While the use of serif vs. sans-serif fonts for visualising health information and global health emergencies has not been extensively researched, existing studies suggest a bias towards sans-serif fonts in screen-based displays. However, definitive conclusions cannot be drawn. It is important to prioritise legibility as the primary display standard for information related to global health events. Overall, empirical evidence suggests that sans-serif fonts are often favoured and occasionally outperform serifs in screen-based visual formats.

3.2.2.3. Type Size

The manipulation of type size is a commonly utilised strategy in text-based mediums, including map labelling and visual text, for the purpose of conveying information and constructing hierarchical structures (Nielsen, 2002). The range of type size differences is limited by factors such as map markers, frame boundaries, and indexed text type heights (Ovsyannykov, 2021). Such variation is particularly apparent in newspaper headlines and pamphlets, where words are often resized to occupy the same amount of space as one another (Tinker, 1966). This technique can also be applied to the beginning of paragraphs within articles. Brath and MacMurchy (2012) experimented with increasing the size of nouns within paragraphs by two to three times (as depicted in Figure 3.8) to achieve different levels of text readability. However, research on reading efficiency suggests that the frequent use and combination of varying type sizes within text strings can decrease reading efficiency (Sanocki and Dyson, 2012).

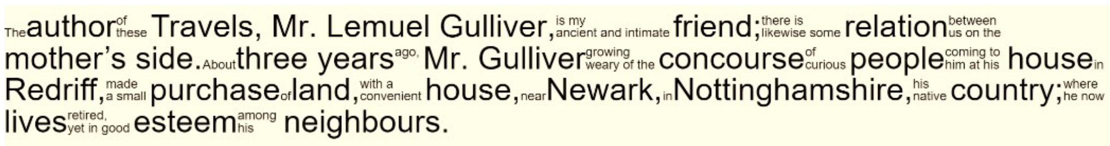


Figure 3.8 Running text set at two sizes: Nouns are doubled in size in the full text (Brath and MacMurchy, 2012).

In research on printed texts, type sizes ranging from 9 to 12 pt have been shown to have similar levels of legibility at the same reading speed (Tinker, 1966). Similarly, Lonsdale (2014), in a review of typography literature, concluded that a type size of 9-12pt is optimal for enhancing text comprehension. Bernard et al. (2003) conducted a pilot study to assess reading efficiency using eight popular typefaces, and found no significant difference in type sizes of 10 pixels, 12 pixels, and 14 pixels. However, it should be noted that the author utilised screen typefaces in the sample material, and thus, the findings may not be directly applicable to printed text. Although the feasibility of typography research for screen typeface applications is suggested, further research is needed to determine whether type sizes used in printed text can be directly applied to screen-based typography.

In the field of visualisation, it has been observed that designers tend to default to a font size of 12 pixels for body text. However, recent studies have shown that larger font sizes, ranging from 14 to 24 pixels, can significantly enhance readability (Chapman, 2019). For instance, Tiao (2017) conducted a study where participants read text passages on 12px and 15px screens, and found that text under 15px was easier to read than text under 12px, despite the paragraphs being identical. Furthermore, according to the UK Government's Accessible Communication Formats regulations, to improve readability, the minimum font size should be 14 pixels (UK Government, 2021). Research also shows that smaller devices, such as mobile phones, contain more pixels per inch and therefore require larger font sizes to ensure optimal legibility. To this end, Kennedy (2018) suggests that when the distance between the user's eyes and the screen is the same, the pixel size of mobile text and desktop text should be kept at about 33% to ensure optimal reading. Font style also can have an influence on text size; designers should use larger X-height in certain contexts without jeopardising readability (Schriver 1997). Despite the growing body of research, there is no clear guidance on the appropriate font size to use in health emergency visualisations. Nevertheless, it is reasonable to conclude that designers should use a minimum font size of 14 pixels for body text and larger font sizes for headings or emphasis text, based on the available research.

3.2.2.4. Type Weight

In the realm of typography, font-weight serves as a powerful visual cue for indicating the importance of text. Varying styles of fonts are assigned different font weights during the design process, enabling users to quickly discern differences and the appropriate applications of various fonts (Dobres et al., 2016). Traditionally, word processing programs on computers offered only two font weight options: bold or normal (Brath, 2017). However, many contemporary typefaces are designed with a wider range of font weights. For instance, the popular font Universe boasts nine distinct weight levels, while the freely available font Source Sans Pro features six weight levels (Cowan, 2022).

The usage of font-weight in typography can be traced back to the Industrial Revolution, where the need to create clear visual distinctions in early advertising arose (Twyman, 1993). In situations where boldface was not readily available, alternative techniques were developed to achieve a bolder typeface. For instance, on manual typewriters, users could backspace over a character and retype it, effectively doubling the amount of ink and creating a bolder appearance. Similarly, on blackboards, mathematicians devised a technique called blackboard bold, which involved doubling the offset of the vertical strokes to create a bold typeface. Notably, studies have shown that boldface is particularly effective in enhancing readability in printed text. Silver and Braun (1993) conducted an experiment comparing the readability of warning messages presented in different fonts, and found that boldface fonts were perceived as more attention-grabbing, thus improving overall readability and human comprehension. Furthermore, it is worth mentioning that both font weight and lightness can alter the intensity of letters, but lightness does not have the same impact on readability, as the contrast between the font and the background is a key factor influencing legibility (Robinson, 1986), as depicted in Figure 3.9.

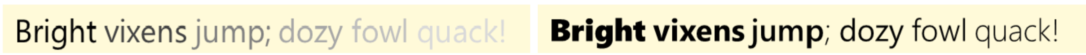


Figure 3.9 Brightness *vs.* type weight: readability is still higher with a larger type of weight.

In contemporary digital media and web information design, font weight has become a prevalent tool for visual communication. In the field of information visualisation, type weights can be utilised in various ways. A straightforward approach involves binary distinctions, where two different categories of information are differentiated based on font weight. However, as proposed by cartographers, font weights can also be employed to encode multiple levels of ordinal or quantitative information. The Cascading Style Sheets (CSS) specification defines the mapping of font weights in web design, as illustrated in Table 3.2. Despite the widespread use of font weights in visual design, there has been relatively limited research on their impact on visual text legibility in both general and specific contexts. For instance, Dobres et al. (2016) investigated the influence of font weights based on the sans-serif font Glance on readability in in-vehicle reading, and found that the legibility of different font weights was associated with the level of the screen rendering system. Lighter font weights were found to exhibit higher legibility under higher rendering conditions. In the domain of universal design, the Irish Universal Design (CEUD, 2020) specifies a style that maximises readability, recommending the use of font weights to "emphasise key words and key phrases," indicating that the usage of boldface throughout the text may impact readability. Especially in the context of frequent global health emergencies, highlighting key data and keywords through font weight can aid users in quickly discerning information categories. Based on these findings, the research suggests utilising bold text (700-900) in addition to normal text (400) as a means to highlight key information and titles, and utilising this value to establish levels to determine the priority of information importance.

Syntax	Value method (Font-weight)
Keyword values	Normal; bold
Keyword values relative to the parent	Lighter；bolder
Numeric keyword values	100-400 (normal); 500-600 (normal to bold); 700-900 (bold)
Global values	Inherit; initial; revert; revert-layer; unset

Table 3.2 CSS standardises font weights in web design.

3.2.2.5. Type Spacing

Spacing in typography refers to the letter distance between texts and the vertical distance between two adjacent lines during the typesetting process, encompassing word spacing and line spacing as key components (Keung, 2021). Text alignment, on the other hand, pertains to the horizontal alignment of text to either the left or right border during typesetting (van Beusekom et al., 2010). In the context of on-screen visual reading, the spacing and alignment of text play a significant role in users' comprehension and overall readability of information (Ling and Van Schaik, 2006). As depicted in Figure 3.10, spacing and alignment in typography have the potential to impact the understanding of information, underscoring the importance of these design elements in visual communication.

Figure 3.10 Differences in text spacing result in different presentations.

Screen research on text spacing has advanced greatly over the past decade. Numerous empirical studies have been undertaken to investigate how different text spacing affects various aspects of screen reading such as speed, accuracy and cognitive load. Research results demonstrate that increasing character spacing and word spacing can significantly enhance readability and reading speed for digital text, while simultaneously decreasing reading errors (Mullet et al. 2001; Tinker 1963). Research also explores how text spacing differs on various screen devices such as computers, tablets and mobile phones, providing designers with invaluable information for selecting appropriate text spacing settings. Strizver (2015) suggests that word spacing should roughly correspond with the width of lowercase letter "n" or "o" fonts currently being used, and 8px grid system defines increments of 8 pixels for web page elements such as size and spacing of page elements (Banus 2022).

According to the Publication Manual of the American Psychological Association (Decleene, 2012), academic papers must be double-spaced for maximum readability and easy review. Ling and Van Schaik (2007) also provided supporting evidence for increased line spacing when examining the English alphabet. In their experiments, they found that employing larger text spacing, such as 1.5 or double spacing, in online texts was effective in improving participants' visual search for the text. The authors further underscored the benefits of presenting information concisely, optimising information for search and legibility. However, it should be noted that the existing research on text spacing primarily focuses on the presentation of paragraphs in the form of articles, and there is a dearth of research on text layout in visualisation, particularly in interactive visualisation charts such as tables, including the alignment of graphics and text. Further investigation in this area is warranted to gain a comprehensive understanding of the impact of text spacing in different visualisation contexts.

3.2.3 Colour

Colour, a multidimensional and complex visual variable in design, is one of the most important and influential tools designers have at their disposal (Gordon, 2021). It can be used to convey meanings and influence user behaviour and perception (Elliot and Maier, 2014). It is often used in several information materials that are visual in nature, not only in diagrams but also in text and buttons, for example. Moreover, colour can facilitate the reading process by making the structure of a text or visual element clearer (Pettersson, 2019).

In general, colour is usually divided into three attributes: hue, chroma and lightness. Hue is usually understood as colour, which refers to the wavelength of maximum energy output from a light source within the visible spectrum (Arhipova, 2018). All hues can be found by passing through the colour wheel. Chroma, known in some theories as saturation, is an expression for the relative bandwidth of the visible light output (Galvan, 2023). As, colours appear sharper or purer as saturation increases, while they appear more faded or discoloured as saturation decreases. And lightness represents the light intensity of the colour ranging from black (low lightness) to white (high lightness). It is important to understand that hue, chroma and lightness are precepts and are relative. For example, the lightness is not only related to the amount of light emitted or reflected; it can also be influenced by the colour properties of the surrounding colour (Kirvan, 2022). For this reason, because visual perception is complex, people perceive different colour contrasts mainly from value, saturation, complementary contrast, simultaneous contrast, tonal contrast, warm and cold contrast (Norman, 1970).

Colour is used extensively in information design visualisation to distinguish and emphasise information and make the presentation of information clearer and more effective (Horton, 1994). It can directly help and attract the user's attention when viewing or reading. Its guiding effect is also found in some cases. In visualisation, important information can be emphasised through colour coding. According to Horton (1994), "colour coding" is an effective tool for making the target stand out more than any other technique. Under the Gestalt-based principle of similarity, the same colour can be used to represent connections between related information (Sheikh and Bovik, 2006). Consistent colour coding can also link related information in a disordered and complex environment, even if they are not in the same location.

Colour also helps icons or buttons to stand out in the visualisation systems. Among icons, those with expected and familiar colours can be more easily recognised and understood by users (Horton, 1994). Experiments have shown that mixed-colour icons are easier to visually distinguish, decipher and understand than grey-scale and monochromatic icons, and also provide a more positive and modern association for the audience (Haist and Mead, 2021). Colour can also make buttons stand out (Niggulis, 2021), and it is considered to be important to ensure that the colour of the button contrasts with the background page and stands out (Hecks, 2021). Anthony (2014) concludes that button colour can reduce the cognitive burden of user behaviour by guiding users through actions and quickly confirming the function of the button through another familiar colour category.

According to Keller et al. (1994), the importance of colour in information visualisation systems lies in the below aspects: improving the accuracy that users receive information, helping users to compare information, reducing confusion and increasing the experience of use, influencing the overall feel of a visualisation system and giving depth, and highlighting important elements. As identified by Wexler et al. (2017), the main factors that influence the use of visualisation are the complexity in the layout of the visualisation system (i.e., the logical distribution of individual design elements and visualisation tools) and the design and presentation quality of the visualisation tools. The visual variables influenced by colour can, to a certain extent, improve the user experience of visualisation. Colour is therefore a key visual variable with a significant influence on the readability and experience of using a visualisation.

3.2.3.1. Colour Harmony

Colour harmony has a wide range of meanings and a unanimous definition has not been reached. Ou and Luo (2006) offered two different perspectives on colour harmony in response to earlier research: 1) Colours can be harmonised when they are selected within a colour wheel or ordered colour space (Itten, 1970; Ostwald, 1969; Cartwright, 2022). 2) Colours can be harmonised when they are similar in hue, lightness or chroma (Chevreul, 1967; Von Goethe and Wolfgang, 2006).

Judd *et al.* (1963) described colour harmony in terms of two or more colours seen in proximity to each other and producing a pleasing effect, a definition that makes a strong connection between harmony and a pleasant response to colour. Today, the concept of colour harmony has been applied to a number of disciplines. Whereas in design, colour harmony is crucial (Westland *et al.*, 2007), a good understanding of colour harmony is essential to the creation of powerful visual images and designs (Murray, 2020).

In the design of visualisation systems, it is necessary to keep the balance between strong contrasts and colour harmony. Weingerl and Javoršek (2018) highlighted the crucial role of colour harmony in visual and graphic communication. Rhyne (2017) and Hu *et al.* (2014) attempted to establish a general scheme of colour harmony to be applied to digital media and visualisation. A visualisation system with harmonious colours can entice users to explore more information, and the role of harmonious colours in helping to improve the readability of visual infographics is reported in the literature (Weingerl and Javoršek, 2018; Wang et al., 2008). This shows that colour combinations based on harmony can contribute to a number of specific design purposes and thus make users feel comfortable. Based on the use of the colour wheel in visualisation, Holtzschue (2012) classified colour harmony in the levels below (Table 3.3):

Classification	Description
Monochromatic (1-Colour)	It is based on one colour to harmonise shades.
Analogous (3-Colours)	It mixes colours by placing them next to each other on the colour wheel.
Complementary (2-Colours)	It mixes colours by placing them next to each other on the colour wheel.
Split complementary	It is required that more colours can be used compared to complementary colours.
Triadic (3-Colours)	It is based on three separate colours equally spaced on the colour wheel as a way of maintaining balance.
Tetradic (4-Colours)	It uses four colours that are equally spaced and relatively complementary.

Table 3.3 Classification of colour harmony in the colour wheel

While colour harmony is a key criterion during the colour selection of reading materials or products to help them find the target information more easily, the influence of user preference and period context are also non-negligible (Dzulkifli and Mustafar, 2013). Based on this, it is difficult to develop consistent and valid rules or models to predict colour harmony, as tastes are transmitted from generation to generation depending on a person's age, gender, race, education and cultural background (Wong, 1986). In other words, colour harmony is the combination of colours that makes people happy, which changes over time and with culture, and is subject to the influence of specific applications (Holtzschue, 2012).

3.2.3.2. Colour Contrast

Colours are relative, so understanding the effect of one colour on another, and how people perceive this interaction, further adds to the complexity of relativity. In contrast studies of textual printed materials, the greater the contrast in brightness between the foreground text and the background colour, the better the readability (Cumming and Tinker, 1967). However, the colours printed and those displayed on the screen do not directly match because of the different calibration of the computer monitor (Bean, 2021). As found by Humar et al. (2014) in a colour experiment conducted on 308 participants, the best combination of legibility and personal preference on the screen is contrasting colour, that is, the contrast between the background and the text in the display colour. In an in-depth study, subjects showed a higher preference for lighter patterns (i.e., darker text presented on a lighter background), suggesting that the luminance contrast released against a light background is more easily accepted by users. It is worth noting that a high contrast ratio against a dark background is more conducive to relieving visual fatigue when the light is dim or when users are viewing a single piece of information on the screen for a long period of time (Xie et al., 2021).

This viewpoint was further confirmed by Mackiewicz (2009), Galitz (1997), Moore and Fitz (1993). They believed that when the contrast between background and text is maximised, the recognition speed and accuracy of information will be higher. In other words, most text should be black on a white background when it is necessary to maximise the readability of the font. This is not to say that all text should be black on white, as the application of colour is often useful, but that careful consideration should be given to the contrast between text and background colour. Breneman also explored the correlation between colour and contrast in his work and summarised how people perceive luminance on the basis of relative values (e.g. perceiving objects differently when they are surrounded by light or dark colours) (Breneman, 1962). Subsequent research by

Bartleson and Breneman (1967) further supported this idea, revealing significant effects of relative surrounding luminance and overall luminance on luminance perception. Overall, it has been reported that people perceive luminance contrast more readily in brightly illuminated environments or surrounds relative to dark environments.

The Web Content Accessibility Guidelines (WCAG) defines contrast as a measure of the perceived "brightness" or difference in brightness between two colours (Webaim, 2021). This difference in brightness is expressed as a ratio from 1:1 (*e.g.* white background and white text) to 21:1 (*e.g.* white background and black text). Further, the minimum standards for contrast on the screen are summed up as follows:

1) The visual contrast ratio of text and images is required to be at least 4.5:1;
2) The contrast ratio between large text and large text images is at least 3:1;
3) Contrast requirements are not required for portions of images that are purely decorative, include text or text images in non-interactive user interface components that are not visible to the user, or contain other significant visual content;
4) There are no contrast requirements for text that is part of a logo or brand name.

One implication of this is that if the difference between text and background, for example, is only in hue then there are likely to be issues with legibility. This has led to the oft-repeated phrase: 'get it right in black and white'.

In contrast, in terms of non-textual contrast, the visual presentation under user interface components and graphical objects requires a contrast ratio of at least 3:1 with respect to adjacent colours; however, due to the proximity and overlap of elements, meeting this requirement may be more challenging for diagrams that contain multiple elements (Elavsky, 2021). Muth (2022) argued that the diagram colours should be less than seven and using gradients as an alternative to this can better reduce clutter and enhance vision. This finding was supported by Cohen-Or et al. (2006) who pointed out that similar colours (*e.g.,* shades of the same colour) can be better combined than contrasting colours (tones) and that similar parts should be regarded as the same object. In addition, as put forward by Kashyap (2020), the intensity of the colour of elements in a chart should be determined by the type of information. He summarised the use of colour as follows:

1) Continuous colours: colours sequential in nature to reflect the continuity of the information.

2) Qualitative colours: colours used to present categorical information that are not inherently sequential.
3) Diverging colours: colours used to present single information when information values can be sorted from lowest to highest.
4) No information colour: a 'neutral' colour used to represent a no information category.

3.2.3.3. Colour Meaning

Colour meaning refers to the mental response to a stimulus (Oyama, 2003). According to market research, over 80% of visual information is associated with colour (Adams et al., 2008), which highlights the importance of colour in visual communication in visualisation systems. Colour recognition gives visual stimuli a distinct and different character and it can also be decoded. Zenati (2021) argues that colour conveys meanings in two different ways, including mental associations and cultural symbolism. The potential meaning of each colour is not universal but changes in each culture. Specifically, people assign specific meanings to colours based on personal experiences, cultural connotations, gender, and context (Zenati, 2021; Birren, 2016).

Although reactions to colour may depend on individuals, there remain some general themes (Madden et al., 2000). Through a study of 23 cross-cultural colour meanings, Adams and Osgood (1973) reported the existence of a strong general trend in the attribution of influence in the colour field. According to their results, red is often represented as an important hue, which is intended to bring out the focus. Black and grey represent relatively passive shades and are used to emphasise weaker parts of an object. Moreover, blue is a popular colour, while white is a relatively aggressive colour. In terms of colour combinations, black accentuates the strong contrast of red (Buechner et al., 2015), and their combined meaning is also considered a strong representation (Adams & Osgood, 1973; Madden et al., 2000).

Furthermore, Jacobs and Suess (1975) argued that the choice of colour can produce mood swings in users. By testing the emotionality of four colours on 40 participants, they found that participants had a higher anxiety response to red and yellow compared to blue and green, and that cooler colours (blue and green) were quick to calm people down. It shows that colour meanings can influence users' perceptions of information through their emotions.

Through an analysis of page colours, Bonnardel *et al.* (2011) confirmed blue, orange and grey to be the most popular colours. Chapman (2010) classified colours as warm, cool and neutral groups and defined basic keywords for the 12 colours through the colour wheel (Table 3.4):

Color sensation	Colour	Meaning
Warm	Red	Passion, Love, Anger
	Orange	Energy, Happiness, Vitality
	Yellow	Happiness, Hope, Deceit
Cool	Green	New Beginnings, Abundance, Nature
	Blue	Calm, Responsible, Sadness
	Purple	Creativity, Royalty, Wealth
Neutral	Black	Mystery, Elegance, Evil
	Gray	Moody, Conservative, Formality
	White	Purity, Cleanliness, Virtue
	Brown	Nature, Wholesomeness, Dependability
	Tan or Beige	Conservative, Piety, Dull
	Cream or Ivory	Calm, Elegant, Purity

Table 3.4 Common meanings of 12 colours in visual display

The usual definition of colour keywords often helps designers to use the right colours for their designs (Lányi, 2017). However, in some special situations and states, the definition and application of colours can differ. Indiana University defined the application of four colours - green, yellow, orange and red - to campus emergencies. Their order was positively correlated with the level of safety (green for safety, red for multiple fatalities and severe damage); Ashworth et al. (2015) conducted a study on the emergency representation of colours developed between hospitals, collecting criteria for the use of colours in 24 hospital codes. The results found that red, blue, yellow, orange, black and green were the most commonly used emergency code colours. However, there was a lack of standardisation regarding the standardised meaning of colours in emergency situations (Ashworth et al., 2015).

3.3 Interactive Information Visualisation

3.3.1 User Cognition and Perception

With learning, human beings have actually been driving scientific research as well as intellectual exploration. The processes through which human beings regard, process, acquire as well as transfer info, expertise as well as skills are complex. As a result, an extensive understanding of the discovering procedure requires to be supported by factor to consider of human cognitive structures. Although it has been shown that the human mind has an unlimited storage space capacity for bit attributes, there is no set basis or restriction for info sensitivity, interest and real-time information processing (Atkinson & Shiffrin, 1977).

In visualisation, a large body of research has been conducted to address the perceptual aspects of graphical properties. In the view of Mazza (2009), the effectiveness of a visualisation depends on the way the information are encoded on the visualisation, that is, the way the information is translated into the visual representation. Information can be displayed on appropriate graphics to match the corresponding information (Mazza, 2009), such as grouping different item groups by different colours, or using different sizes to show the number of item groups in a way that suggests their independence in the user perception. This can facilitate users to detect patterns in the information presented to them. The more clearly these patterns are differentiated, the more impressed the user will be and the higher their ability to remember will be, thus ultimately reflecting their ability to perform tasks efficiently.

3.3.1.1. Type of Memory

In cognitive psychology, the types of information humans store through memory are divided into three main categories: sensory memory, short-term memory, and long-term memory (Mazza, 2009). The human sensory memory and the ability to remember information are subject to a significant influence of the graphical properties of a visualisation, making it important to consider the memory impact of different visualisations and to develop information visualisations without compromising user performance.

Sensory memory refers to the ability of people to retain information after experiencing external stimuli (Huitt, 2003). The five sensory receptors in humans (*i.e.* auditory, visual, taste, touch and smell) receive information within 200 to 500 milliseconds of exposure, and then such information is processed and entered into the memory bank (Sperling, 1960). Of these, the memory resulting from vision is independent, allowing it to occur without the need for concentration (Mazza, 2009). Short-term memory, in contrast, usually represents information that is initially exposed to and retained by the senses, usually for up to 60 seconds (Mazza, 2009). According to Miller (2003), unlike sensory memory, short-term memory is not a memory store formed automatically by the subconscious mind, but requires conscious behaviour of remembering information. The brain is usually able to hold about seven items of short-term memory storage at one time. Even so, items under short-term memory only last for one minute before they are forgotten. It should be noted that short-term memory can be transferred to long-term memory when the brain is regularly stimulated or items make meaningful connections with the brain (Loftus et al., 1980). For example, if a person is exposed to multiple visualisations and one of them has a very unique characteristic, such as having a very high degree of information connectivity and completeness, he/she is more likely to remember the content of the visualisation and its detailed design because of this characteristic.

Working memory, also known as short-term memory, is a theoretical framework for processing and storing information in different parts of the brain (McLeod, 2008). Baddeley (2000) proposed a three-component model of working memory that divides the concept of working memory into multiple storage systems. The model processes perceptual stimuli from the external world through separate cognitive channels. In addition to separate channels for processing phonological, visual and spatial information, it includes a central executive module for controlling and manipulating all cognitive processes through human attention. Thus, the phonological circuits and the visuospatial module act as subordinate systems to the central executive system (Baddeley et al., 2020). Baddeley (2000) further extended the model by introducing the plot buffer, thus providing an interface between the two slave systems, as shown in Figure 3.11. The plot buffer also supports the integration of information extracted from multidimensional external perception with information retrieved from long-term memory. Through the context buffer, the central executive models the external environment through selective attention mechanisms and generates novel cognitive representations that contribute to problem solving and task execution (Baddeley, 2000). The visuospatial map board stores visually presented information, while the phonological loop holds speech and auditory information. The affective buffer is thought to combine information from the visuospatial map board and the phonological loop as well as long-term memory.

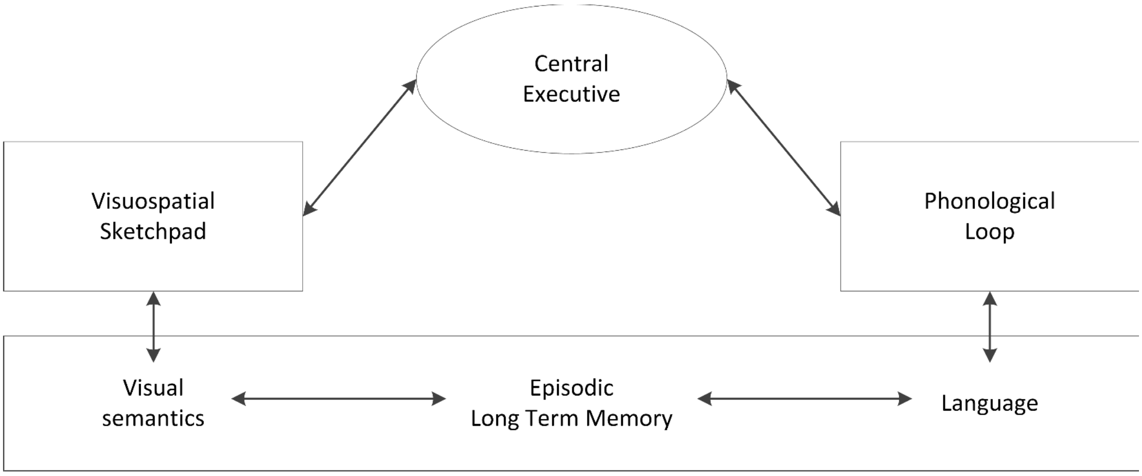


Figure 3.11 Working memory model proposed by Baddeley.

When a person is exposed to a visualisation that displays a large amount of information and data sets, the graphical meaning presented by the visualisation will be an important criterion to consider, and it has the potential to affect users' ability to remember. The information displayed in a visualisation practice can be of different levels and types. When poor graphic choices are used to represent the meaning of information, these graphics and information can easily overwhelm users, thus affecting the user experience and process.

3.3.1.2. Human Cognition Architecture

When people receive new information, they engage in perceptual activities shaped by prior knowledge (Greeno, 2011). This implies that the cognitive structure of a person plays an important role in understanding information. Typically, research in a field generates extensive abstract knowledge that eventually leads to laws and models (Kuhn, 2021). Currently, psychological research based on user cognition forms a body of knowledge containing many facts, experiments, and methods, as well as some theoretical descriptions and some mathematical models and laws, such as memory models (Norman, 1970; Fitts, 1992; Meyer, 2021). Psychology-based visualisation studies can draw from this body of knowledge. In addition, many non-experimental studies have used the results of visual perception research to develop new visualisation techniques (Interrante, 2000; Nowell et al. 2005; Ware and Knight, 1995).

Additionally, researchers have adopted two recognised approaches to exploring the supporting role of cognitive structures in human perception, cognition, and behaviour—behaviourism and cognitivism, respectively. Behaviorism describes cognitive processes in terms of stimuli, perceptions, and behavioural responses (Paivio, 1986). In addition, during the process of learning and information reception, the target is regarded as a partial simulation of sensory, motor, and internal reflection states. These states are regarded as active simulations and are dispersedly stored in specific areas of the brain to form perceptual states (Barsalou et al., 2003). Cognitivism, on the other hand, relies on an information processing model that abstracts information from stimuli and internal processing in the human brain, detaching it from specific sensory modalities (Barsalou et al., 2003).

The learning problem mainly explains why people only retain part of the entire input unit when perceiving it, specifically, selectively retaining one of the units. It can be understood with the filtering theory put forward by Broadbent (1958), as shown in Figure 3.12. This theory suggests that sensory perceptions undergo a filtering operation before entering the cognitive processing system. Such filtering can be considered an adaptive response that prevents overload and optimises the function of a limited capacity cognitive processing system.

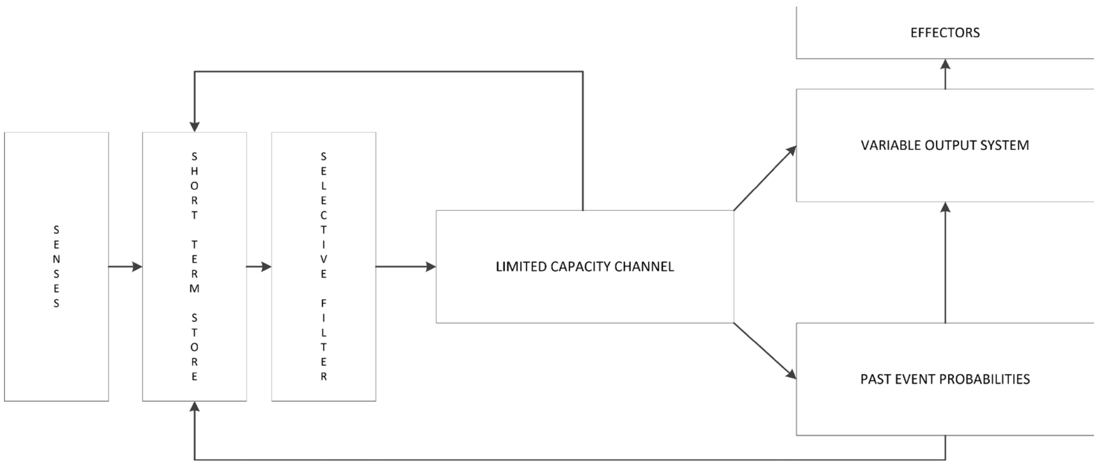


Figure 3.12 Information flow architecture process of human cognitive process (Broadbent, 1958)

3.3.1.3. Ware Theory

The contribution of Colin Ware to the field of psychology and information visualisation learning is noticeable. He not only defined 'science of visualisation' as the process by which users learn to understand visual information, but also based best practice in information visualisation design on empirical findings about the visual perception of people (Ware, 2019). Through extensive research in this area, Ware put forward a cognitive theory of interactive information visualisation learning, while providing a useful description of the visualisation process from the perspective of entities in the meantime.

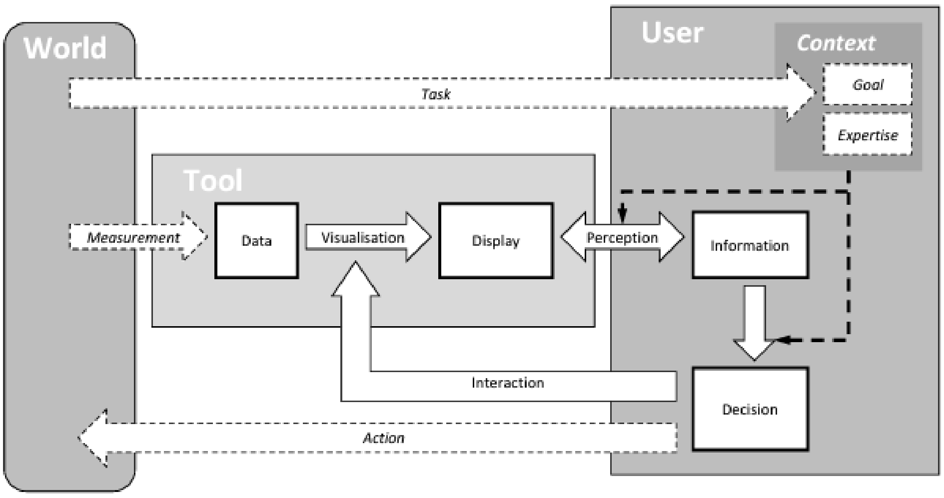


Figure 3.13 Model of processes involved in visualisation comprehension.

Figure 3.13 illustrates mind mapping and flow chart models for visualising comprehension processes (Csinger, 1992; Tory and Moller, 2005; Van Wijk, 2005; Ware, 2019). The overall structure of the model consists of three concentric feedback loops. The first outer loop involves the interaction between users and the external world, including the task assignments of analysts, the visual analysis operations they perform, and the measurement data introduced into the system (Ware, 2019). In the second loop, users can interactively adjust the parameters of the visualisation to change how it is presented (Tory and Moller, 2005). The final loop represents the abstraction process of internally perceiving stimuli, with users perceiving and making decisions through context, continuously fine-tuning to reflect iterative perceptions and decisions (Van Wijk, 2005; Csinger, 1992). Overall, the entire process is based on positive user interaction.

3.3.2 Interactive Design

Interactive design refers to "the practice of designing interactive digital products, environments, systems and services" (Cooper *et al.*, 2007). It focuses on digital products, services and spaces, as well as the user experience that is correlated with the relationship between form, function and content (Fallman, 2008). Therefore, Interactive information visualisation should be based on visual and graphical elements, and reflect user-centred interaction so that users can better understand the information.

Nowadays, the rapid development of society boosts the advancement of computer science and technology, which brings unprecedented new possibilities in the fields of science, engineering and business. At the same time, the "automation of measurement data, the networking of sensors and the digitisation of processing procedures, as well as large-scale computer simulation" (Fekete *et al.,* 2008) have produced a large amount of data. Facing such massive new information, people's capacity to analyse and understand it all is limited. And it is difficult for them to get an overview (Shneiderman, 2003). Under this context, the growing field of interactive visualisation offers a new generation of tools and technologies that can help solve this capacity problem.

3.3.2.1. Interactive versus Static Information Design

Static data presentation remains the primary method of data presentation and analysis. This approach has applications in many ways, including generating data displays for articles and reports (in fact, the vast majority of data displays are still static). Furthermore, it also plays a role in data exploration since many important statistical findings rely only on static data presentation (Wu et al., 2007). However, nowadays, users are exposed to a large amount of information; thus, their needs cannot be satisfied by the data visualisation in a static display. According to Murray (2017), static visualisation provides a pre-synthetic "view" of the information, while multiple static views are often required to present various perspectives on the same information. The dimensions of the information are also limited when all visual elements must appear on the same surface simultaneously. Although the information design of static displays simplifies the user's operation, it fails to present information more concisely and immediately.

As the types of information continue to increase, it becomes more and more challenging to explore information sets. It is difficult for users to get an overview of a large amount of information (Shneiderman, 2003). However, the interactive display is able to achieve better information classification (Shneiderman, 2003). Both static and interactive types of information visualisation play an essential role in information communication. They often provide much information to the user in a more concise and digested way through visual delivery and well-designed typography (Norman, 2013). Apart from these similarities, they have differences in communication media. Static information visualisation is mainly based on data transmission, which can be applied to the poster and other paper/print communication. Interactive one, which increases the interactive nature of users and provides users with more possibilities to access information, is more applicable to technology products such as computers and mobile phones. Moreover, the latter is an upgrade based on static visualisation. Nowadays, the high speed of Internet connection has allowed a sea of information to flood in, and people are no longer satisfied with obtaining resources only by watching the interface. Interaction has become a way for people to participate in information searching and displaying.

As highlighted by Murray (2017), interactivity can also encourage users' interaction with information in ways that a static image cannot. With animation transformations and well-designed interfaces, exploring information becomes more like playing a game. Interactive visualisation serves as an excellent medium attracting viewer who may be familiar with the topic or data at hand. During a global health emergency, for example, due to the unknown and mysterious nature of the virus, people are eager to fill the information gap caused by the virus (Judson et al., 2015). Through proper information dissemination, they can recognise and understand the danger of viruses and reduce the harm to society. During this period, relevant information needs to be communicated quickly and in real-time. Interactive information visualisation can provide users with digested information to the maximum extent and reduce any misunderstanding or information gaps.

A simple example comes from an article in The Washington Post by Harry Stevens (2020), who added interactive principles to a line chart (Figure 3.14) of information visualisation to reveal more information. Figure3.13 is a digital curve of COVID-19 confirmed cases in the United States from January 22 to March 13, 2020. From the static visualisation, we can only observe the significant increase in the number of confirmed cases to 2,179 by March 13, but we cannot analyse the development in depth. However, the interactive visualisation allows us to confirm the daily changes in the number of cases by using the mouse, and the exponential curve starts to have profound significance. We can also calculate the outbreak point of the virus based on the daily cases, so as to find the source of the disease more quickly.

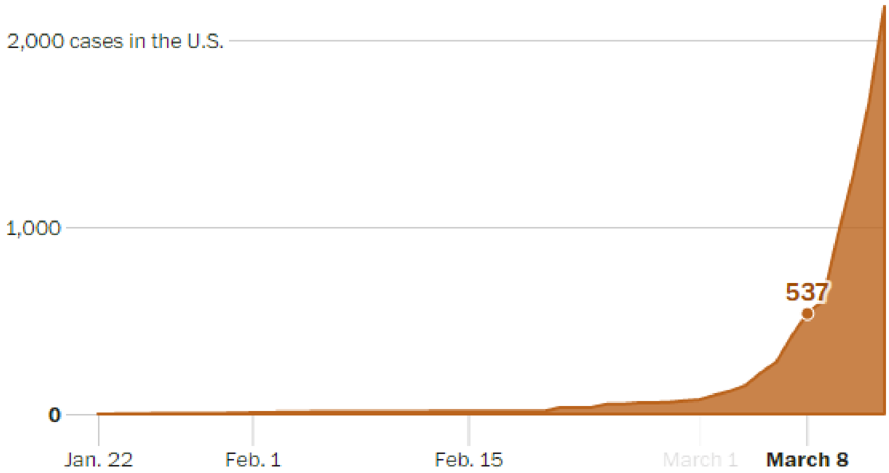


Figure 3.14 An example from the Washington Post article, where the user can further explore the chart information through mouse interaction.

3.3.3 User Experience-Based Interaction Design Principles

According to Vanhamäki *et al.* (2017), compared with data visualisation, information visualisation is not only focused on the processing of complex data. It is more like a visual system integrating all information from text, graphics and data. Interactive technology allows users to witness, explore, and even immediately understand large amounts of information (Vanhamäki *et al.,* 2017). In the past few years, the focus of information visualisation has been posed more on representation than interaction. With the advent of the era of big data, people gradually began to focus on the processing of big data, interactive information visualisation has been greatly popularised, boosting the development of standard information charts. Until recently, the emergence of some new interactive technologies (OrthoZoom for one dimensional (1D), Melange for 2D, Control Tree for large trees and Topology aware navigation for networks) has extended the applications of interactive information visualisation (Fekete, 2020).

Through the creation of new interactive technologies, it often brings a different experience to the user (Fekete, 2020). Similarly, interactive information visualisation gives information designers new insights (Shneiderman, 2003). Therefore, good design in this field should be user-oriented and accord with information design principles to enhance the user experience and engagement (Zhang, 2013).

Design principles related to direct manipulation will provide useful guidance for the development of interactive information visualisations. As with other interdisciplinary approaches (e.g., human-computer interaction), design principles for interactive information visualisation systems need to meet the needs of users, including their goals, expectations, and motivations (Wassink et al., 2009).

Sharp et al (2015) distinguish between usability goals and user experience goals, which are relevant for the design of interactive systems. User experience goals relate to the overall experience of using an interactive visualisation system, while usability goals relate to whether an interactive product meets specific usability standards. According to Nielsen (1992), the core characteristics of usability include learnability, memorability, efficiency of use, reliability and user satisfaction. In addition, characteristics related to interface design include accuracy, clarity of presentation, understandability, and flexibility of operation. Constantine and Lockwood (1999) believe that design goals should be determined based on the user's role characteristics. For example, in visual design, navigation plays a key role for users who combine complex interactions with large amounts of data.

In addition to usability goals, user experience goals also mean to make interactive products more aesthetically pleasing (Nocera et al., 2007). These goals are related to the way users experience subjective interactive products. Therefore, the usefulness of interactive information visualisation is evaluated from the perspective of users rather than the system.

According to Sharp et al. (2015), usability goals are as important as user experience goals. In other words, the interactive visual design must meet both usability goals and user experience goals to offer a pleasant user experience. These goals and design principles are summarised as the general principles of interactive information visualisation design as Table (Table 3.5) below:

Principle	Describe	Reference
Maintain consistency	A consistent sequence of operations needs to be used in similar contexts, while the same terminology should be used in the interface, such as commands, prompts, menus and help screens.	Mayhew, 1991; Nielsen, 1992; Shneiderman et al., 2016; Tognazzini, 1992.
Cater to universal usability	Recognise the needs of diverse users. Add features to meet the needs of novices (explanations) and experts (shortcuts) to enrich interface design and improve perceived system quality.	Nielsen, 1992; Shneiderman, 2003.
Provide feedback	Provide users with system feedback and status information to inform them of the progress;	Mayhew, 1991; Nielsen, 1992; Shneiderman et al., 2016; Tognazzini, 1992.
Visibility of system status	Provide adequate visual feedback on the manipulation of objects	Norman, 1970;
Permit reversible actions	Reversible actions can reduce user anxiety and encourage the exploration of unfamiliar options. Actions must visible, rapid and reversible.	Card, 1999; Shneiderman et al., 2016; Tognazzini, 1992.
Support error handling, prevention & recognition	Prevent serious errors and provide mechanisms to assist users with recognising, diagnosing and recovering from errors. Use clear, explicit error messages.	Mayhew, 1991; Nielsen, 1992; Shneiderman et al., 2016.
Support internal locus of control	Provide status information and feedback within easy view to keep users aware and informed. Indicate progress in task performance.	Nielsen, 1992; Shneiderman et al., 2016; Tognazzini, 1992.
Reduce memory load	Keep displays simple and consolidate multiple pages. Incorporate 'see & point' rather than 'remember & type' techniques. Make all available actions/commands salient.	Nielsen, 1992; Shneiderman et al., 2016.
User control	Mark exits. Allow users to initiate and control actions. Provide visible means to redo/undo commands and actions.	Mayhew, 1991; Nielsen, 1992; Tognazzini, 1992
Simple and aesthetic integrity	Graphical elements should be in the simple design (use natural dialogue, eliminate extraneous words or graphics). Avoid clutter, information should appear in a natural and logical order.	Mayhew, 1991; Nielsen, 1992
Incorporate logical constraints wherever possible	Provide logical constrains in the position or order of direct manipulation objects or graphical elements.	Norman, 1970; Norman, 2013.
Incorporate perceptual affordances	Ensure that operations and manipulations are performed on a direct manipulation object, and graphical elements are obvious.	Norman, 2013; Norman, 1970.
Incorporate mapping of data attributes	Ensure appropriate support for the mapping of different data attributes to visual variables, including position, colour, texture, motion and so on.	Norman, 2013; Norman, 1970; Ware, 2019
Offer a pleasurable user experience	Ensure that interactions with a visualisation UI create a fun, enjoyable, pleasurable, satisfying, rewarding, and aesthetically pleasing user experience.	Jordan, 2002; Nocera et al, 2007

Table 3.5 The interactive information visualisation principle.

3.4 Dashboard Design

Digital dashboards provide real-time visual displays with key data summaries and trend models designed to aid users in monitoring progress, identifying trends, and making informed decisions (West, 2012). Dashboard design incorporates information visualisation techniques that facilitate better user comprehension (Subotin, 2017). Customisable components and configuration options enable users to display various forms of data, providing users with a means for monitoring progress towards goals while tracking metrics through interactive features like drill-down, filtering, and data exploration. Interacting with data in various ways gives users a deeper understanding of its information (Dash et al., 2019). Dashboards have become an increasingly common technology used across industries like healthcare, finance and business to keep employees up-to-date and make data-based decisions more easily.

"Dashboard" refers to an internal panel in a vehicle which displays relevant performance information about it. Today's digital dashboards incorporate principles from many fields including information visualisation, human computer interaction and data science. Digital dashboards have become an indispensable asset across various industries, particularly healthcare where they have been utilised to improve patient outcomes by providing real-time updates about a patient's status and allowing clinicians to monitor progress or detect potential issues (Sarkar et al. 2016). Finance professionals use digital dashboards to assess financial performance and spot risks and opportunities (Bolivar-Ramos et al. 2015). Effective visual communication, user-centric design and data-driven decision making are cornerstones of dashboard implementation in healthcare industries like medicine. Figure 3.15 depicts an example of such a template being utilised.

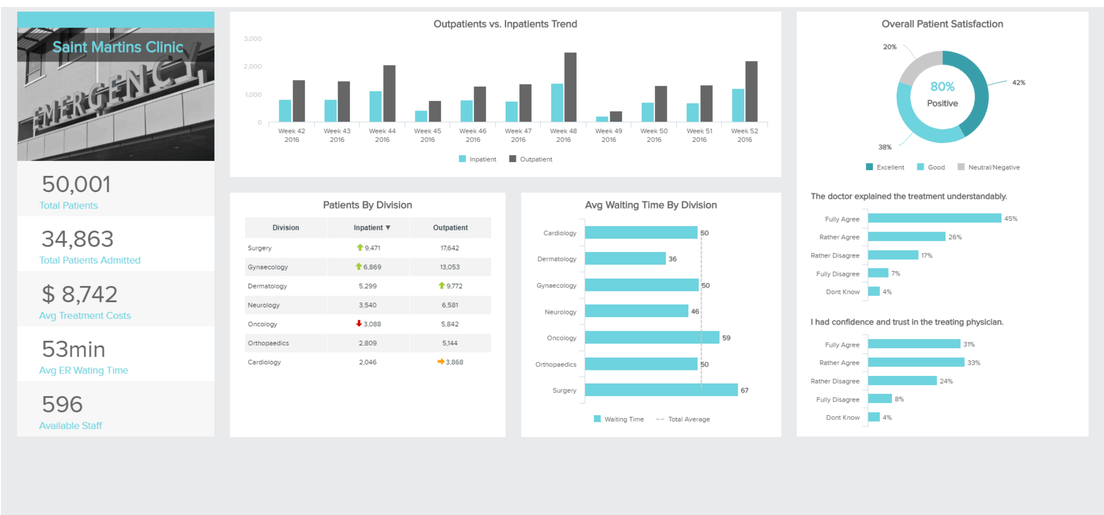


Figure 3.15 Digital Dashboard Mockup Applied to Healthcare (2022)

Chong, Lin and Tsai (2013) provided a comprehensive framework for designing digital dashboards which includes four components - information source, information structure, presentation format and user interaction - in a digital dashboard design project. They highlighted the significance of user-centric design, emphasising how dashboards must be flexible enough and customisable enough to suit different user profiles. Kim, Chung and Lee (2015) identified several essential features that contribute to the effectiveness of digital dashboards: usability, interactivity, visualisation and integration. As they argued, an effective digital dashboard must provide users with an accessible interface as well as interactive features that allow for manipulation and exploration of data. Furthermore, they emphasised the significance of data visualisation techniques which allow users to quickly recognise trends and patterns in data. Underlying this, several dashboard visualisation research projects such as FastDash (Biehl et al., 2007), ENDViz (Badgeley et al., 2016) and Bubblenet (McKenna et al., 2016) have been created; pages feature user interaction links or buttons which navigate users from one dashboard view to the next. Through this kind of interaction, users can more effectively explore and discover compelling information in the data. In this respect, Sarikaya et al. (2018) analysed the impact of dashboard functionality on situational awareness and mission performance, examining the basis of interaction levels in dashboards. Nadj et al. (2020) found that dashboards with interactive features enhance user engagement while keeping users involved. Additionally, Chou et al. (2010) demonstrated that interactions triggered by various page transitions can affect users' self-perception. This is reflected in the coordinated design of interactive links and buttons under different information and the familiarity of the dashboard design structure to users after page jumps. Furthermore, North and Shneiderman (2003) studied link highlighting and link navigation as effects of coordinated interactions. Qu and Hullman (2018) suggested maintaining consistent attention across multiple views to mitigate the impact of dashboard structure changes on users.

Moreover, research attention has also been paid to multi-view layouts. For instance, Spotfire and IVEE were designed to regroup widgets in some dashboards (Ahlberg and Shneiderman, 1994), and later Spotfire tools allowed users to drag and drop views (zoom in and out only). Similarly, Snap-together (North and Shneiderman, 2003) allows users to combine visualisations to create customised combinations; Improve (Weaver, 2005) integrates multiple visual elements into a compact space; Keshif (Yalcin et al. (2018) enables users to create visualisations across different parts of the page.

3.4.1 Layout Framework in Dashboard

In dashboard visualisations, layouts have an influence on user control. Many ways are available to create visual dashboards, including D3.js, highcharts, and such tools as Tableau, SAS or Power BI. Datahero can be used to cast interfaces to create dashboards, and Shinydashboard or Highcharter can create multi-view dashboards according to user needs. However, so far, there has been no systematic study of try-layout strategies, nor tools focused on try-placement using specialised syntax. In this section, the view tool and dashboard system and their use are introduced. Typically, visualisation tools can be classified into three main categories based on their functionality: 1) view systems, which are built by developers to present various view visualisations; 2) visualisation tools, which allow users to generate preset visualisation templates ;3) Dashboard visualisation system tools enable users to customise dashboards using visual syntax.

A number of these tools, Excel, D3, Adobe, Tableau, Vega-Lite and some other tools all have layout limitations though they assist people in quickly creating visualisations (Harper and Agrawala, 2018), such as no indexing and no way to add data annotations. Additionally, other tools can also be used to create and conduct layout visualisations. For example, with the tool created by Becker and Cleveland, users can interactively explore and brush data sets (Becker and Cleveland, 1987). Another closest tool is Snap-together, where views are snapped together by the users (user controls) (North and Shneiderman, 2003). It's clear that developers have used a number of layout techniques to place visualisations on the screen. However, when using a visual dashboard, users are forced to employ a developer-specified approach but have no access to changing the visual layout, which reduces the effectiveness of visualisation.

After classifying the design patterns, feature targets, and data types based on the dashboards currently on the market, Bach *et al.* (2022) finally identified 6 types of dashboards:

-Static dashboards: It presents traditional static pages on the screen with no interactive features, and mainly presents a single page of information. These pages typically include concise elements such as individual values and their rates of change, small charts, arrows, and numbers (Roberts, 2007). The layout of static dashboards is designed in advance by developers, with each part presented in a regular manner. Users connect the visualisation in their minds mainly with the text information on the dashboards. As shown in Figure 3.16, the static dashboard, as a non-interactive visualisation, must present all visual information on a single page concisely. On one hand, users have to find the connection and meaning of the information in these visual elements. On the other hand, the dashboard layout only follows some of the enclosure principles in the Gestalt theory. In fact, users cannot get specific data from the visualisation for further analysis.

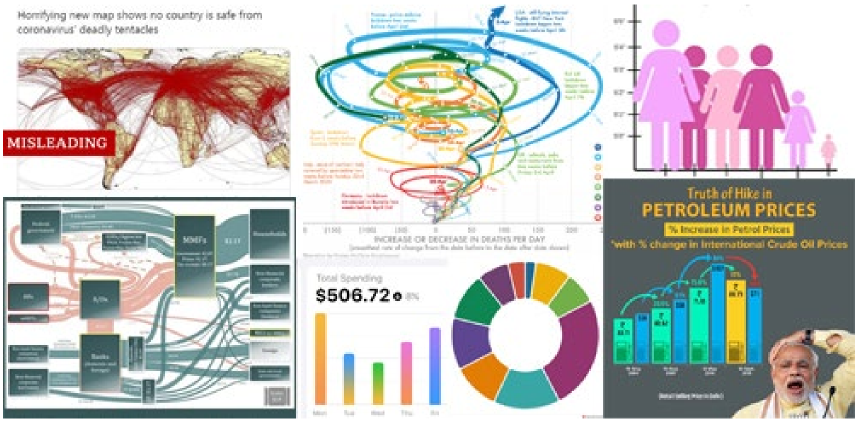


Figure 3.16 Data visualisation based on a static dashboard

-Analytical dashboards: Generally representing a faceted analytical display (Few and Edge, 2007), they share both similarities and significant differences from coordinated multiple views (CMVs) (Roberts, 2007). CMVs focus on harmonise, with single views reacting to interactions in another view to provide complementary view tasks. In contrast, a dashboard may contain multiple views that share no data, information, or interaction between them, and each view can be completely independent and not necessary for the general task (Roberts, 2007). In actual dashboard analysis, comprehensive visualisations and tables are often used to present broader and more detailed data sets. Many of these views are fully interactive, allowing users to freely explore, navigate and drill down. Additionally, parameterised options, tabs, or other linking mechanisms can be provided to enable users to switch between different pages of the dashboard. Importantly, overflow pagination is not employed in case of complicating the visual dashboards by scrolling (Few and Edge, 2007).

-Magazine-style dashboards: Many dashboards related to climate change, politics, etc. are developed by news organisations and similar media organisations, often as part of news articles and presented in a magazine-like visual style (Segel & Heer, 2010). These dashboards are often split into multiple pages and overuse screen real estate on a single page, and visualisations are positioned in place within the text to tell a story about what the information is showing. In other words, magazine dashboards do not occupy the entire page when being "embedded" in the centre of a certain page. They can provide very detailed visualisations and tables on their own, under the premise that they are laid out and interpreted with a great deal of context. Therefore, in addition to regular visual updates, the textual content needs to be updated frequently as the "story" evolves. These dashboards naturally require more design and maintenance work. Although visual elements may automatically update as information changes, editorial oversight is still necessary to ensure consistency between the story and the changing information and its visual presentation.

-Infographic dashboards: They consist of decorative graphic elements and other non-data decorative elements displayed together with the data representation. Similar to magazine-style dashboards, these dashboards use non-informational media to explain and embellish information. On an infographic-style dashboard shown in Figure 3.17, information presentation is enhanced by text, annotations, and others, which in turn helps information tell a story (Roberts, 2007). Attractive looks, pictograms, numbers, and detailed visualisations can be applied to infographic dashboards to represent static data sets, such as presenting critical, non-clickable snapshots of information by month or year. In the absence of clear layout constraints, these infographics tend to outgrow vertical screen space and require scrolling to explore, which undoubtedly increases the cognitive load on the user. Additionally, infographic dashboards may require additional time to design the artistic content, and the annotations and modifiers chosen are specifically formulated for the particular data point, and therefore do not apply to dynamic dashboards that require frequent changes. Therefore, these dashboards may have different intended uses, with viewers expecting to be able to browse over an extended period of time rather than view updates frequently.

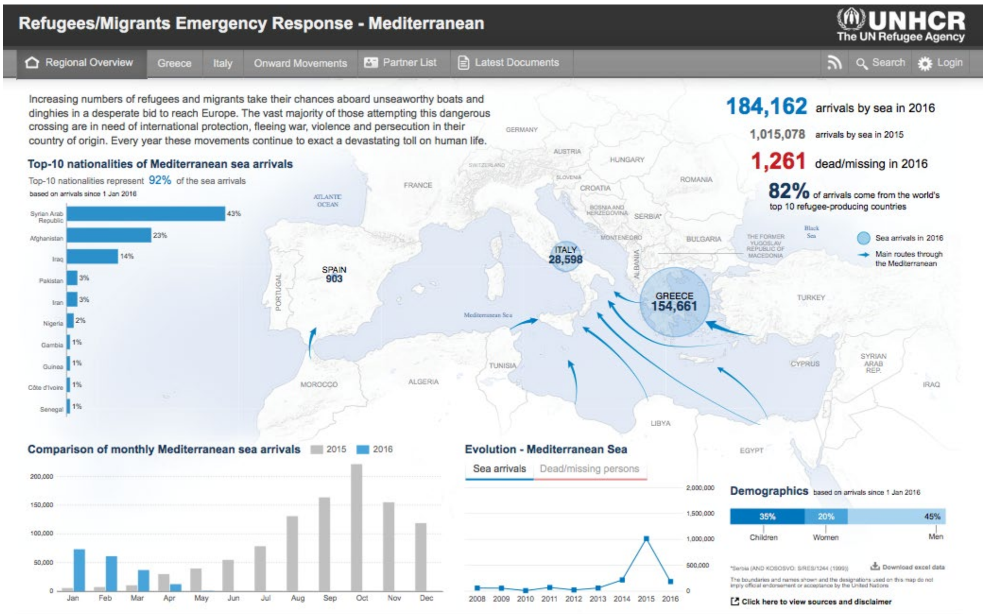


Figure 3.17 Example of infographic dashboards

-Repository dashboards: They are designed to list a large number of charts on multiple pages, but the overflowing structure prevents correct analysis. The common applications include professional information exploration and in-depth information comparison. Diagrams can be very particular, but often lack any textual interpretation, other than metadata (often extensive). In order to distinguish the importance of lots of information, colour is particularly important in the application of repository dashboards. Charts may offer some interaction, often with links for users to explore, drill down, and ultimately download open information. Information and visualisations are regularly updated, with a selection of very common visualisations and figures, and parameterisation are carried out to select data sets. The purpose of offering extensive metadata is transparency in most cases (Mathieu et al., 2020).

-Embedded mini-dashboards: This type of dashboard is one that is embedded in other applications (e.g. news sites), they are very compact, take up a small portion of the screen, and usually feature clear visualisations (Roberts, 2007). Their applications can be divided into two main groups. One is an interactive feature for navigation and quick parameterisation of content. The other is a visual illustration of a single piece of information. To be more specific, an overall visual coverage of the entire data set is not provided, and more than one mini-dashboard usually appears on one page (Roberts, 2007).

A generic classification description of the current dashboard layout framework by Bach *et al.* (2022) is given below (Table 3.6):

Layout	Description
Open	Place widgets (possibly with different sizes and aspect ratios) in an open-ended manner that doesn't require obvious specific rules. Widgets are usually arranged on a grid following classic design guidelines. The location and proximity of widgets are not strongly semantically associated, and each widget seems to have equal importance.
Stratified	Widgets are rendered in top-down order. Stratified layouts can be used to emphasise information at the top over the rest.
Table	Arrange widgets into semantically meaningful columns and rows. They can be used to repeat information and visually encode, for example, across different facets or data items. Tabular layout makes it easy to retrieve and correlate information
Grouped	Widgets (which can be of different sizes and aspect ratios) are arranged in an open-ended manner without specific rules. Widgets are usually arranged in a grid following classic design guidelines. The position and proximity of widgets is semantically independent and each widget is considered to be of equal importance.
schematic	Place widgets in some schematic relationship, such as physical space layout, network or possibly process workflow.

Table 3.6 Generic guidelines for dashboard layouts

3.4.2 Effective Content & Display Pattern

The essential abilities of dashboards are to condense large amounts of information on a single screen and to present it at a glance without sacrificing anything important or reducing clarity (Few, 2013). In addition, they also need the appearance of effective communication. That means every piece of information on a dashboard should be presented in the clearest and richest possible way, usually in a small amount of space (Sarikaya *et al.*, 2018; Bach *et al.*, 2022). This requires a good understanding of the information that the dashboard will present, such as information categories, metadata processing, and representation of visual information in use (Scott and Glaser, 1971). Not only that, but there is a need to take advantage of the display elements available, such as the design elements that are customised, and sometimes created specifically for dashboards, and an understanding of the context and visualisation in which each type of information should be displayed (Few, 2013; Bach et al., 2022).

Using the constant comparison method (Scott and Glaser, 1971), Bach et al. (2022) attempted to modularise the user interface for the first impression of the dashboard, and in the second time for the structure, visual design and interaction of the dashboard performance improvement. It has been found from experimental improvements that more consistent design elements are generated when the focus is put on the information intent of the dashboards during the process. To this end, content and composition design patterns that affect dashboard design should be inseparable (Bach et al., 2022).

3.4.2.1. Content Design Patterns

The dashboard content is composed of various dashboard elements and modules, where the design elements related to information and its presentation are the key. Specifically, three groups of information patterns related to the content of the dashboard are data, metadata and visual representation of data. Among other things, informational content design ignores purely decorative or ornamental visual components such as illustrations, dividers, and borders:

-Data: Information schema defines the ways in which collected data (semi-structured data) is structured, indexed and searched available (Panjwani, 2015). It determines the type of information presented and the level of visualisation abstraction (Bach, 2022). Programmes range in form from complete detailed datasets to more abstract modality to simplify and decrease information volume, with the former providing a more comprehensive view. In addition, the information in the views can be categorised into aggregated data, filters, derived values, thresholds and single values (Duncan *et al.*, 2022). Among them, aggregates, filters, and derived values offer an approach to using summary or analysis and producing a purposeful summary of the information (Mullins, 2020). Thresholds represent states and values that have a certain meaning (Andrade, 2019). Individual values are more extensive and often the most recent values in the time series (In and Lee, 2017).

-Metadata: Metadata often provides additional information for context and interpretation (Chapple, 2003). In some cases, it represents information implicit from the context in which the dashboard is used, such as the current date, or information published by a particular organisation (Chapple, 2003). According to the dashboards' context, usage environment, and authoring agencies such as the designers, the specific categories of metadata are information source, disclaimer (to inform the users of information processing and background), information description (to explain the content displayed on the dashboards), updates (time stamp) and notes, including additional graphic decorations added by designers to highlight specific points, changes, developments, *etc*.

-Visual representation: Visual presentation comes in many forms. Like data patterns, it can cope with varying levels of information presentation, such as tables, lists, and detailed visualisations, which provide detailed information and allow viewers to read precise values. Visualisations can stand alone as components with appropriate axis labels, legends and resolutions, can range in size from 1/3 of the dashboard to the full width or height, and also include numbers and trend arrows (Few, 2013). It is important to note that micro charts are small, concise visualisations without axis descriptions, labels, or tick marks that are designed to provide a quick sense of trends rather than present precise numerical values (Azzam and Evergreen, 2013). Figure 3.18 provides examples of micro charts, which are simplified versions of common visualisation forms.

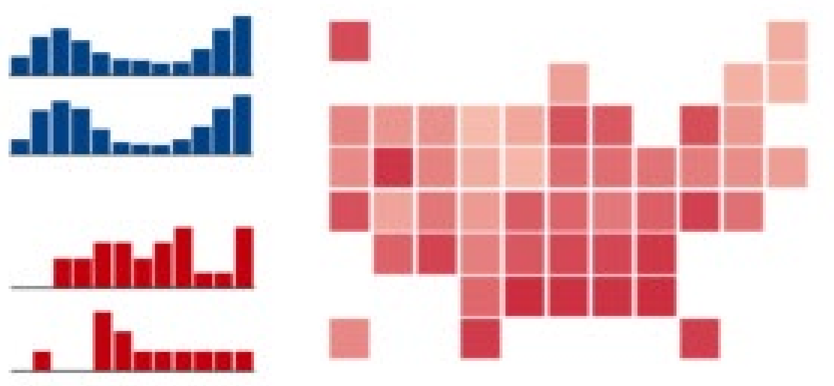


Figure 3.18 Examples of micro-charts where only trends in information can be viewed in a static visualisation.

In addition, gauge and progress bars are also a type of visual data coding to visualise a single numerical value (such as a percentage) in the system. In practical applications, they are usually presented in the form of semicircular instruments, linear progress bars, thermometers (Cahyadi and Prananto, 2015). Values in some dashboards are ranged by positive and negative thresholds. Moreover, trend arrows are usually a way to indicate values, with the small ones pointing up/down to manifest the orientation of change in data values. Another way of expression is numbers, considered a digital representation of a single value. They are placed prominently on the dashboard and are mainly used to present single values, thresholds or derived values (Bansal, 2014). Typically, these are abstract graphics used to express concepts or symbols on dashboards and are also applied to instruments (Santolin, 2020). Figure 3.19 shows the application of gauges and progress bars in visualisation, and the meaning of different colours can help users quickly understand and locate the meaning of information.

Figure 3.19 Applied to the display of the gauge and progress bar under the colour meaning in the visualisation.

3.4.2.2. Composition Design Patterns

Dashboard composition determines how the individual content components of dashboards are combined and displayed. Multiple information elements are displayed by dashboards and their structure and placement on the page are meaningful design decisions (Subotin, 2017). Here, five effective design combinations for dashboards are introduced, including page layout of components, screen space on the dashboards, content structure across pages, range of interactions supported by the dashboards, and colour palette impact of the dashboards.

-Page layout patterns: This pattern mainly defines the layout mode of components on the dashboard (Few, 2013). There are many layout categories for visualisation diagrams, such as graphical summaries, infographics, and sketch notes (Hullman & Bach, 2018; Bach *et al.*, 2018; Zheng *et al.*, 2021). The specific design patterns for each layout category are listed in Table 3.7. Page layout patterns are usually composed of multiple visual components, a main title and many sub-headings, and possibly a small amount of metadata. On many dashboards, information and visualisations are grouped hierarchically, yet it can be difficult to clearly define groupings within any visual composition (Bach *et al.*, 2018). In the dashboard example shown in Figure 3.20, numbers, gauges, and partial pictograms are integrated to represent the same piece of information, thus forming a special form of complementary information grouping. These patterns can also assist designers in determining how higher-level widgets are organised on the page, as well as highlighting and emphasising some visual components of a large amount of content.

Type	Design mode
Graphical summaries	linear, circular, zigzag, forking, nesting, parallel, orthogonal, centric, free
Infographics	large panel, annotated, tiled, grouped, grid, parallel, network, branched, linear
Sketch notes	freeform, grid, radial, linear

Table 3.7 Specific design patterns for each layout category

Figure 3.20 Dashboard integrating numbers, gauges, and pictograms to represent information.

-Screen space patterns: Such patterns describe solutions to fitting content to a single screen page (Anderson, 2017). While content can be split across multiple pages or overflow the screen, the attention of viewers is limited to one page at any given time, even in a multi-screen situation. Nonetheless, layers can be built in a limited screen space through interactive operations, thereby releasing more information and elements. Table 3.8 organises the applications of screen space patterns through interactive operations:

Type	Description
Screen fit	All the content of the page can be rendered directly on the screen without interaction through scrolling or tooltips, etc. This is the standard solution for clean and static dashboards.
Overflow	It allows more pages than available direct screen space. Overflowed content is typically explored via vertical scrolling, and the size of the overflow may be unlimited.
Detail on demand	Additional content is displayed, such as tooltips on mouseover and open popups on buttons or widget clicks. More information may be accessed without displaying it with other content.
Parameterisation	It defines visible information, displays more information or specifies filters on data sets, with parameters set via sliders, checkboxes, or drop-down menus. Parameterisation can reveal latent and multifaceted data sets, but requires manual specification and typically only shows one state at a time.
Multiple pages	Split content across separate pages that are accessible via navigation patterns.

Table 3.8 Application screen space patterns through interactive operations

-Structure patterns: In the simplest case, the dashboard has only one page. Hence, screen space patterns (such as overflow, detail on demand, or parameterisation) may be required to fit the desired content into a single page or screen. However, in the use of multiple pages, the structural patterns connect the relationships between them. Multiple pages can exist through their relationships. Few (2013) summarised the following three structural patterns to concatenate multiple pages:

- Parallel: implying repetition of layout, information and visual representation
- Hierarchical: used for drill down and able to generate a series of pages, with each page gradually revealing more details
- Open: capturing other types of structural relationships

-Interaction patterns: Such patterns describe common interaction methods used for dashboards (Tidwell, 1999). They are represented by interaction information entities, such as information as interfaces, user interface elements, and window-level interactions (Tidwell, 1999). Moreover, interactions on dashboards serve four main purposes (Table 3.9) and are often supported by overlapping UI components such as tabs, sliders, dropdowns, and more.

Purpose	Description	Example
Exploration	Allow viewers to explore information elements, acquire new information, view information in different ways, and explore relationships between information.	Brushing and linking
Drilldown	Allow viewers to find or focus on specific information, i.e. features that are of interest to them in a particular task.	Text fields, drop-down menus, radio buttons, and check boxes
Navigation	Allow viewers to navigate between the pages of a dashboard, or between the screen features of a dashboard.	Scroll bars, navigation buttons, page tabs, hyperlinks
Personalisation	Allow viewers to redefine and configure the information displayed on the dashboard according to personal preferences and task needs.	Select new information features to visualise, resize, or reorder existing coding in the dashboard for more customised dashboard configurations

Table 3.9 Interactive uses, descriptions, and examples on dashboards

-Colour patterns: Colour is an important visual variable in visualisation. Well-applied colours can not only serve different purposes of dashboards, but also be a culturally meaningful style of the dashboard as a whole. The colour schemes suitable for dashboards summarised by Few (2013) and Bach *et al.* (2018) are shown in Table 3.10:

Scheme	Description
Shared colour	Primarily provide a uniquely identifiable colour for groups or faces in the information, helping to maintain consistency and familiarity across the dashboards.
Data encoding	Use colour primarily as a visualisation variable to encode categories or proportions in the data.
Semantic	Metrics that primarily represent multiple meaningful thresholds are used with progress bars.
Emotionally	Add aesthetic power and generate an emotional response in the audience.

Table 3.10 Colour schemes for dashboards

3.5 Chapter Summary

This chapter discusses the influence of information design, interaction design, and dashboard design on the principles of interactive information visualisation systems. It is followed by the review and analysis of major design elements in information design theory, including gestalt theory, typography, colour, and interaction applicability design principles. Knowledge of dashboard design is emphasised, focusing on the dashboard structural framework, information structure, information quality, and interaction design elements. Currently, there are few studies on dashboards that affect users' reading comprehension and information readability in specific contexts. Nonetheless, in many areas of dashboard design, applicable design principles to improving dashboard design have been explored. This improvement can be defined in many forms, such as accuracy of understanding, speed of information localisation, information memorability, aesthetic rating or user preference. In this chapter, the research in the literature review is evaluated and a framework of design principles including Gestalt theory, colour, typography, interaction principles, and related areas of dashboard design is introduced.

Good-quality visual elements in visualisation systems can effectively speed up the information search and understanding process, while the structural framework should be carefully selected to improve the accuracy of information transmission. In this sense, the design principles summarised below provide a preliminary standard for the visual design and system framework in later research. Further details on the application of the aforesaid framework to visual design were investigated in the following case studies by examining the assumption that successful application of these principles would facilitate more effective learning. Three epidemic cases of SARS, H1N1 and COVID-19 were selected. Combining basic information design principles and a framework of interactive information visualisation principles based on usability and user experience, the applications of information visualisation (interactive information visualisation) in global health emergencies were analysed. The research results will help determine whether the application standard can optimise the design of dashboards.

3.5.1 Framework of Design Principles

A design principle refers to a set of statements used to communicate what people want from a project or product (Strid, 2017). It can make sure people reach a consensus on core principles for measuring work. A framework established for a particular product or project plays an effective role in facilitating designers to make design decisions and provide constructive feedback (Strid, 2017). As argued by Proper and Nedar (2022), a sound framework of design principles should be user centred. That means the core values reflected by the principles should better respond to the feedback given by users.

So far, the application of the design principle framework is of a very wide scope, even including the design of interdisciplinary products or projects. Tens of thousands of design principles have been formulated based on different perspectives, occupations and products, and some of them may be repetitive. In academic research, Bangert (2004) created 7 principles for online teaching evaluation, and Hicks *et al.* (2015) put forward 3 design principles for implementing integrated healthcare information systems. Notably, the principles for practical application are more general W3C (2022) developed a strict set of design rules for the design of web pages, Rosala (2020) proposed product-specific design principles to support better decision-making, while Georgieva (2022) created simplified and core design principles from the perspective of user experience.

In this literature review, the study primarily focuses on introducing and collecting information design theory related to visual system construction that affects users' cognitive understanding and the interaction design theory that considers the impact of users on information understanding during use, including the structural layout and components of digital dashboard design. In particular, this study aims to create a framework of applicable design principles for interactive information visualisation systems that can be used by the general public during epidemic-induced global health emergencies. The principle framework consists of seven key aspects, which are summarised in Appendix 1 in the form of a table. By developing this principle framework, this study seeks to provide guidance for the design of interactive information visualisation systems that can facilitate the comprehension of complex health data by a wide range of users.

3.2.2.1. Summary of Principles Collected From Literature Review

Part 1. Layout

1. Page scrolling
Ensure that the system layout reduces page switching and scrolling interaction so that the same type of data exists in the same page space.

2. Draw attention

Important data and information should appear in the most conspicuous position on the screen. Reject the second click or operation (swipe or click).

3. Page integrity
Get an overview of the entire collection in the layout system (*e.g.,* main options, data, map information, etc.).

4. Unnecessary decoration
Use a clear and simple layout structure and avoid useless decorations. It not only does not help users understand the meaning of the data faster, but it will directly affect the speed at which users understand the data.

5. Information chunking
Place related objects (such as images and explanatory text) together so that users can explain that they are grouped.

5. Overall consistency
Ensure that the overall system (*e.g.,* content style, framework, general information) is reflected in the overview instead of too much detail and precision)

Use similar layouts in different pages of the system to effectively reduce the cognitive burden of users.

6. Layout association
The arrangement of the layout should be meaningful based on the text environment, so that users can understand the meaning between components.

Make sure that the layout structure of the entire system caters to the components so that they can be well integrated.

Part 2. Typeface

1. Simple typeface
Choose simple fonts and avoid design elements that may draw unwanted attention or reduce the legibility of information.

2. Typeface size
Use 14-to-16-point font size for body text.

Under different terminal display, the font size between desktop text and mobile text should be kept at about 33% to achieve the premise of optimal reading.

3. Typeface legibility
Display text in a simple, uncluttered style to prioritise text readability.

4. Suitable for screen reading
Use a typeface design that is more suitable for the screen to display text in the system.

5. Typeface weight
When using font weights, put good readability first.

6. Line space
Use line spacing of 1.5 or 2 to optimise the legibility in a block of text.

7. Uniform arrangement
Justify text to the left to optimise legibility of online text.

Part 3. Colour

1. Convey meaning
The connection between colour and content is not just a decorative tool, but in line with the meaning of information transmission.

2. Complementary colour
When using colour, you must fully understand the background. Reject the presence of complementary colours (such as backgrounds, graphics, and text) that do not conform to colour harmony.

3. Gradient Limits
Display relevant information using the same or gradient colours, and the maximum number of

gradients shall not exceed 4 colours.

4. Contrast between colours
When defining different types of information, ensure that the colours are clearly different, so that the difference in colour is clear.

5. Attract attention
Use colour to draw attention and accent colours to bring out the most important information.

6. Suitable quantity
Limit the colour to 2 or 3 tones (no more than 5) to reduce visual clutter, changing chromaticity and value.

7. Contrast between colour and graphics
Visual presentation contrast ratio of colour brightness to text and images of at least 4.5:1.

Ensure strong colour contrast between variables and emphasise important statistics.

8. Colour space
Create enough contrast between foreground and background colour to optimise visual legibility.

Part 4. Design Element

1. Less ornamental
Clarify the functions of icons and buttons to reduce user confusion caused by excessive decorative meanings.

2. Consistent button style
Maintain a consistent design style (the same function button should not have multiple design styles).

3. Simplified design
Avoid trying to include too much information in one chart, use animations optional and user--user-controlled to make the chart more simplified.

4. Histogram display data
Use simple histograms to clearly display information. Avoid using stacked or three-dimensional histograms to interfere with the viewing of information.

Ensure that the graphics clearly represent the information they are visualising.

5. Meaningful measurement
In order to make the measurement meaningful, we must know the content to be measured and the expression unit of the measurement. If a measurement method is not the clearest and most effective way to convey what the dashboard viewer should understand, then the measurement method is flawed.

6. Emphasis on data presentation
Ensure strong colour contrast between variables and emphasise important statistics.

7. Avoid complex images
Avoid using complex image backgrounds on chart; ensure consistent styles between chart of infographics.

8. Clear Information Jump
By displaying the selected content in each menu, clearly mark where the user is in the system and where they can go (menu formats should be fixed and easily visible).

9. Appropriate data interval
Designing visually good media components can convey information clearly and effectively without distracting people. (e.g., have enough filling space and interval to display data in the chart).

Part 5. Content

1. Consistency of content attributes
Consistency should be maintained in system interface design and operation sequence (e.g. the content or display of the same attribute should use the same colour, terminology).

2. Easy to retrieve

When appropriate, the instructions for use of the system should be visible or easily retrieved (e.g. reduce cognitive burden for users' search through fuzzy matching).

3. Simplified design
Avoid trying to include too much information in one chart, use animations optional and user-- user-controlled to make the chart more simplified.

4. Remove irrelevant information
Data should not contain irrelevant information or rarely needed information (e.g., useless decorations, it cannot help users understand the meaning of data faster, on the contrary, it will directly affect the speed of users' understanding of data).

5. Interpret metadata
Metadata should exist to explain the source, purpose, intent, and other context of the data.

6. Minimise content
Allows the user to see the exact values in the table and minimises the data format and presentation of the content.

Part 6. Interactive Function

1. Quick feedback
The system should let users understand what is happening through appropriate feedback within a reasonable time (e.g., display a progress bar to feedback the loading of the system; Corresponding actions performed through feedback messages, etc.).

2. Easy to operate
Interactive functions should be clear and easy to operate (e.g., clearly mark the zoom in and zoom out buttons on the map; clear filters around the diagram).

3. Outstanding features
Highlight all buttons and functions (*e.g.*, Through colour, background, font size and thickness, etc.).

4. Support for undo and redo

Save the history of user operations to support undo and restore operations.

5. Share and download
Allow users to share and download system data to facilitate presentation and sharing on various platforms (e.g., social media or link format etc.).

Part 7. Display Pattern

1. Same interaction scene
The presentation of the data in the system should use the same interactive scene (e.g., the data pop-up of way, format or layout), even if the presented data is different.

2. Adjust in time
The value should be adjusted in time with the relationship between the items (under the same interface, if the data is adjusted, the corresponding map and table should be changed in a consistent manner to correspond to the display of the data).

3. Merge simple components
Keep the display simple, merge multiple system pages to reduce the frequency of users repeatedly jumping to view.

4. Keep an interface
Incorporate 'see & point' techniques rather than ‘remember & type'(*e.g.*, place the display content and related interactive functions in the same place where the system page is visible).

5. Share and download
Allow users to share and download system data to facilitate presentation and sharing on various platforms (e.g., social media or link format etc.).

6. System design visibility
Users can easily open and find the location of the system to ensure the basic operation of the system (e.g. the open, enter information, execute or cancel)

7. Component dependencies
Place related objects (e.g. a images and explanatory text) together so that users can understand

that they are grouped

8. Reasonable logical order
Avoid clutter. Information should appear in a natural and logical order (e.g. present information in an orderly sequence, logical structure, timeline, or prioritised by importance)

9. Support attribute mapping
Ensure proper support for mapping different data attributes to visual variables, including position, colour, texture, motion, etc.

4 Case Studies: Evolution of Interactive Information Visualisation Design in Global Health Situations

4.1 Introduction

In the previous chapter, a framework of design principles based on interactive information visualisation was constructed through a literature review. The section below examines the application of information visualisation and interactive visualisation systems in several global health emergencies based on the constructed framework. Specifically, the effectiveness of visualisation cases during the pandemics was evaluated and measured from two perspectives, including the usability of the design elements presented and the influence on the process of using the system. Moreover, case studies were conducted on the infographics and interactive visualisation systems used during global health emergencies as defined by the World Health Organisation.

In the first stage of this research project, health emergencies having a significant impact on the world were selected for case studies. The cases include three events of Severe Acute Respiratory Syndrome (SARS), Hemagglutinin 1 Neuraminidase 1 (H1N1), and Corona Virus Disease 2019 (COVID-19) pandemics. Examples were collected of infographics and interactive information visualisation systems released to the public by different agencies and countries during these health emergencies, and then analysed (information exchange for scientific investigation purposes was not included here). Additionally, the framework of design principles constructed previously informed the analysis. Whether the visualisation cases fit with the framework was determined by their design characteristics, such as the design structure, the use of colour, the legibility of fonts, and the memorability of information. The influence of these elements on visual design, interactive features, complexity and effectiveness of the displayed patterns were evaluated and measured. Subsequently, an evaluative framework was established to assess each case study, classifying the visualisations into three levels: "basic," "intermediate," and "advanced." The categorisation was determined based on the extent of information visualisation present in relevant databases and the adherence to principles within the established framework. This classification method offers the advantage of systematically categorising and comprehending recurring patterns of issues and limitations observed in information visualisation over time. By evaluating visualisations from different time periods, this approach serves to validate the applicability and effectiveness of the principles framework, while also identifying the evolutionary directions in the design process of visualisation systems across various time periods. Such findings provide valuable guidance for the research and design of present and future interactive information visualisation systems.

In the second phase, an online questionnaire was conducted to investigate the dynamics of information communication during the COVID-19 pandemic. This study aimed to explore the extent of public demand for information, the modalities through which information was sought, and the feedback and application experiences related to the interactive information visualisation system employed during the pandemic. The majority of participants were residents of Wuhan, who were experiencing quarantine measures during the initial stages of the outbreak. The inclusion of this specific population served two main purposes. Firstly, it aimed to understand the specific information needs of users and the practical application environment of the interactive information visualisation system during the state of emergency, particularly under the government's stringent isolation measures. Secondly, it sought to gather user feedback and suggestions regarding the visualisation system used in the early stages of the pandemic, thereby validating the effectiveness of the principle framework and establishing its guiding significance. The findings revealed participants' overall positive feedback regarding the utilisation of the interactive information visualisation system as a tool for pandemic communication during the outbreak. Additionally, participants provided valuable feedback emphasising limitations of the designs, that informed the research process. Notably, some of the participants' suggestions aligned with the principles outlined in the framework. Consequently, the study posits that health visualisation systems that incorporate a greater number of design principles are more likely to exhibit improved efficiency of use and enhanced information readability in emergency scenarios.

4.2 Analysis of Design Principles of Interactive Information Visualisation in Global Health Emergency

4.2.1 Procedure

A total of 28 visual charts and system cases in different global health emergencies were examined. In this phase of the study, a comprehensive examination of 28 visualisations and system cases related to three distinct global health emergencies - namely, SARS, H1N1, and COVID-19 - was conducted.

The rationale behind selecting these specific periods lies in the potential for conducting research and making comparisons based on the information needs arising from diseases with similar characteristics (all three being respiratory diseases). Furthermore, these infectious diseases were all designated as "global health emergencies" by the World Health Organisation during their respective outbreaks, posing significant threats to both societal development and public health.

The process of gathering these cases involved utilising online search engines, primarily Google, and employing a combination of relevant keywords, including "SARS," "H1N1," "COVID-19," "Visualisation System," "Dashboard," "Visual Diagram," among others. This approach allowed for an extensive search for relevant visualisations and system cases associated with the specified health emergencies. Additionally, pertinent references cited in relevant publications were also thoroughly examined to supplement the search and incorporate any additional studies that could enrich the dataset. They were evaluated using the framework of design principles and then classified into three levels' advanced', 'intermediate' and 'basic'.

The framework of principles comes from the seven assessment areas formed in the previous chapter, including structure, colour, typeface, elements, content, interactive function and display pattern. As each area of the design principles framework contains more than one design principle, the evaluation criteria for the cases was formulated based on the percentage of application of the principles to each design principle framework area. Moreover, the accuracy of comprehension was determined based on public graphic symbols. Currently, two levels of evaluation criteria for comprehension accuracy of public symbols are commonly used, including the International Standards Organisation (ISO) with a comprehension rate of 67% and the American National

Standards Institute (ANSI) with an even higher rate of 85% (An *et al.*, 2017).

The application of standardised methods for critical assessment of comprehension has gained prominence across diverse domains. For instance, Berrio et al. (2022) utilised these methods to evaluate the comprehension of traffic signs. Similarly, Mayhorn and McLaughlin (2014) applied the ISO information understanding standard to analyse comprehension during extreme public disaster events. In the realm of medical health, Gutierrez et al. (2022) employed a set of standards to assess the comprehension ability of drug pictograms in Filipino adults. These studies demonstrate the broad applicability and relevance of standardised comprehension assessment approaches in various fields.

There is a minimum requirement for an unconditional tolerance percentage (tolerance less than 10%) based on the Measurement Systems Analysis (MSA). In this case, 76% based on the 'median' mean was taken as the threshold and visualisation cases with a value equal to or larger than this threshold were considered to be 'advanced'. In other words, each case at an 'advanced' level was required to apply at least 76% of the principles in the framework. Conversely, when the application rate of design principles was below 24%, the case was defined as 'basic'. This means that the 'intermediate' level was defined by the average interval, which was selected between 24% and 76%. The 'intermediate' threshold was chosen based on interval values ranging from 38% to 62%, as calculated below:

The three intervals of length 24 were set as follows:

α= [0, 24]; β= [76, 100]; γ= [X, X+24]

Based on the exact distance between γ and α, β, then X was obtained as:

[76-(X+24), 100-X] = [X-24, X+24]

X=38;

Thus, the cases with the principles proportion falling in the range of 25-37% or 63-75% were not applied. This approach reduced the influence of classification differences based on small percentage threshold intervals (12%) and ensured that cases had meaningful differences based on the number of design principles per interval. At last, 12 cases were included in the evaluation, where the display samples of design elements in the W3C Accessibility Design were used as an evaluation reference to reduce subjectivity.

During the case assessment process, the framework of principles for interactive information visualisation identified in the previous chapter will be used as the main criteria for the assessment. The assessment will examine the cases in seven areas: structural integrity, tonal composition, typographic choices, design elements, content relevance, interactive features and display modes. Each principle criterion will be carefully assessed to determine the extent to which the case complies with and implements the principles. This assessment process employs a quantitative algorithm that utilises percentages to assess individual categories of principles as well as overall compliance. Specifically, the total number of principles embodied in the seven dimensions of the Principles Framework is quantified by the number of principles that meet a given criterion. Compliance with these principles is then quantified as a percentage. For example, if a case complies with seven of the 10 principles relating to structural layout, the score is 70 per cent; conversely, if only three principles are complied with, the score is 30 per cent. Subsequently, the cumulative percentage data for the case is derived from the assessment scores in the seven areas. This methodology ensures the impartiality of the assessment process and facilitates a comprehensive exploration of the design elements that influence the visual communication of information. Figure 4.0 delineates the seven categories along with their overarching definitions within the assessment framework.

[Types of principles and definitions of evaluations]

Type of evaluations	Overall definitions
Layout	Evaluating the rationale for visualisation in structural layouts, including the layout and navigation of information and components
Typeface	Evaluation of font application type, size, line spacing, and other typographical issues
Colour	Application of colour to cases, including principles of contrast and colour meaning in backgrounds, text and visualisations
Design Element	Evaluation of the impact of the design elements presented in the case in use, e.g. design features of buttons and functions, logos, etc.
Content	Evaluation of the layout and presentation of information, including its readability
Interactive Function	Evaluation of the reasonableness of the interactive features, including the way the interaction is performed and the reading order and presentation of information affected by the interaction
Display Pattern	Evaluation of the potential impact of display elements in individual visualisation components in the case on the process of use, also including other display elements such as advertisements

Figure 4.0 Seven areas of evaluation and general definitions

In conclusion, the classification system established on the aforementioned criteria serves as a foundational framework for future research endeavours. Through a systematic comparison of visualisation cases across different time periods, this study can effectively discern the areas where significant progress has been made with the advent of digitisation, as well as identify lingering limitations that merit further attention and improvement. This comprehensive analysis contributes to a deeper understanding of the evolution and advancement of visualisation systems over distinct time horizons, thus illuminating the developmental trajectory of the field.

4.2.2 Results

In general, a "basic" visualisation system fails to meet the criteria outlined in the Design Principles Framework in all aspects, while an "advanced" visualisation system successfully fulfils these criteria. Based on the assessment of visualisation cases related to global health emergencies discussed earlier, a significant portion of the "basic" visualisation cases can be traced back to the SARS epidemic in 2003. These cases were characterised by a single information display method and generally exhibited basic adherence to the principles outlined in the framework. On the other hand, a greater number of "advanced" visualisation cases originated from more recent global health emergencies, such as the COVID-19 pandemic. By studying the evolutionary process of visualisation design, it becomes evident that various visual components and rich design elements have played a particularly prominent role in the development of interactive information visualisation.

4.2.2.1. Case Study 1 –SARS Pandemic

Four examples of visualisations used in the SARS pandemic were evaluated based on the framework of design principles, with the results summarised in Figure 4.1.

Basic design

A design defined as "basic" according to the principle of infographic application, which threshold intervals below 24% are defined as "basic".

Basic 0-24%

Country	Cumulative number of case(s)	Number of deaths	Local transmission*
Canada	28	3	*Yes*
China +	806	34	*Yes*
Hong Kong	367	10**	*Yes*
Taiwan	6	0	*Yes*
France	1	0	*None*
Germany	4	0	*None*
Italy	2	0	*None*
Republic of Ireland	2	0	*None*
Romania	3	0	*None*
Singapore	78	2	*Yes*
Switzerland	2	0	*To be determined*
Thailand	3	0	*None*
United Kingdom	3	0	*None*
United States	45 §	0	*To be determined*
Viet Nam	58	4	*Yes*
Total	**1408**	**53**	

Notes:

Cumulative number of cases includes number of deaths.

As SARS is a diagnosis of exclusion, the status of a reported case may change over time. This means that previously reported cases may be discarded after further investigation and follow-up.

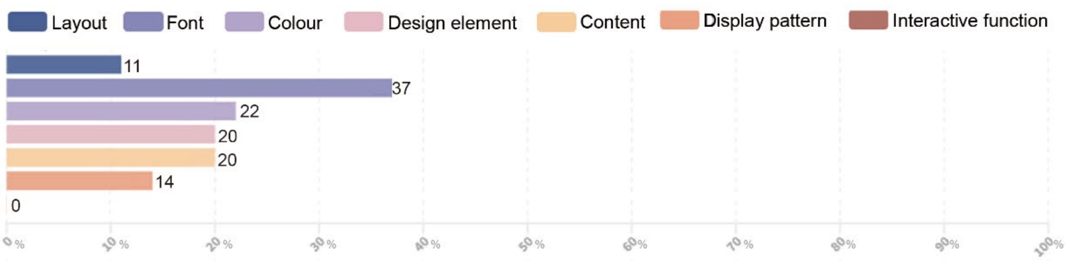
***National public health authorities report to WHO on the areas in which local chain(s) of transmission is/are occurring. These areas are provided on the list of Affected Areas.**

+ 792 cases, including 31 deaths, reported from Guangdong Province cover the period 16 November 2002 to 28 February 2003. These cases were compiled from investigations as well as hospital reports and may include suspect as well as probable cases of SARS.

§Due to differences in the case definitions being used at a national level, probable cases are reported by all countries except the United States of America, which is reporting suspect cases under investigation.

**One death attributed to Hong Kong Special Administrative Region of China occurred in a case medically transferred from Viet Nam.

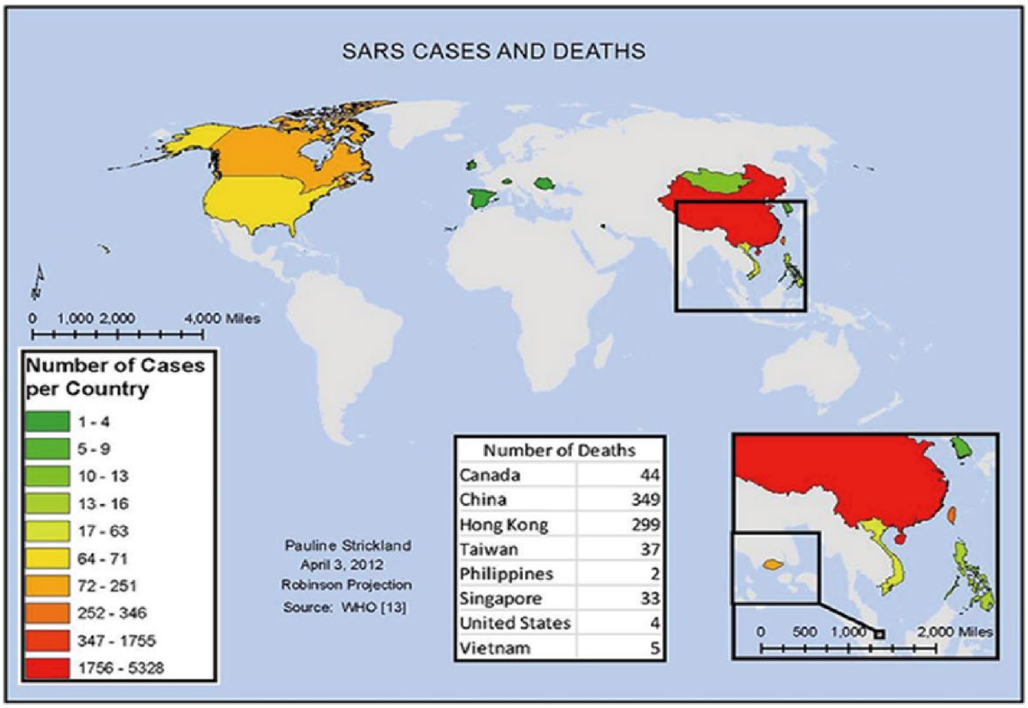
Average Score: 17%



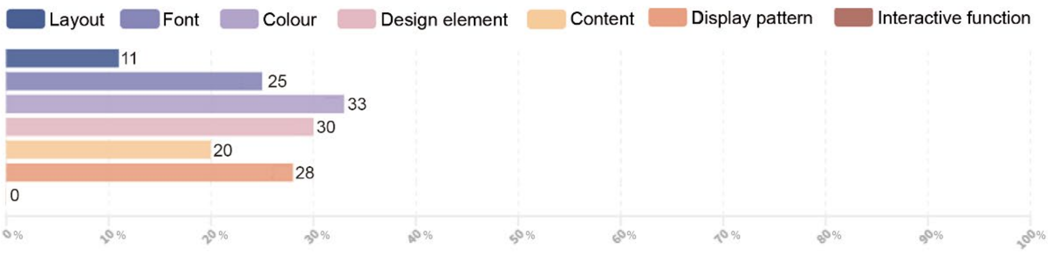
Basic design

A design defined as "basic" according to the principle of infographic application, which threshold intervals below 24% are defined as "basic".

Basic 0-24%



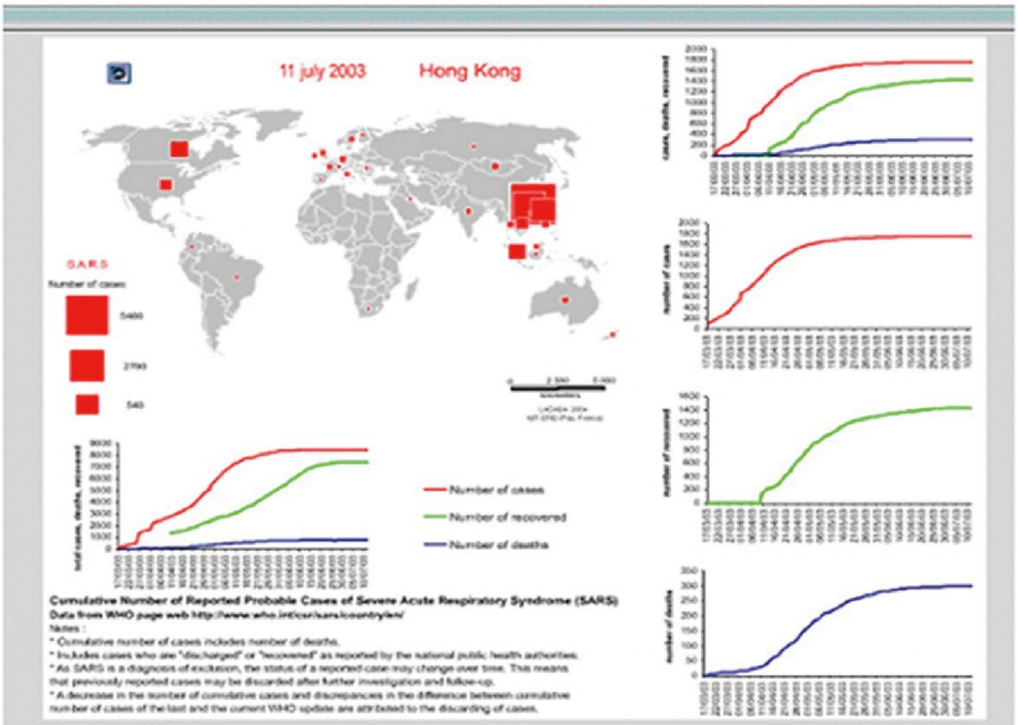
Average Score:21%



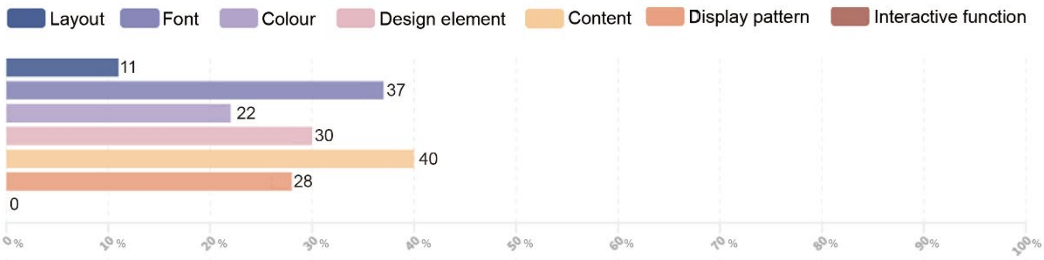
Basic design

A design defined as "basic" according to the principle of infographic application, which threshold intervals below 24% are defined as "basic".

Basic 0-24%



Average Score: 24%



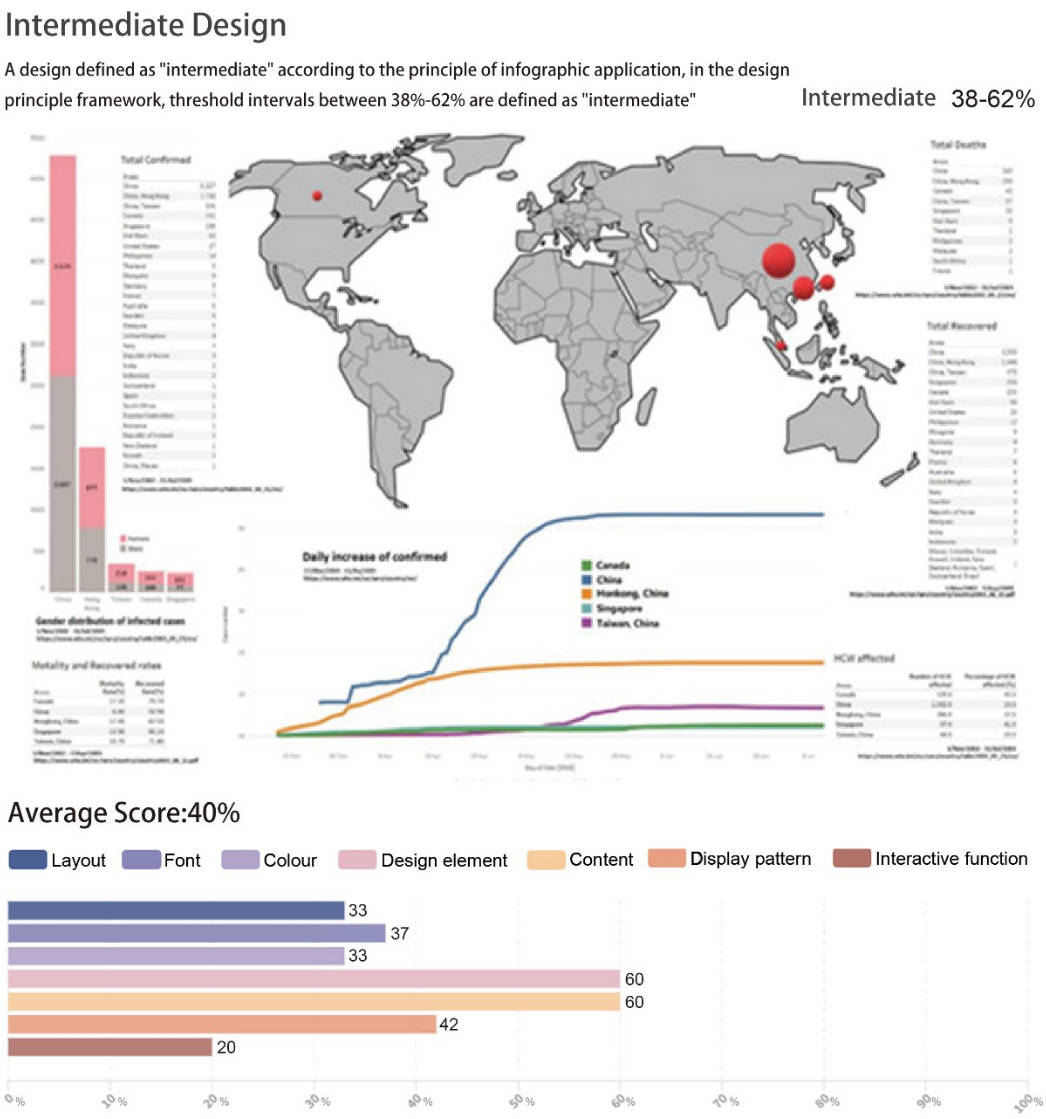


Figure 4.1 Evaluation results of visualisation examples in the SARS pandemic

In 2002, the Severe Acute Respiratory Syndrome (SARS) pandemic was initially identified in Guangdong, China, and rapidly spread to Southeast Asia and other regions worldwide. The global response to the outbreak led to its eventual containment by mid-2003 (Huang, 2004). A total of 4 visualisation cases displaying SARS-related information were collected, and their layout, font, colour, graphic elements, content, interactive function and display mode were evaluated according to the framework of design principles. According to the evaluation using the framework, most visualisation cases failed to meet the relevant principles in each category, especially the layout. Therefore, three out of four cases were classified as 'basic' visualisation cases.

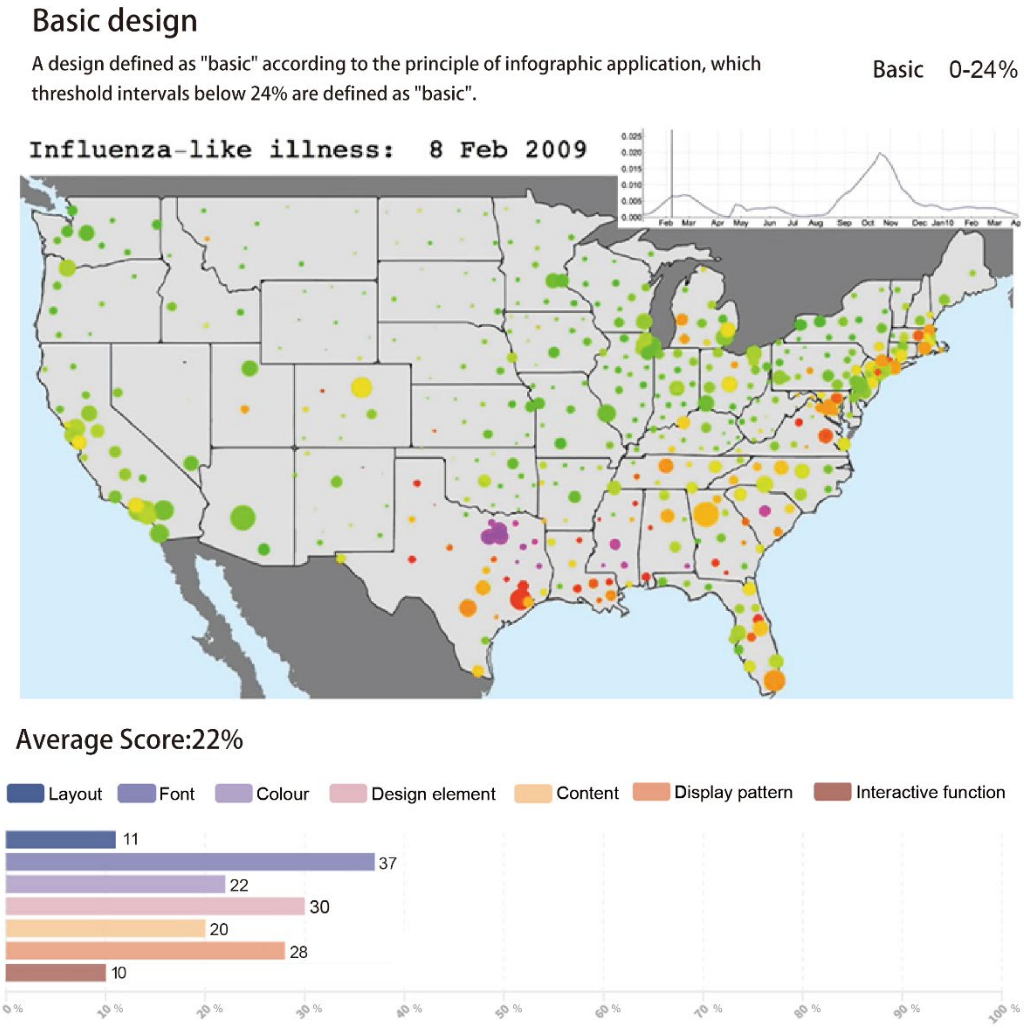
The majority of cases rated as "primary" in terms of visualisation quality employ a single data visualisation method, typically displaying data for a specific country or a particular time period using visual components such as charts and data maps. While this approach provides accurate information, it often results in incomplete visualisation content. For instance, in Figure 2, the map component serves as a crucial means of data exploration. However, the lack of interactive functions such as zooming limits the visibility of data in smaller areas, leading to missed or difficult-to-identify information. Additionally, some information presentation is unclear. In the map, the colour red indicates the severity of confirmed cases, but the accompanying table only randomly displays the number of deaths in certain countries, making it very difficult to ascertain the specific number of confirmed cases. Another limitation pertains to the colour palette, as highlighted by Hall and Hanna (2004). Excessive use of colour or poor contrast between background and text colours can reduce the legibility of textual information. In Figure 3, although data is presented through a combination of different visual components, the lack of interactivity limits the data to a single day's situation (July 11, 2003). Moreover, the text displayed in the visualisation is too small, failing to meet the font specifications outlined in the principles framework for optimal readability.

Certain visualisation cases rated as "intermediate" incorporate various components to showcase data diversity. However, the inclusion of too many data types can dilute the user's attention (Burmester et al., 2010). Figure Group 4, derived from the WHO's data analysis dashboard for SARS from November 1, 2002, to July 31, 2003, and created using Tableau Public, exemplifies a visualisation system featuring an excessive number of data types. The absence of a clear reading order and overlapping components due to insufficient spacing make the entire interface crowded and confusing.

It is worth noting that during the SARS pandemic, which marked the first global pandemic of the 21st century, visualisation tools like maps were not as widely used as they are today. As a result, user access to real-time data was complicated.

4.2.2.2. Case Study 2 –H1N1 Pandemic

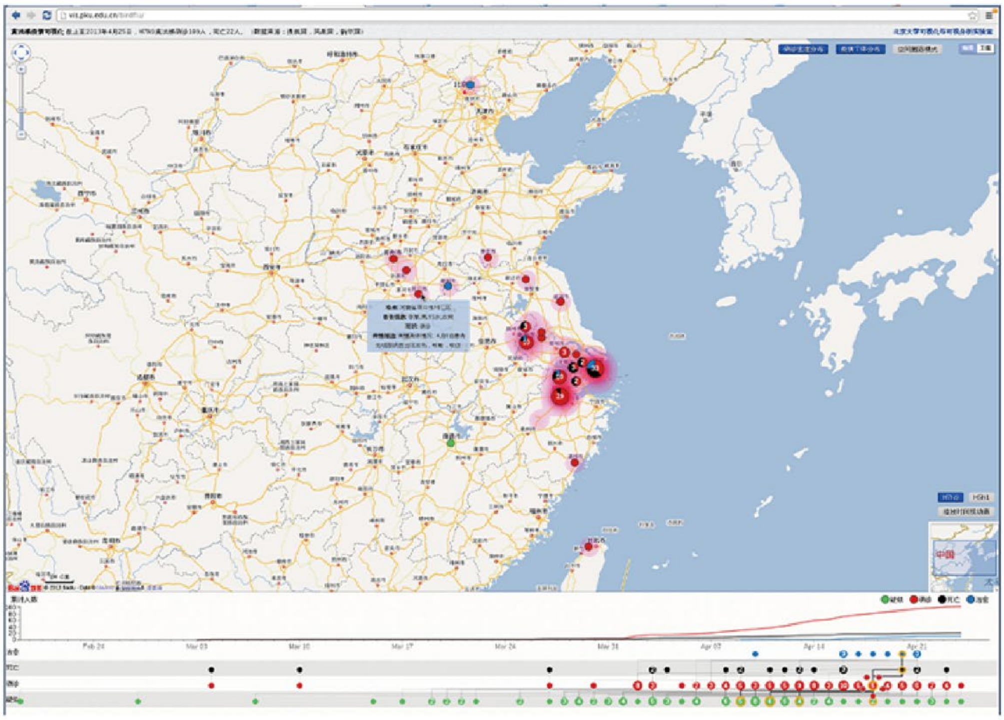
In 2009, the H1N1 influenza pandemic emerged in the United States and quickly spread to 214 countries and territories, resulting in a significant number of fatalities, with an estimated death toll of nearly 200,000 individuals (Hajjar, 2010).. This promoted the wide application of visualisation in information communication at that time. The framework of design principles was used again to assess visualisation cases in the H1N1 pandemic.



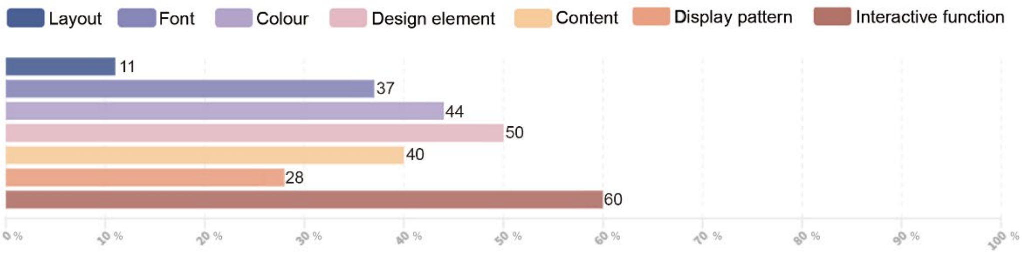
Intermediate Design

A design defined as "intermediate" according to the principle of infographic application, in the design principle framework, threshold intervals between 38%-62% are defined as "intermediate"

Intermediate 38-62%



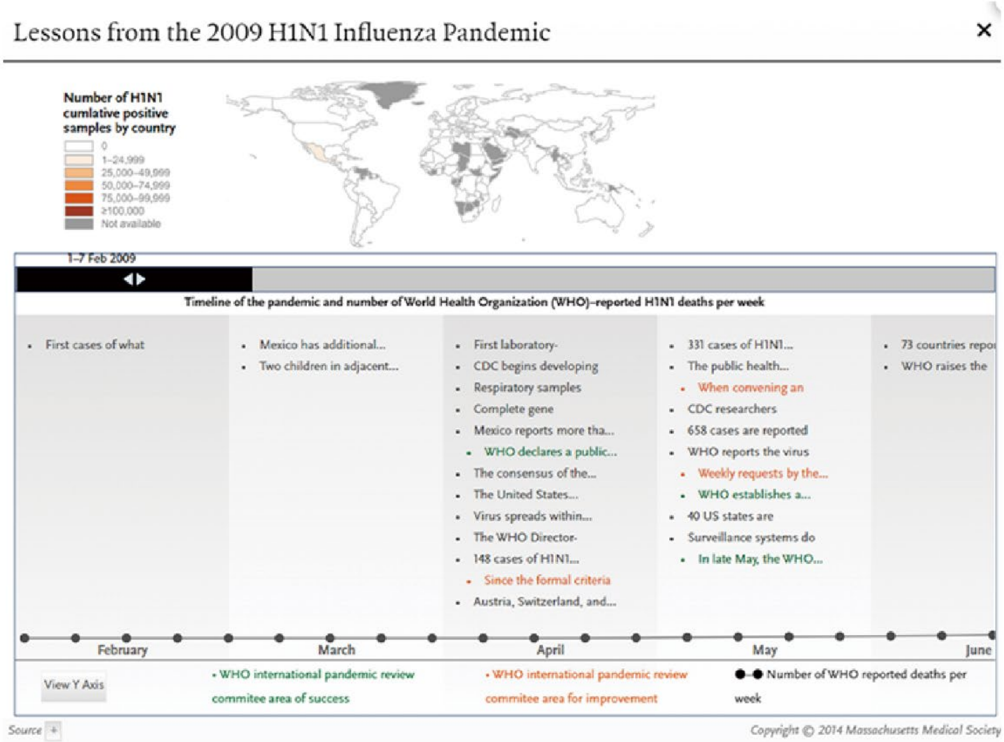
Average Score:38%



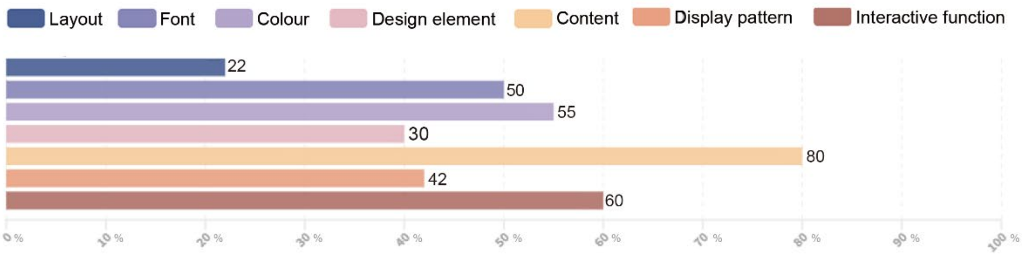
Intermediate Design

A design defined as "intermediate" according to the principle of infographic application, in the design principle framework, threshold intervals between 38%-62% are defined as "intermediate"

Intermediate 38-62%



Average Score:48%



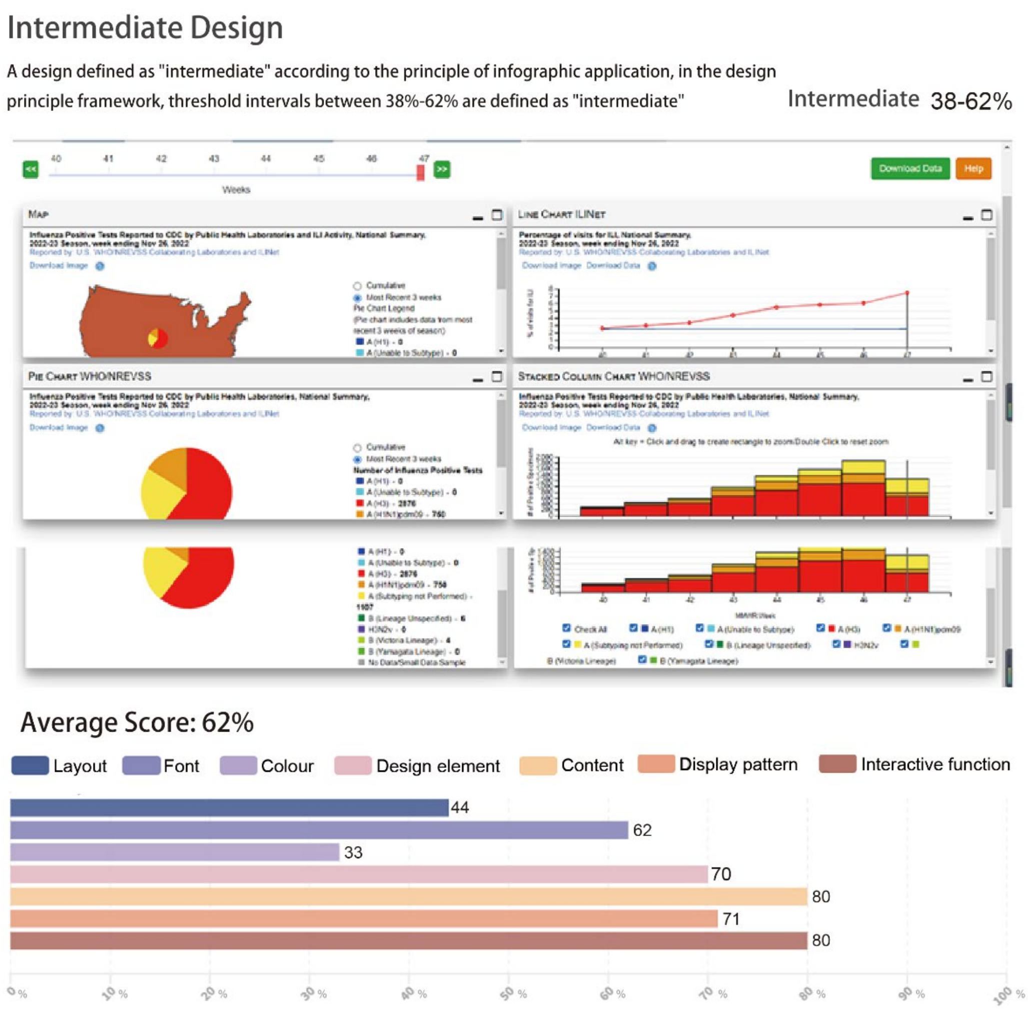


Figure 4.2 Evaluation results of visualisation examples in the H1N1 pandemic

Figure 4.2 showcases four sets of interactive information visualisation case studies applied to the H1N1 pandemic. A comparison with the SARS period reveals an increased emphasis on visual animations and interactive operations within the components to present information. For instance, Figure 1 demonstrates more interactive representations of information across different dates on the map. This interactive approach effectively enhances the visualisation's effectiveness in conveying the severity of the epidemic in different regions through colour coding. It enables readers to comprehend the information more quickly and efficiently compared to textual descriptions. However, the map's lack of metadata annotations and specific information annotations renders it incomplete. Furthermore, the use of more than seven different colours to indicate epidemic severity, with multiple colours representing different situations within a single region, can confuse readers and make it challenging to remember the meaning of each colour. Additionally, relying solely on the map and lacking interactive connections with other components in the practical visualisation layout hinders the improvement of information comprehension (Gibson, 2009; Ware, 2019). Figure 2 addresses this issue by using only four colours to represent the information and providing annotations and explanations. However, due to the small size of certain regions, some colour labels cover the original map information due to their large size.

Based on the evaluation results of the four cases, the use of map components to embody interactive visualisation was a common technique at that time. Maps serve as effective geographical visual tools that enable readers to access practical epidemic information relevant to their locality and gain an overall understanding. Different colours are employed to indicate the distribution and severity of the virus, and hovering the mouse over an area displays the number of cases in that region. However, in certain cases, viewers need to scroll the page with their mouse to access detailed information. In Figure 4, the entire system is divided into six small views, each presenting a visualisation set to depict epidemic data. Nevertheless, viewers still need to scroll up and down to fully comprehend the visualisation content. In other words, while interactivity enriches the exploration of the visualisation, it also increases the frequency of user scrolling, which can impede the reading process (Few, 2013).

In general, the inclusion of more interactive operations in the components of these case studies enhances the richness and exploratory nature of visualisations. However, these case studies also reveal limitations in information comprehension arising from the details of the visualisation elements and the structural frameworks employed. This suggests that there is scope for improvement in these aspects to optimise the effectiveness of interactive information visualisation. Moreover, it is important to note that the application of interactive operations discussed in these case studies is specific to data visualisation. It does not extend to other aspects of information presentation or communication.

4.2.2.3. Case Study 3 – COVID-19 Pandemic

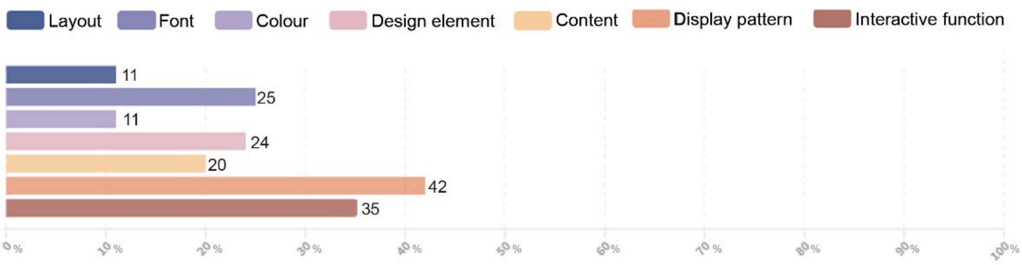
On December 1, 2019, the initial report of a novel coronavirus infection case was documented in Wuhan, China. This marked the onset of the COVID-19 pandemic (Wu et al.,2020). Two months later, the World Health Organisation declared an international health emergency outbreak and officially named the virus COVID-19 on February 11, 2020. Since the unprecedented spread speed before the worsening of the pandemic, many countries and institutions have launched a series of visual charts and systems to inform the public of the pandemic situation. Notably, interactive information visualisation systems are employed for information exchange instead of static instrument charts.

Basic design

A design defined as "basic" according to the principle of infographic application, which threshold intervals below 24% are defined as "basic".

Basic 0-24%

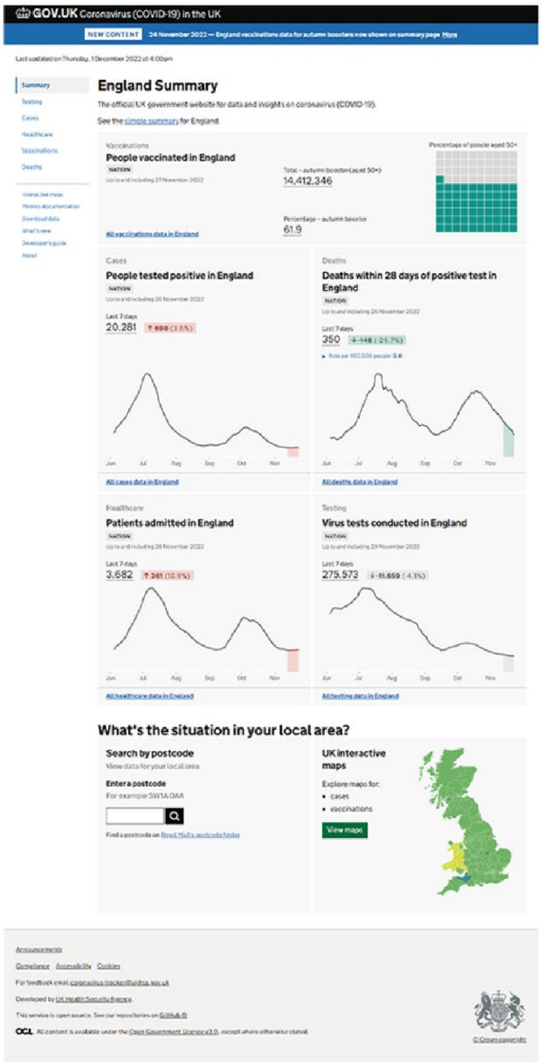
Average Score:24%



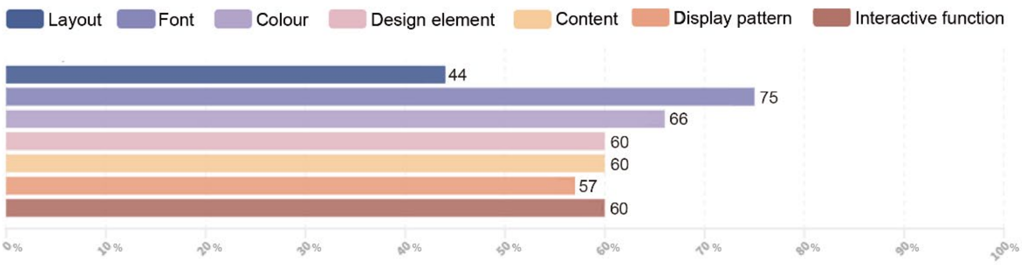
Intermediate Design

A design defined as "intermediate" according to the principle of infographic application, in the design principle framework, threshold intervals between 38%-62% are defined as "intermediate"

Intermediate 38-62%



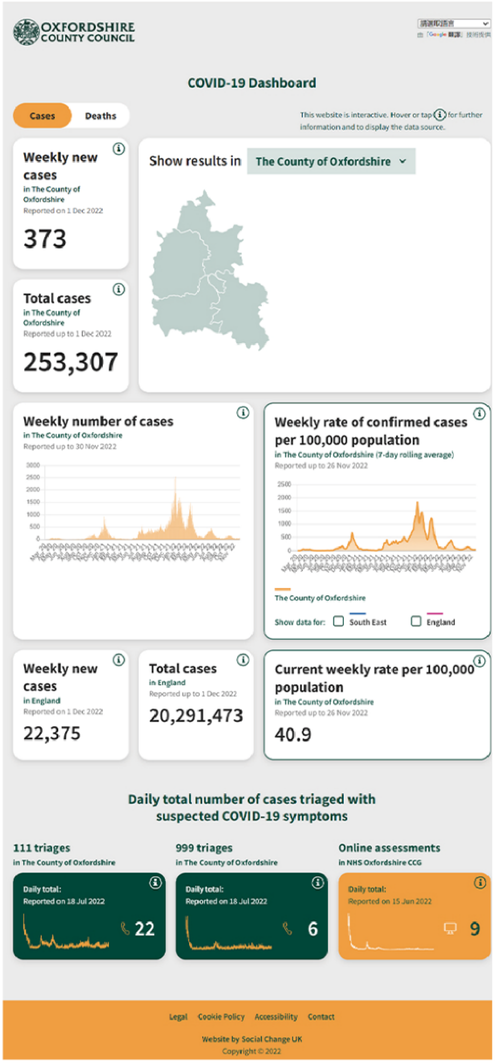
Average Score: 60%



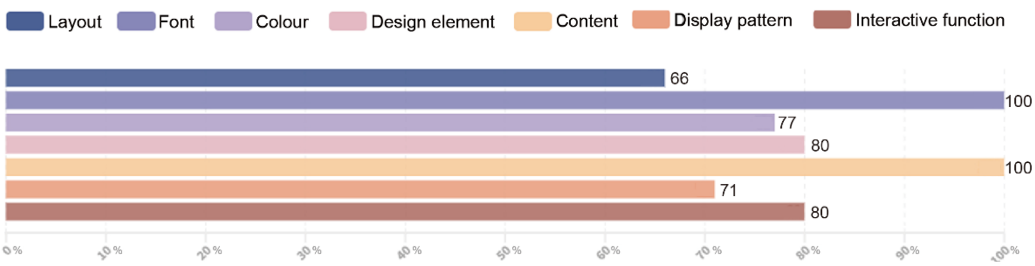
Advanced Design

A design defined as "advanced" according to the principle of infographic application, in the design principle framework, threshold intervals over 76% are defined as "advanced"

Advanced 76-100%



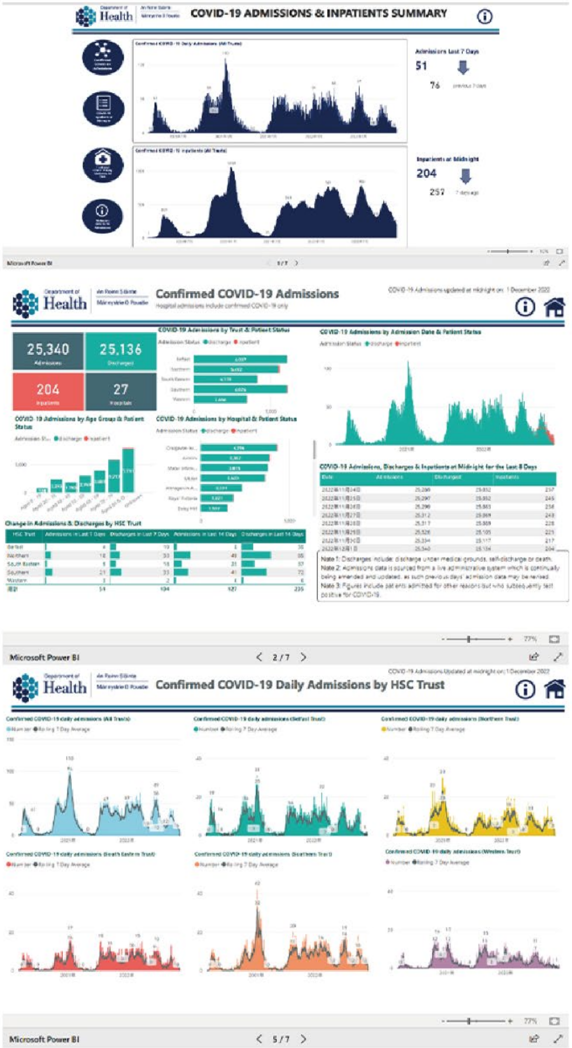
Average Score:82%



Advanced Design

A design defined as "advanced" according to the principle of infographic application, in the design principle framework, threshold intervals over 76% are defined as "advanced"

Advanced 76-100%



Average Score:82%

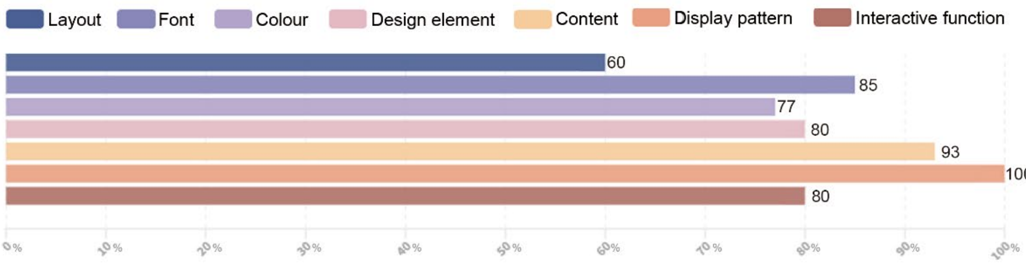


Figure 4.3 Evaluation results of visualisation examples in the COVID pandemic

Figure 4.3 presents an evaluation of dashboard samples used during the COVID-19 pandemic based on the design principles framework. Compared to the previously discussed cases, the COVID-19 era exhibits greater diversity in its cases, featuring a plethora of visual components and various structural combinations. Some arrangements of components enrich the layout, as exemplified by Figure 2, showcasing a visualisation dashboard instituted by the UK government during COVID-19, which includes three distinct visual components on the homepage to present essential information. However, it can be observed that amidst the multitude of components derived from different visualisations, bolded titles attempt to assist readers in delineating and guiding their relationships, as no explicit framework and hierarchy were designed to segregate this information. Consequently, readers are required to autonomously filter and sift through the information during the reading process. If insufficient space is provided between different components, it can easily result in reader confusion during interactions, thereby augmenting the cognitive burden on readers. In contrast, Figure 3 significantly improves upon this aspect by artificially classifying different types of data information and visualisations, allowing readers to quickly discern data categories. Furthermore, critical information and figures are bolded and enlarged to facilitate users' immediate comprehension of the points they are interested in. Despite these improvements, certain aspects of information design still impose constraints and hinder comprehension within the visualisations, such as excessive unit labels on the X-axis of charts and incomplete map representations. Additionally, a noteworthy observation is the occurrence of visual elements and components being used to display information unrelated to the pandemic, such as organisational details and advertisements. As Nguyen et al. (2020) have pointed out, the excessive application of visual elements can also affect readers' reading strategies and experiences to some extent.

Another area worthy of discussion is the interface layout in interactive information visualisation systems. As mentioned earlier, the prevalence of more visualisation components during the COVID-19 period has enriched the construction and layout of interfaces, allowing for entirely different interface design combinations for the same content in the visualisation systems. However, it is essential to note that completely different interface layouts can similarly lead to user confusion regarding the presentation of established information during usage (Stone et al., 2005). Figure 4 displays three completely different interfaces found in the dashboard issued by "Operation of Health" during the COVID-19 period. It is undeniable that the designers avoid information omissions caused by users scrolling with the mouse, facilitating users' view on a single screen, which aligns with the theoretical requirements for structural design within the principles framework. Nevertheless, the disparate interface layouts within the same system also necessitate users to spend more time familiarising themselves with the new interface, consequently posing challenges to users' comprehension during the operation process. Notably, due to the fact that interactive information visualisation systems are issued by different institutions and countries, and their practical application for global pandemic diseases is relatively limited, there currently lacks a template for structural design in system interfaces under such circumstances. As Few (2013) points out, a dashboard's interface layout should not be uniformly consistent throughout. However, for similar interface layouts within the same system, the user's familiarity with it and its impact on information comprehension should be taken into consideration.

4.2.3 Discussion

From the above cases, it can be seen that with the continuous progress and application of digital design in today's society, compared with the SARS period, in the COVID-19 period, more excellent design examples that conform to the design principles framework and are applied to interactive information visualisation are constantly increasing. With the advancement of technology, more design principles are presented in the form of interactive visualisation through information design. In addition, compared with static visualisation, interactive visualisation provides a more effective way of information access (Dix and Ellis, 1998), that is, through exploration and real-time updates to improve user efficiency of use and information reception, and more fluent understanding of more information. For example, users can use the mouse for interactive operations, explore and switch data information in different periods by clicking, and explore and compare the detailed differences of different groups of data. These outstanding features reflect the active role of interactive functions in visual presentation and the increasing consistency between interactive information visualisation technology and design principles. However, a good design output does not only mean having sufficient interactive operations and rich visual presentation but needs to focus on user understanding and improve the readability of information through design. Therefore, it is crucial for designers to strike a balance between interactivity and information comprehension in interactive information visualisation systems to achieve optimal user experience.

Furthermore, the rapid development of technology and the increased availability of data have led to the flourishing of interactive information visualisation systems, especially during global health emergencies. However, it is important to recognise that the success of these systems lies not only in their technical capabilities but also in their adherence to established design principles and their ability to address the specific information needs of users during crises. As the COVID-19 pandemic has demonstrated, interactive information visualisation has become an indispensable tool for communicating critical information to the public, and its evolution over time reflects the advancements in both design and technology.

Judging from the preliminary investigation, the cases at this stage reflect two points that are worth improving and discussing in the principles assessment. Firstly, the impact of interface layout on user understanding is a critical aspect to consider. As interactive information visualisation systems have transitioned from single static views to more complex layouts, such as interactive maps and multiple visual components, the layout design needs to align with users' perspectives. In some cases, the lack of a coherent and consistent layout can lead to confusion and increased cognitive load for users. Elements such as switching, sliding pages or interactive pop-up windows during reading can have an adverse impact on a reader's comprehension, potentially diluting its coherence (Salmeron et al. 2005). Therefore, it is of critical importance that information placement and user interactions be given careful thought, in addition to considering their influence on overall comprehension of visualisations. Balance should also be maintained between presentation and interactivity when designing visual components. Concerns exist around visual elements which interfere with information reading and interactions on interactive map components, specifically visual elements which interfere with reading of information and interactions on these features. Issues often arise when visual elements don't align with information in their components - either through size or format specifications - leading to problems for users in clicking accurately or understanding displayed information. To ensure effective interactions and information presentation, designers should take great care in considering alignment of visuals to both data as well as anticipated user interactions when designing visual elements.

Tackling these two issues during the design phase of interactive information visualisation systems will result in user-friendly and understandable interfaces that enhance effectiveness and usefulness for global health emergencies and other crucial circumstances. Furthermore, as interactive information visualisation advances further, designers must engage in user-centric design practices, conduct user testing, and gather feedback in order to continuously tailor systems to the unique requirements and expectations of emergency situation users. Doing this makes these systems even more powerful tools for information communication and decision-making during global health crises.

Overall, studying interactive information visualisation in global health emergencies provides essential insight into design principles and their effects on information comprehension. By continually refining and evaluating these systems, designers can better cater to the diverse needs of users and provide more effective and user-friendly solutions in future health emergencies. Moreover, the lessons learned from the COVID-19 pandemic underscore the importance of data-driven and user-centric design approaches in creating successful interactive information visualisation systems for public health communication.

In the next stage, interactive information visualisation systems (panels or dashboards) used for the COVID-19 pandemic were further tested and studied. First, a questionnaire survey was carried out to evaluate the effectiveness of the design principles at the current stage, helping to understand the users' information needs and hence determining the impact of the layout on information presentation. Then, participants from different countries were recruited for performance testing to understand the public's needs better and check existing cases' limitations.

4.3 Questionnaire: Public Demand for Information During Pandemic and Feedback on Application of Visualisation System

In the second stage of the project, an online questionnaire survey was carried out to investigate the specific information needs of users in global health emergencies and the application of interactive information visualisation. The survey results will provide a reference for the application of interactive information visualisation in global health emergencies. Overall, the data collected from the questionnaire, together with those collected from the case studies, will lay a basis for interactive design in health emergencies.

4.3.1 Procedure

The questionnaires were distributed to 346 general participants on social media by retweeting and sharing. Wuhan, China is the first city where COVID-19 broke out. The Chinese government imposed a home isolation blockade on Wuhan in February 2019, which was also the first Chinese city to be blocked due to the pandemic. In this case, an in-depth understanding of the information barriers brought to people by the pandemic can help us to better understand users' information needs and preferences for information presentation methods, laying a good foundation for research.

As a researcher residing in Wuhan city, located within Hubei province during the outbreak, an opportunity arose to observe and directly experience the initial phases of the pandemic. This provided valuable insights into the information needs of individuals and their behavioural patterns when seeking information under the constraints imposed by strict quarantine measures during the early stages of the COVID-19 pandemic. In order to better understand the urgent information needs of the public subjected to the quarantine policy, most of the participants in the experiment were from Wuhan, Hubei Province, and had experienced a severe outbreak of a pandemic. Figure 4.4 shows the provinces and cities that participated in the questionnaire survey.

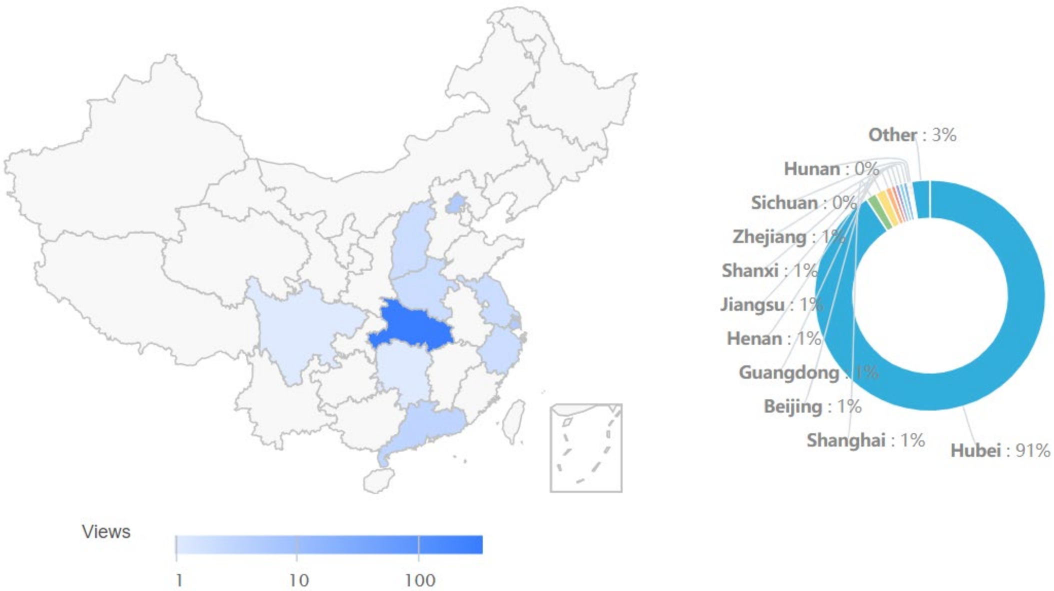


Figure 4.4 The provinces and municipalities participants mainly came from (the proportion of participants from Hubei provinces reached 91%).

The questionnaires were posted online due to the lockdown in China (the first country to impose the lockdown in the world), Of these participants, 65.3% (226) were female and 34.7% (120) were male. 99.1% of the participants were concentrated between the ages of 18-50 (343 out of

346 participants), among whom 47.98% of participants (166 out of 346 participants) were aged 25-30.

According to Kelley et al. (1999), the elderly population requires short-term training, including computer operation instructions, to enhance their computer skills. This is especially crucial for elderly individuals who have limited or no prior experience with computers, necessitating repeated training sessions. Given that the questionnaire filling and participant recruitment processes were conducted online, proficiency in basic computer skills was essential. However, due to strict government control measures during the pandemic, offline computer training proved to be challenging. Consequently, the target group for this study focused on individuals under the age of 50, as they were more likely to possess proficient computer skills and have access to interactive online information. Among the participants, 81% reported having a bachelor's degree or higher, while only 5% were employed in occupations related to data analysis or information design.

Participants were asked to answer questions about the types of information they received during the pandemic and their preference for the best way to receive information. The questionnaire was composed of two parts. The first part was about the needs of users for information types in global health emergencies. The second part focused on user preferences for different types of information exchange and the role of interactive information visualisation in such a context. The reason for this two-part structure was to lay a basis for examining the effectiveness of the design principles framework. The first part could help understand whether the content presented by the existing interactive information visualisation met the users' requirements during the pandemic. The second part was conducive to help understand user preferences for information communication during the pandemic, as well as the application of early interactive information visualisation and corresponding user feedback.

The collection of the infographic comes from the extraordinary period when the government implemented quarantine measures in Wuhan, China. Therefore, the subject matter of the infographic on COVID-19 could be of a sensitive nature to most (if not all) participants. The virus has a high infection rate and fatality rate, coupled with the serious measures of the government, which caused people to panic during the pandemic stage (Alimolaie, 2020). Therefore, participants were informed of these issues before the recruitment and during the survey, and they had the right to withdraw from the study without bearing any consequences. Ethical approval was granted by the Faculty of Arts, Humanities and Cultures Research Ethics

Committee (FREC), with the reference number of LTLCS-116. The data collected from the questionnaires was only used to understand the preference of participants for information exchange methods, the types of information they were most concerned about, and their suggestions and opinions on the visualisation cases of current interactive information.

4.3.2 Results

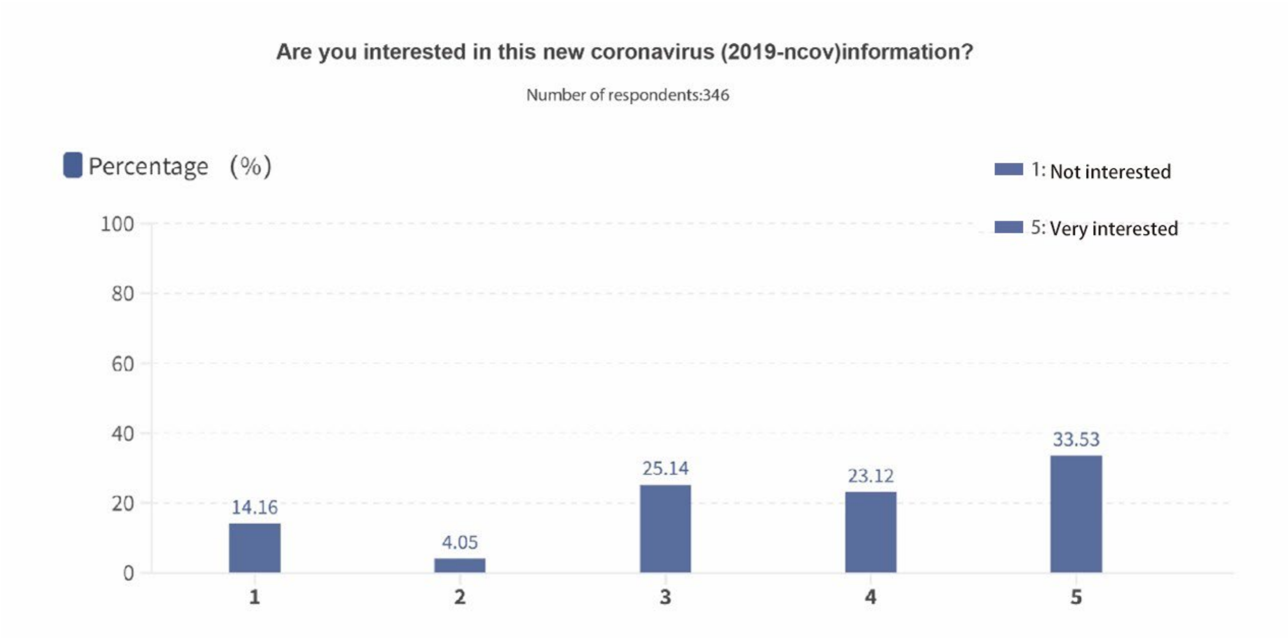
The online questionnaire survey was carried out for the main purpose of gaining essential feedback and evaluation of the current application of information visualisation in global health emergencies. It was composed of three major parts including personal information, pandemic data, and visualisation design (including information design and interaction design).

4.3.2.1. Types of Information and Ways to Acquire Information

The types of information determine whether the users are concerned about the COVID-19 during the current global health emergency. Moreover, the ways to acquire information can provide a basis for the information presentation of future research. These two can help quickly confirm the users' attention to information and the advantages of interactive infographics in information communication during global health emergencies.

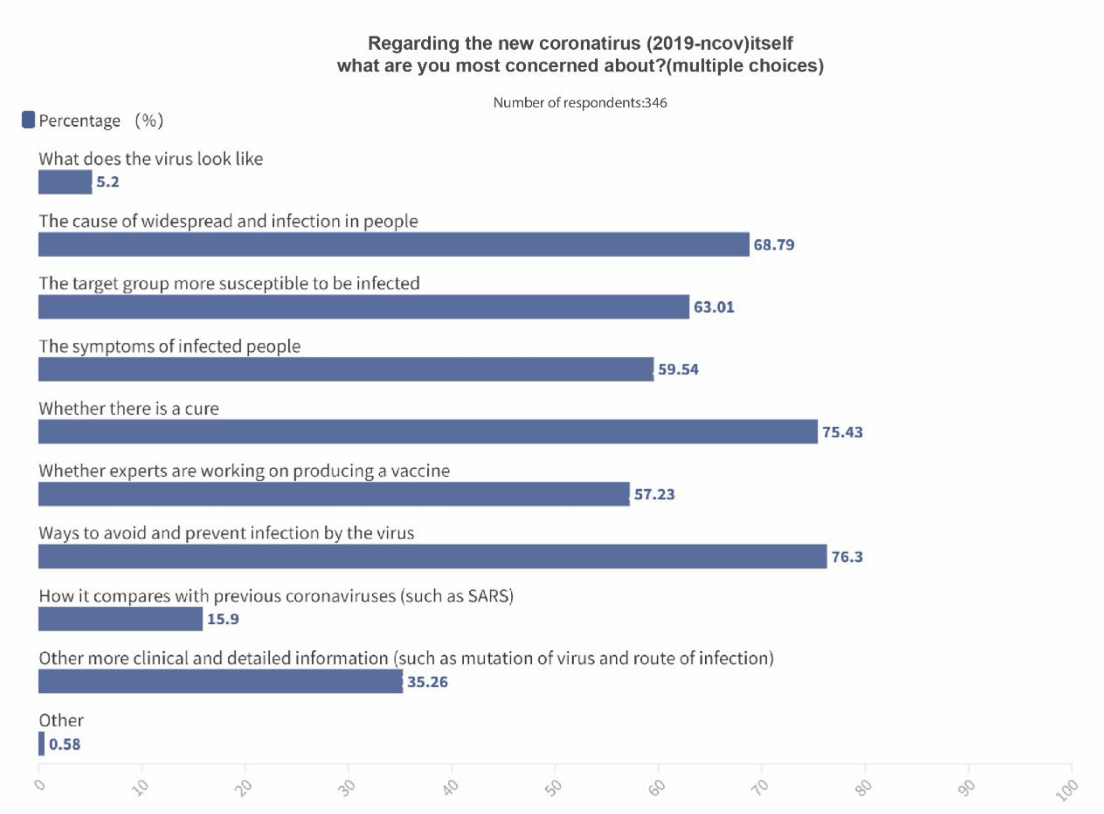
The primary focus of the online questionnaire is whether people want to explore details and information related to COVID-19. This is to learn the type of information that people pay attention to during the global health emergency of COVID-19 and their attitude toward the emergency. To this end, relevant data collected are summarised in Figure 4.5.

Figure 4.5 The number of participants' interest/attitude toward the COVID-19.



According to the Figure 4.5, the answers are classified by five scales, from 1 (not interested) to 5 (very interested). About 14.16% of participants (49 out of 146 participants) chose 1, while 33.53% of participants (116 out of 346 participants) chose 5. The proportion of participants choosing 2 to 4 is 4.05% (14 out of 346 participants), 25.14% (87 out of 346 participants) and 23.12% (80 out of 346 participants), respectively. The average age of the participants not interested in detail about COVID-19 is 20.2 years old, lower than that of the participants (average age: 29.8 years old) having great interest. This situation can be partially attributed to the government's audience strategy regarding published information. During the early days of the pandemic, official news bulletins served as a primary source of data and details, predominantly disseminated through television news programs by China Central Radio and Television. The nature of this information was official and serious, which indirectly attracted an older audience demographic. In contrast, younger individuals demonstrate a greater inclination to seek information through social media platforms and the Internet.

In order to understand the types of information required by people during the COVID-19 pandemic, as well as their attitudes toward this global health emergency, the online questionnaire was designed to focus on 'whether you are interested in viruses' and users were surveyed in two aspects. Relevant data collected are summarised in Figure 4.6.



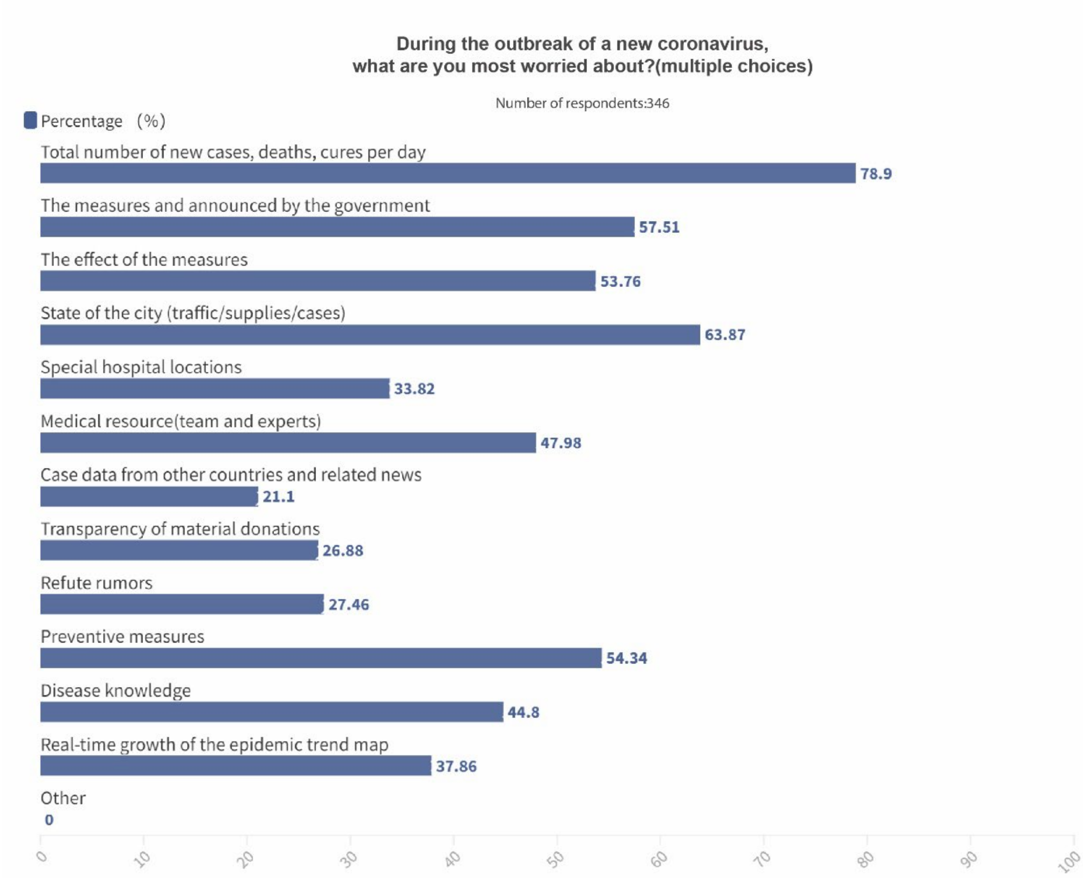


Figure 4.6 Data of 'Different types of information'

According to the results of data analysis, participants paid more attention to issues such as types of transmission and infection, symptoms, treatment and preventive measures. Specifically, 76.3% and 75.43% of participants chose 'avoid and prevent viral infections' and 'whether it can be cured', respectively. In addition, 68.79% and 63.01% of participants chose 'causes of the widespread and infection' and 'target population more likely to be infected', respectively. In contrast, participants that would like to acquire scientific research information (such as 'symptoms of infection by the virus' and 'other more clinical and detailed information') accounted for less than 40%. Regarding concerns, more than half of participants chose 'daily cases ', 'government measures', 'impacts and city conditions (transportation/ materials)'. In particular, the majority of participants (78.9%) expressed concern about "the number of new cases/deaths/cured cases per day", and the rest participants (21.1%) chose 'case data and related news from other countries'.

In addition, participants in the cities with severe pandemic situations (such as Wuhan) demonstrated a higher demand for such information. Among the various topics explored, certain themes such as "avoiding and preventing virus infection" and "daily statistics on new cases, deaths, and recoveries" hold significant relevance to the public's assessment of their immediate surroundings and the adoption of precautionary measures to mitigate the risk of infection. These particular areas of interest necessitate users' close observation and comprehension of the presented data to draw informed conclusions. Moreover, the prominence of these high-priority topics underscores the criticality of pertinent data in shaping public life and even individual well-being. Specifically, 87% of participants in Wuhan focused on real-time data, such as' cases per day', 'supplies', 'transportation and medical treatment'. The detailed percentages of the options are shown in the Table 4.1 below:

Information needs of participants in the outbreak

Options	Reply (Percentage)
The total number of new cases, deaths and cures per day	79
City conditions (transportation/ materials/ cases)	64
Relevant measures announced by the government (including distribution of materials and other benefits)	58
Precaution	54
Effect of measures	54
Medical resources (teams and experts)	48
Disease knowledge	45
Designated hospital	34
Real-time growth of trend graphs	38
Refute rumours	27
Transparency of material donations	27
Case data and related news from other countries	21
other	0
Number of respondents: 346	

Table 5.1 The percentage of each option reflecting the participants' information demand during a global health emergency.

4.3.2.2. Different Ways of Accessing Information

The next step in the questionnaire was to find out how users accessed the information. In order to verify the contribution of visualisation to information exchange, participants were surveyed from the perspective of channels and measures. The data are summarised in Figure 4.5.

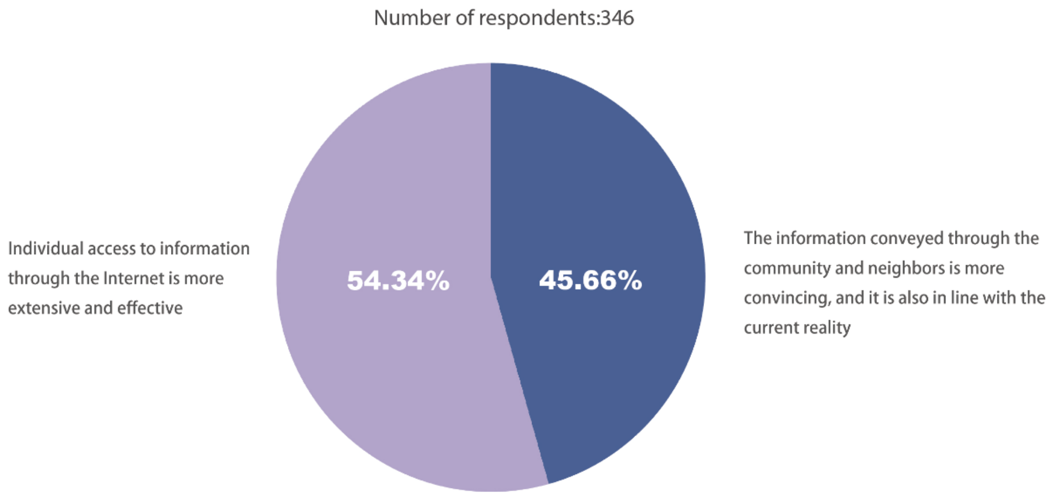


Figure 4.7 The way to spread information during a lockdown period.

As illustrated in Figure 4.7, the pie chart showcases participants' preferences regarding the most effective means of information dissemination during the lockdown period. A majority of respondents (54.34%) expressed a preference for the Internet, citing its convenience and lower risk of infection compared to face-to-face communication. Conversely, 45.66% of participants acknowledged the importance of government and community actions in ensuring effective information dissemination, while recognising the limitations imposed by the mode of dissemination during isolation. Notable was that participants who preferred Internet platforms tended to have an average age of 25.4 years - lower than that of respondents who favoured government and community channels (34.3). When interviewed about why their preferences varied between platforms, older respondents noted "lack of familiarity with visualisation techniques" and concerns over accuracy as major influences in their choices.

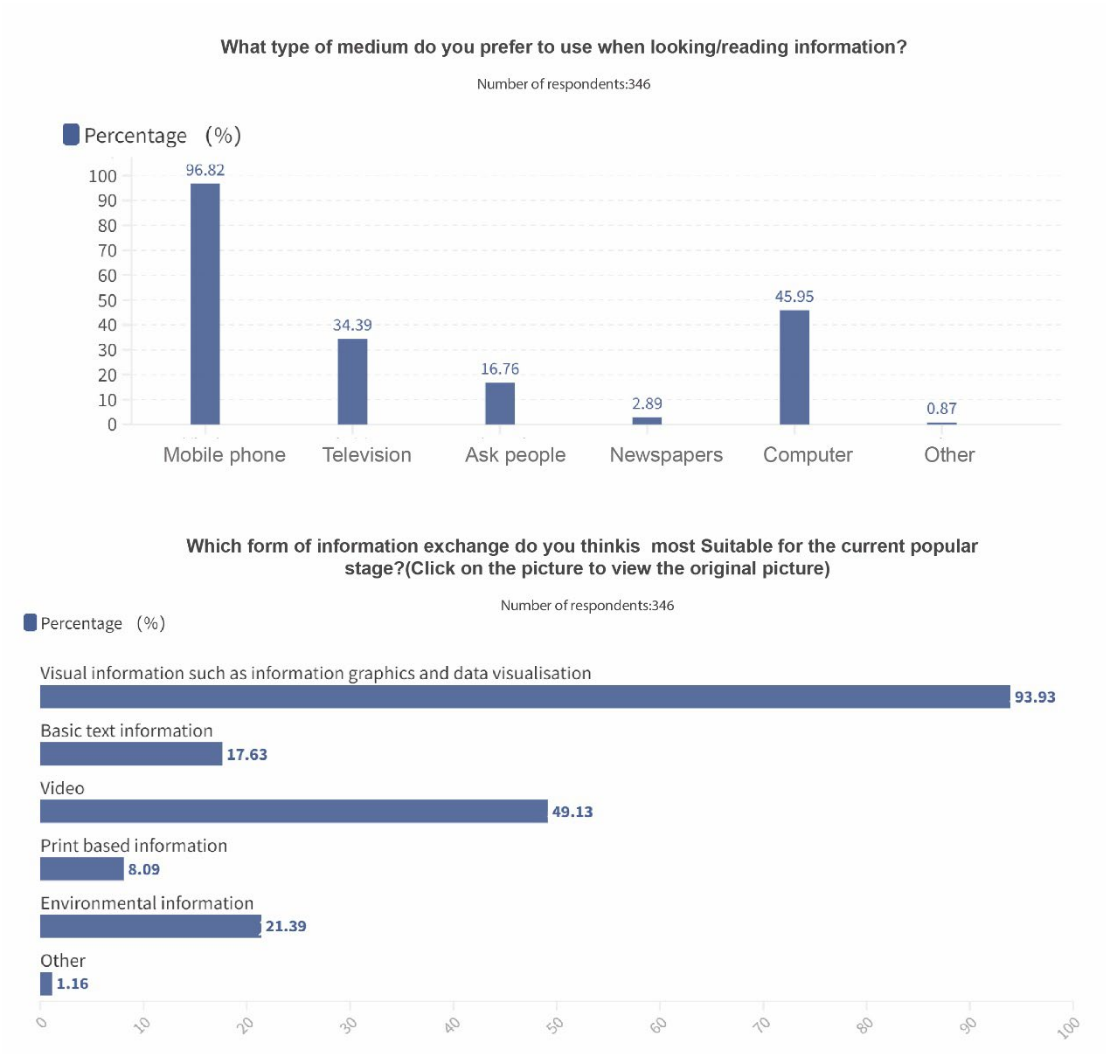


Figure 4.8 Data of 'different ways of accessing information'

Figure 4.8 provides insight into user's preferences when accessing information independently. A large majority (93.93%) expressed their preference for visual information such as infographics and data visualisation, due to its intuitive presentation of trends that allows more accurate conclusions to be reached by participants. 49.13% also considered videos an effective medium for understanding information in current circumstances - thanks to their combination of visuals and explanations that allow viewers to gain greater insights into pandemic development trends.

Considerations should be given to video content's longer production cycle and potential delays in updating or transmitting it, which might make information disseminated by hospitals less credible and preferred sources such as environmental posters such as hospital posters. By contrast, text information (17.63%) and printed materials (8.09%) like magazines, leaflets or newspapers may have lower reading efficiency or limited accessibility during special quarantine periods; which might make environmental sources such as these more acceptable to participants.

Concerning media consumption, most participants (96.82%), particularly students, preferred mobile phones as the source for gathering information; followed by computers (44.95% of participants) and television (34.39%). Furthermore, approximately 16.76% of participants relied on conversations with others to obtain information, while a smaller proportion (3.17%) of participants, with an average age of 39 years, sought information from traditional paper-based sources. These findings underscore the popularity of internet-based information retrieval during the pandemic.

4.3.2.3. Limitations and Advantages of Interactive Information Visualisation

This section provides insights into the general trends in interactive information visualisation during global health emergencies. To facilitate participants' understanding of the research question "What do you think about interactive data information visualisation?", an example (Figure 4.9) was presented in the questionnaire. This example was taken from the "China Novel Coronavirus Data Visualisation" dashboard that was released during the outbreak in Wuhan.

The selection of this dashboard was based on two reasons: Firstly, it demonstrated interactive visualisation of pandemic data in China, aligning with the basic requirements of this research for an "interactive information visualisation system". Secondly, during the period when Wuhan was under isolation, this dashboard emerged as an early representation of how Chinese citizens perceived and interpreted pandemic data, thereby providing users with a significant impression of the usage of an "Interactive Information Visualisation Dashboard".

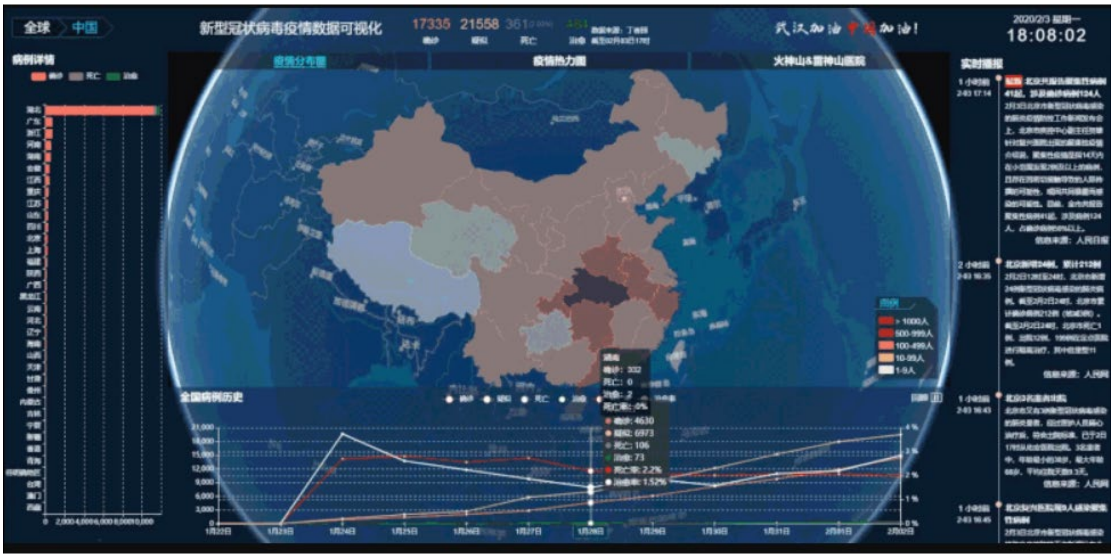


Figure 4.9 An example of interactive information visualisation

Figure 4.9 shows the interactive infographic of the Chinese pandemic situation (COVID-19). By clicking and dragging, users can view the daily number of Chinese cases from January to February (such as daily news/deaths/cured cases). Similarly, the map will change when the user's swipe, indicating the historical changes in the severity of each city through the depth of the colour. The histogram on the left shows the specific confirmed cases in each city, and the text area on the right updates the latest information and news in real-time. Participants were asked to experience and evaluate this interactive infographic from 1 "not helpful" to 5 "very helpful".

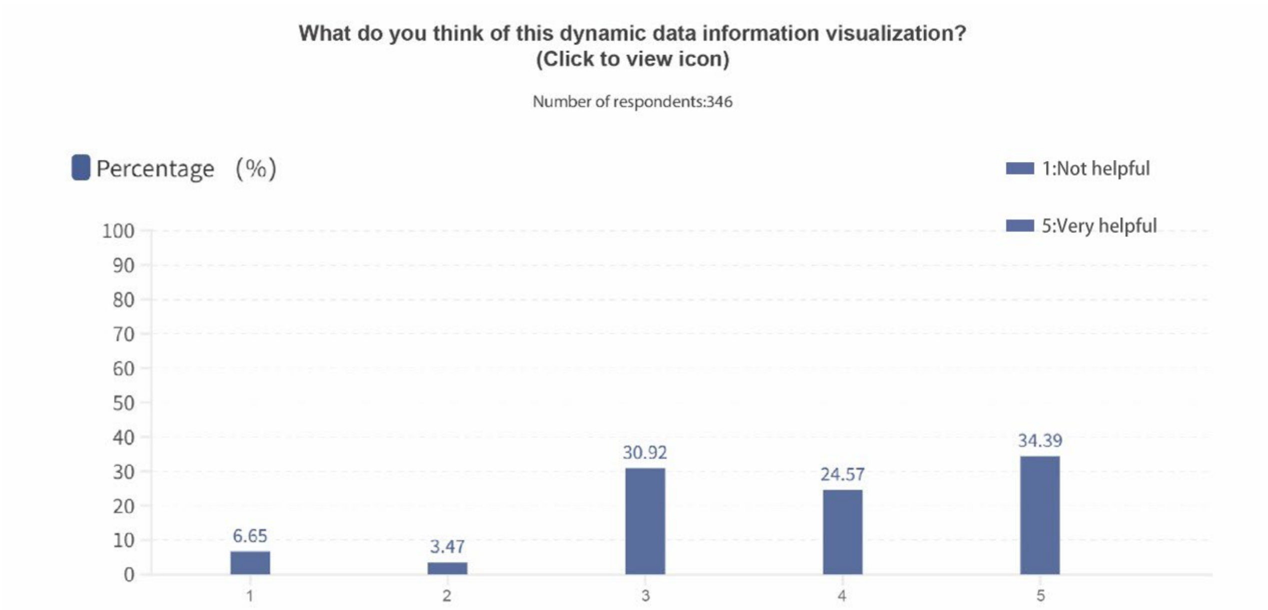


Figure 4.10 Feedback of participants on the example of interactive information visualisation

Figure 4.10 illustrates the distribution of participant responses regarding their perception of the interactive infographic. Notably, 34.39% of participants rated it with a score of 5, indicating a high level of acceptance. Conversely, only 6.65% of participants gave it a score of 1, suggesting a limited understanding of this type of interactive infographic. It is worth mentioning that the mean age of participants who rated it as 1 was higher than those who rated it as 5 (mean age of 42.1 years for option 1 and 26.2 years for option 5).

This finding may be attributed to the fact that older participants tend to be more accustomed to information dissemination through traditional communication and paper media, as evidenced by their responses in the previous questionnaire. To further examine user perspectives of interactive infographics, participants who rated it between three and five were invited to provide more in-depth responses for question "What do you consider is the difference between interactive and static information visualisation?".

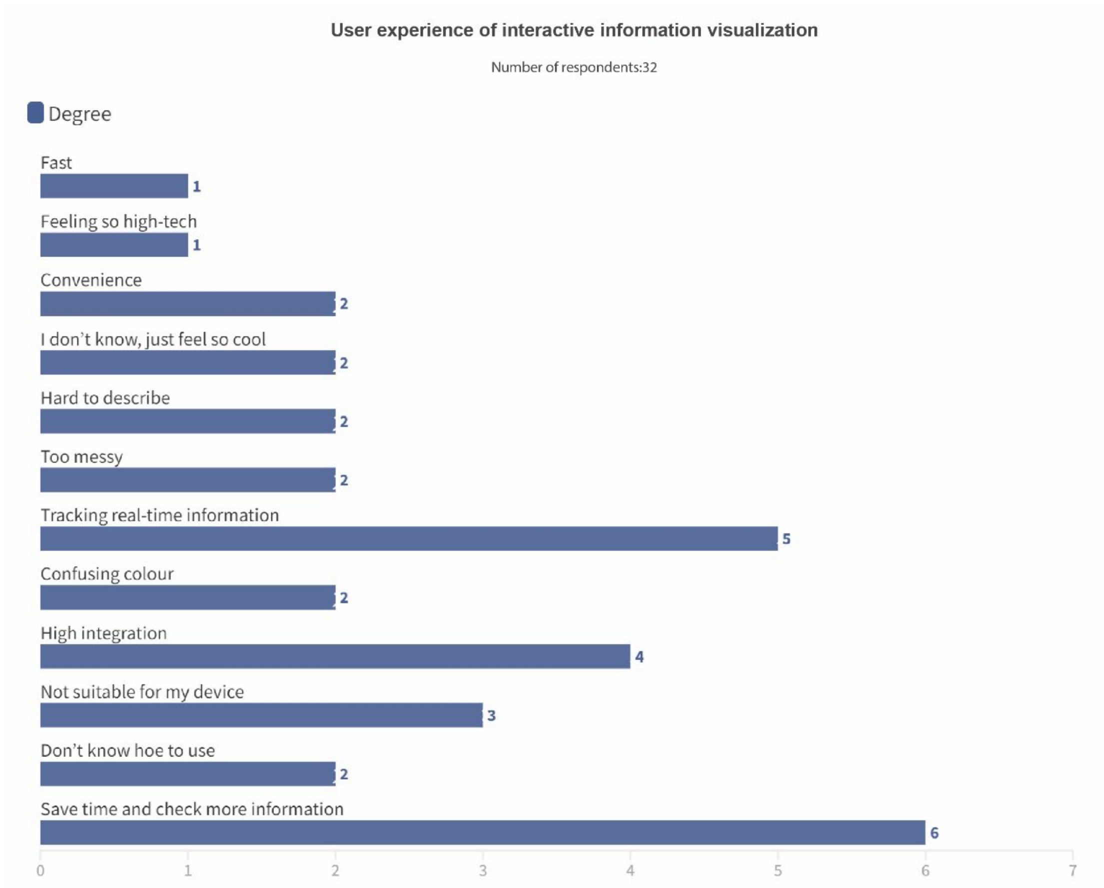


Figure 4.11 User experience of interactive information visualisation

A total of 32 participants provided valuable feedback regarding the question mentioned earlier. The results are summarised in Figure 4.11. Among the respondents, 19% (6 out of 32) believed that interactive information visualisation offers a more comprehensive presentation of information compared to static visualisation. They emphasised that the variable nature of the data in interactive systems reduces the need for time-consuming searches on search engines. Another 16% (5 out of 32) appreciated the real-time updates provided by interactive information graphics, enabling them to track the development trends of the pandemic over time. 13% (4 out of 32) participants also noted the increased information integration achieved through interactive information graphics, as well as real-time updates in guaranteeing completeness in information systems/informational products/informational processes.

Regarding limitations, 3 out of 32 participants highlighted difficulties associated with viewing and engaging with interactive information visualisation on multiple devices. They found it much simpler and intuitive to access information via computer rather than mobile phone. 1.3% (4 out of 32) participants expressed dismay about the dominance of blue hues in visual representations, leading them to experience visual confusion and hinder understanding. Furthermore, 6.2% (2 out of 32) admitted their unfamiliarity with interactive information visualisation platforms as this was their first exposure and they weren't sure how best to operate these visualisations effectively.

In conclusion, participants recognised the key advantage of interactive information visualisation as its ability to integrate vast amounts of information within a single system, thereby providing users with a comprehensive understanding of the subject matter. However, participants also voiced concerns regarding the presentation and visual design of interactive information visualisation systems, emphasising their potential impact on users' ability to comprehend the information effectively.

4.3.2.4. User Suggestions

In order to collect suggestions for the application of interactive information visualisation systems during the pandemic, the questionnaire mainly covers two aspects: information content and design requirements. The information content not only provides users with more practical information communication and information assistance during global health emergencies, but also builds a useful content framework for later redesign. Participants offering useful feedback on design requirements can better guide the future interactive information visualisation design according to the user-centred design concept.

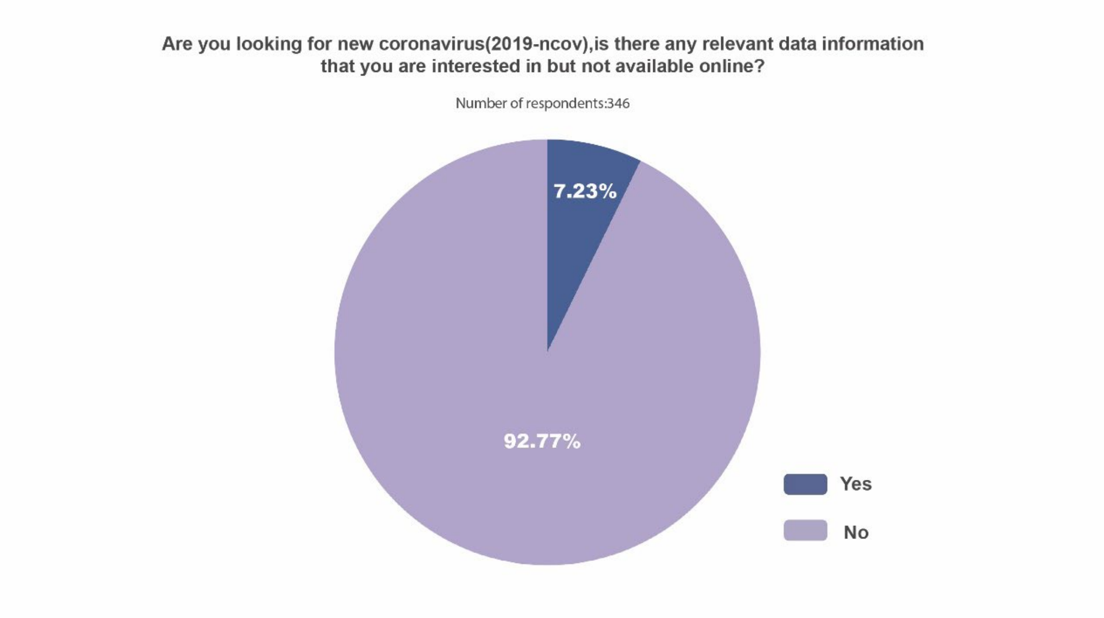


Figure 4.13 Feedback of participants about information omissions

Based on the analysis of the pie chart presented in Figure 4.13, it is evident that a majority of the participants (92.77%) indicated that the available information during the COVID-19 pandemic adequately met their information needs. However, a small proportion of participants (7.23%, or 25 out of 346 participants) expressed challenges in accessing specific information, noting that certain information was either unavailable or difficult to locate. In order to gain deeper insights into the nature of the missing information, this section of the questionnaire was designed to collect suggestions from these participants, allowing for the collection of valuable feedback regarding the specific content they felt was lacking or challenging to find.

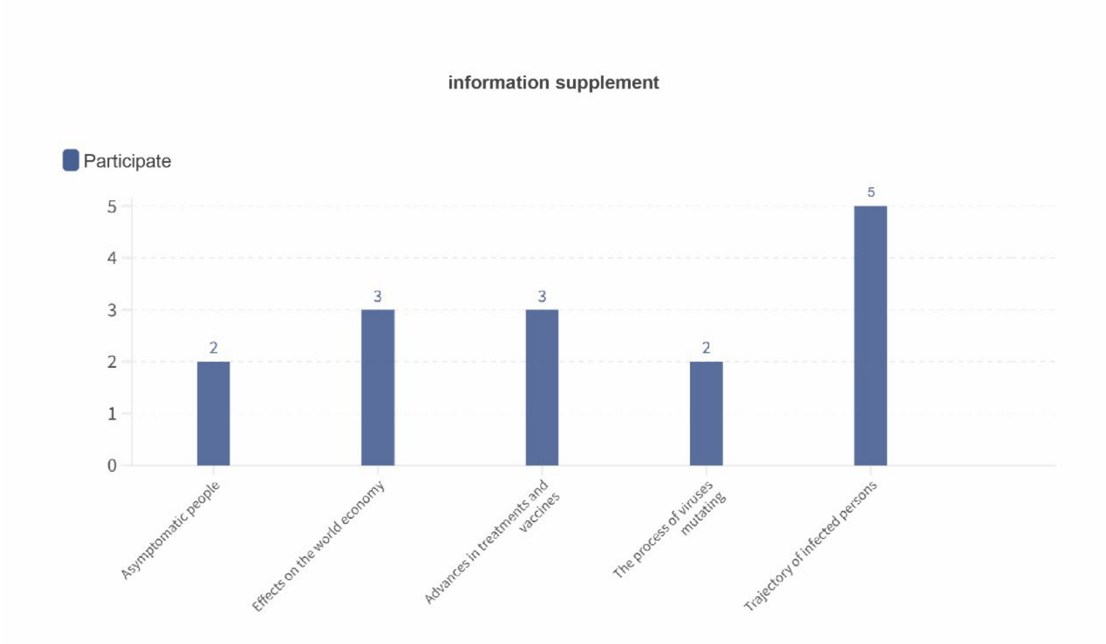


Figure 4.14 Feedback of information supplement from some participants highlighting information omissions.

Figure 4.14 depicts the additional information needs expressed by participants during the pandemic. Among the respondents, 20% (5 out of 25) emphasised the importance of understanding pandemic trends for enhanced prevention and outbreak detection. Their suggestions included displaying the activity trajectories of infected individuals and visually contrasting the infection time between new and old cases. Another 12% (3 out of 25) of participants highlighted the evolving nature of COVID-19, with varying symptoms and severity.

They emphasised the need to segment and clarify different data categories, enabling the public to comprehend the severity of each stage. For instance, they suggested annotating evolving outbreaks, specifying their symptoms, and separately listing basic data such as new cases and deaths. Additionally, 16% (4 out of 25) expressed concerns regarding the impact of COVID-19 on the global economy and the specific process of virus evolution. Another 12% (3 out of 25) participants exhibited a particular interest in treatment methods and vaccine development.

This focus on treatment and vaccines likely stems from the severity of the initial stages of the pandemic and the corresponding societal response, such as the strict lockdown measures implemented in Wuhan, the most severely affected city. In summary, the participants' information needs predominantly cantered around information classification and trends. Addressing these needs and visually presenting the data through visual comparisons of different

types and degrees can aid the public in determining and forecasting future trends.
For understanding the feedback of participants on the design of interactive information at this stage and providing an essential structure for future research in combination with design principles, a question asked "Overall, did the information you found about the new coronavirus (COVID-19) grab your attention due to its design?"

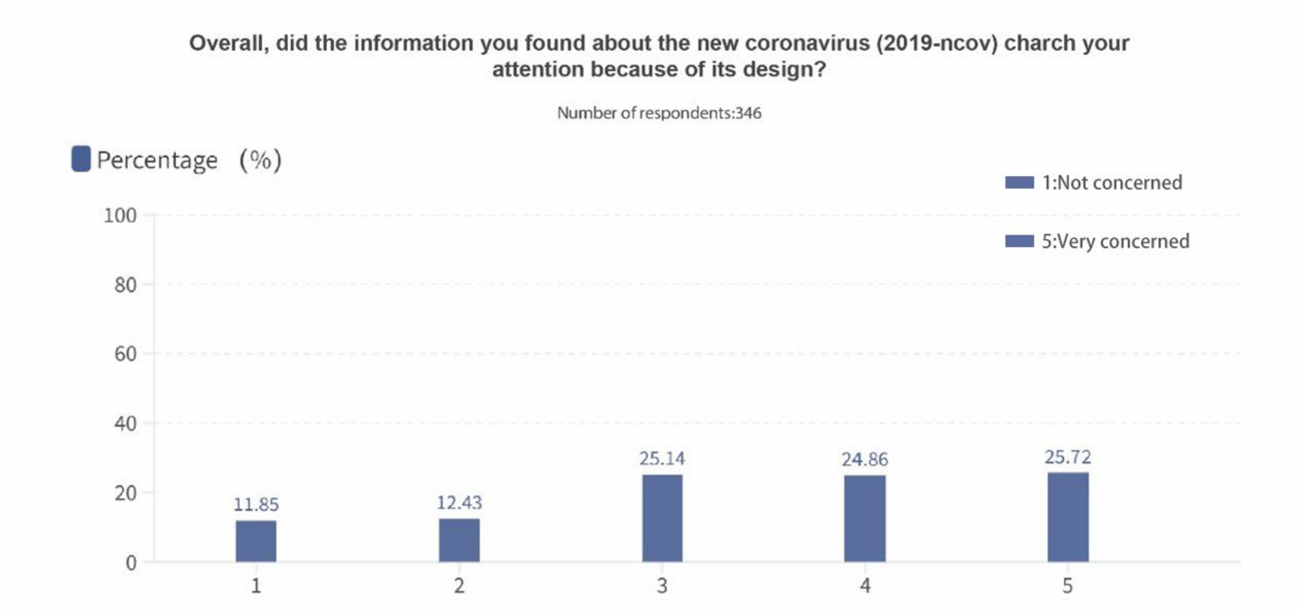


Figure 4.15 Participants attracted by the design of the information about the new coronavirus.

As shown from the histogram (Figure 4.15), 25.72% of participants paid more considerable attention to the design of interactive information visualisation, and 11.85% of participants paid no attention to it. On this basis, a further question was provided for participants who chose 3 to 5 (262 participants), "Can you describe which part of the design caught your interest or attention?"

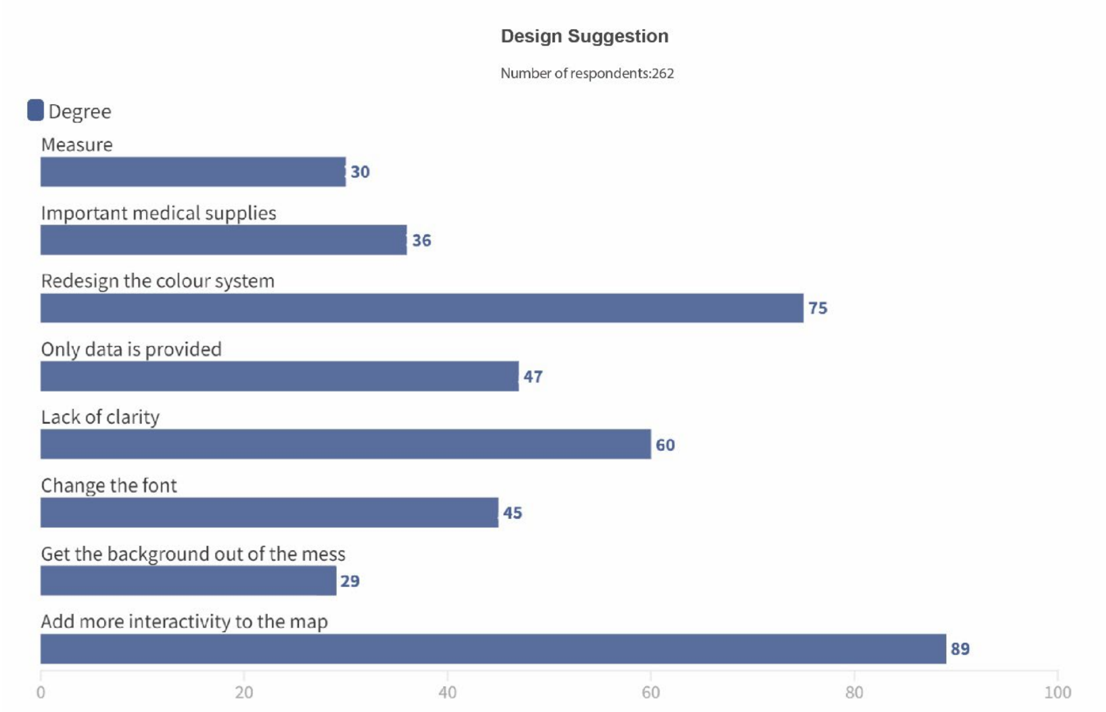


Figure 4.16 User feedback on the design.

Figure 4.16 presents a summary of participant responses, including their suggestions and feedback on the design of the interactive information visualisation system. In terms of interaction, 34% of participants (89 out of 262) recommended incorporating additional functional interactions, particularly within maps. They believed that since maps occupy a significant area on the page, providing more geographic-specific information and assistance would be beneficial for the public. Additionally, 23% of participants (60 out of 262) expressed that the current information visualisation lacked clarity. Specifically, they found that certain data visualisations in the system, such as histograms and line graphs, lacked means for exploring specific information and were not adequately represented elsewhere in the system.

On the information level, 16% of participants (41 out of 262) noted that data updates were not timely. They suggested implementing a specific daily update schedule in the system to help users determine the most effective time to access the latest data. Furthermore, 14% (36 out of 262) and 11% (30 out of 262) of participants desired the inclusion of more conclusive information, such as preventive measures and the availability of critical medical supplies. These suggestions catered to the needs of users seeking quick access to actionable measures. Regarding visual design, 29% of participants (75 out of 262) advised caution in selecting colours for the design system. Based on

previous examples, they believed that colours are an effective means of presenting data clearly and unambiguously. Another 17% of participants (45 out of 262) recommended standardising fonts, emphasising the importance of a clear range and display of font types and sizes within the system. Lastly, 11% of participants (29 out of 262) expressed a preference for a consistent background that does not interfere with the presentation of graphics and text.
In summary, participants provided initial proposals regarding three key aspects of the interactive information visualisation system. They believed that incorporating interactive operations would enhance user operability and exploration within a single screen. Participants also expressed a need for additional details and information, suggesting the inclusion of more operational space within components. Furthermore, participants emphasised the importance of clearly indicating the data source and information, not only to ensure data accuracy but also to guide users in utilising the interactive information visualisation system. Regarding visual aspects, participants focused on enhancing readability and understanding, aiming to improve the overall interface design and data information legibility.

4.3.3 Discussion and Conclusion

The survey results demonstrated the effectiveness of visualisation in facilitating information communication during the global health emergency caused by COVID-19. Amidst the severe outbreak and stringent government quarantine measures, participants placed significant value on COVID-19-related information and expressed notable concerns regarding urban conditions, vaccine development, preventive measures, and related information. They exhibited a stronger interest in government-released data or information directly relevant to their daily lives, such as the daily case count during the outbreak and the severity of their respective cities, along with corresponding recommended measures. In contrast, scientific information pertaining to virus composition and research findings was of lesser interest. These types of data are more effectively presented through visual displays, such as graphs and charts accompanied by concise textual explanations. Consequently, effective data visualisation serves as an important and effective means of communicating information during an outbreak scenario.

Diverse user characteristics, including age, socioeconomic status, and environment, contribute to varying information needs and expectations (Smiciklas, 2012). Regarding information presentation, older participants tend to focus more on specific data outcomes, such as the aggregate number of confirmed cases as a significant indicator. In contrast, younger participants are more interested in the presentation of information itself, such as analysing the growth curve of outbreaks to predict and summarise future trends. This observation aligns with previous research by Strong and Wong (2006), which highlights age-related differences in information consumption and perception of design materials.

In the questionnaire, significant differences were observed between older participants (mean age: 37.2 years) and younger participants (mean age: 22.2 years) in terms of information perception and usage efficiency when utilising interactive information visualisation tools. This discrepancy is evident from the scores assigned by participants of different ages during the questionnaire. Specifically, older participants tended to spend more time comprehending and utilising data presentation within the interactive information visualisation system, whereas younger participants exhibited greater sensitivity to information and demonstrated higher proficiency in finding information and using the interactive information visualisation system. However, it is important to acknowledge that the online nature of the questionnaire and the age range of the majority of participants (18 to 50 years) may have influenced the results. Older participants may have lower computer skills compared to younger participants (Nagle and Schmidt, 2012). Consequently, the age-based data analysis may introduce bias. Therefore, future performance tests should employ more stringent age level screening to mitigate this potential limitation.

The analysis of the questionnaire yielded valuable user feedback, revealing several challenges and limitations in the application of visual design within the context of global health emergencies. While participants acknowledged the effectiveness of interactive information visualisation as a tool for disseminating information during the pandemic, they also identified certain issues related to its visual design and the types of information presented. One prominent concern raised by participants was the confusion caused by similar colours in charts. When different types of data exhibited similar trends, overlapping colours created difficulties for users in interpreting the information. To address this, it is recommended that information design materials employ colours with high contrast and a sense of layering to reduce clutter and enhance readability (Brase, 2006). Additionally, incorporating interactive design features that highlight a single colour can improve information recognition and reduce confusion (Sandamal, 2020). These feedback suggestions align with the guidelines framework for colour and interaction.

Furthermore, participants emphasised the organising information based on its significance, such as arranging cities based on the severity of the pandemic, and displaying them using visual components. This approach facilitates the connection between various components in the system, allowing users to integrate and comprehend the information more effectively. It aligns with the principle of display mode in the framework of principles. Insights from participants working in data analysis and design-related fields (32 participants, or 5% of the recruited sample) were particularly valuable. They highlighted the need to increase the diversity of presentation within a single component through interactive functionality. Additionally, they recommended the development of a comprehensive interactive visual layout with a logical flow, including a clear reading sequence. These suggestions underscore the importance of structural guidelines outlined in the Principles framework for constructing interactive information visualisation systems. Another recommendation put forward by these professionals was the redesign of the colour system to incorporate background colours, ensuring that the colour palette aligns with the medical and health domain. This suggestion paves the way for future visual presentations in specialised medical environments. The professional opinions provided serve as valuable references and lay the foundation for the next stage of research.

In summary, this questionnaire helped to provide insights into the information needs of the public during the early stages of the COVID-19 pandemic under lockdown and quarantine measures. It also captured public attitudes and perceptions of interactive information visualisations as an information exchange tool during this period. The results of the questionnaire provided initial requirements and feedback on the content and design of interactive information visualisations. Notably, participants expressed positive feedback on the visualisation cases presented in the questionnaire, which is consistent with the criteria for "advanced" cases outlined in the principles framework. On the other hand, participants raised concerns about the relationship between structure and information presentation, and the impact of colour context on the readability of information. These areas highlight potential areas for improvement in the design of interactive information visualisation systems.

Additionally, given the impact of the COVID-19 pandemic on global human health and the potentially different impacts of visual communication design in different cultural and domain contexts, there is a need to explore how these findings can be applied beyond the pandemic context. Information dissemination through visualisation has penetrated both the viral communication and human health domains, and the insights that good visual presentation and logical layout can enhance the readability of relevant information as well as the cognitive efficiency of the user are valuable for the development of data dashboards, especially those related to health in a variety of contexts. Future experiments should select a globally widely used interactive information visualisation system as a test case, based on the user suggestions and data information from this experiment, to ensure the adaptability of the visual communication design in different cultures. In addition, recruiting participants from different cultural backgrounds in future studies will help to address potential differences in information needs across cultures, thereby enhancing the inclusiveness and effectiveness of visual communication design strategies.

4.4 Chapter Summary

This chapter's primary aim is to evaluate a design principles framework for interactive information visualisation within the context of global health emergencies as defined by WHO. Furthermore, this examination seeks to follow visualisation cases over various time periods using this principles framework in order to detect any limitations observed and demonstrate its efficacy or relevance.

By reviewing a diverse set of visualisation cases from global health emergencies, this research seeks to gain an insight into the application and impact of design principles framework. Assessment will shed light on the strengths and weaknesses of various visualisation approaches as well as interactive features in facilitating information comprehension during health crises. Furthermore, this chapter seeks to demonstrate the utility of design principles framework as an instrument to assist developers of interactive information visualisation systems. Through an assessment of how closely cases adhere to principles and identification of areas for improvement, this study will demonstrate the practical utility of this framework in informing design decisions and improving usability of interactive visualisation systems during global health emergencies.

This study begins by collecting 12 visualisation cases used during global public health emergencies across three distinct time periods, then classifying their design elements according to three levels - primary, intermediate, and advanced - according to how closely they adhered to design principles framework. Results provide insights into layout, colour schemes, typographies, graphic elements content interactivity presentation of cases that best embody those principles, rating them advanced. Design cases at the "intermediate" level demonstrate a comprehensive application of fundamental principles, while those with the least adherence to principles are rated as "junior." This analysis establishes a positive correlation between the application of design principles and the quality of interactive information visualisations, with more principles leading to improved design outcomes. For instance, during the SARS period, the limitations imposed by the digital age and the relative unpopularity of visualisation practices resulted in limited usage of visualisation components. Information was predominantly displayed in static formats, such as tables, and the visual colour palette was confined to grayscale. In contrast, during the recent COVID-19 period, visualisations predominantly took the form of dashboards, incorporating a greater number of visual components and design elements. This advancement in visualisation practices can be attributed to improved technology and heightened public awareness during the pandemic (Xie et al., 2020).

It is essential to emphasise that the application of design principles should prioritise information readability and cater to user-oriented information needs. To further comprehend users' information requirements, communication methods, and assess the specific effectiveness of the design principles framework during the epidemic, an online questionnaire survey was conducted in the subsequent phase. The survey collected primary data from 346 members of the public during the latest phase of the COVID-19 pandemic.

The results indicated that visualisation significantly facilitated information exchange during the global health emergency caused by COVID-19. Specifically, 65% of the participants provided positive feedback on the use of interactive functions, which streamlined tasks such as information search and comparison. Additionally, 35% of participants positively acknowledged the rich visual design and component assignments, including content within each component. This positive feedback aligns with the embodiment of the "advanced" visualisation examples outlined in the design principles framework. On the other hand, most of the negative feedback stemmed from issues such as inadequate detail in visual elements and frequent changes in structural layout.

Concerns were raised about unclear information structure due to background clutter, insufficient interactive exploration, and a lack of guidance in layout. These user suggestions primarily focused on improving readability and interactive operations, addressing the limitations observed during the principles evaluation in the initial stage. Additionally, the online survey revealed differences in the use and understanding of related interfaces among different age groups. A comparison between the general public and design-experienced participants indicated that even though the public lacks familiarity with design principles and theories, their perception of good design is often in alignment with the principles, particularly concerning content diversity, interactive visual layout, and the colour system.

In the next chapter, two interactive information visualisation dashboards will be used as testing material to conduct performance tests. The aim is to explore the relationship between user understanding and system layout, as well as understand its limitations by observing the actual operation of the dashboard by the public. First, through the performance test of the dashboards, their commonalities and limitations will be analysed from the perspective of the usage time, the number of interactions and the usage process. Then, the feedback during the user behaviour process will be collected through a follow up interview/questionnaire and analysed based on the experimental data, so as to find out the factors influencing the usage process.

5 User Performance Test: Evolution of Interactive Information Visualisation Design in Global Health Situation

This section conducts a deep performance testing of two widely used global health dashboards in the context of COVID-led health emergencies to evaluate their ease of information readability and user experience. Previous case studies of interactive information visualisation systems were analysed to provide a basis for this examination. The study aims to identify any structural and visual limitations that hinder readability by analysing user performance in terms of usage time, number of interactions, and search order. The findings from this study can provide insights into the design of interactive information visualisation systems to enhance the user experience in future global health emergencies. Subsequently, the interview will be based on the participants' user experience, usage impressions, design preferences and suggestions on the use of the dashboard. Contrast and study the design factors that affect users' use of dashboards. At the same time, this move can also clarify the uncertain factors generated in the experimental process.

5.1 Introduction

As articulated in Chapter 1, it is of utmost significance to heighten public consciousness regarding pandemics, given the frequent outbreaks occurring globally and their profound effects on society and daily life. The significance of such outbreaks highlights the necessity of practical visualisation tools in assisting the public's comprehension of the situation and surrounding conditions. According to the World Health Organisation's (2022) statistics, since the inception of the COVID-19 pandemic in 2020, an estimated 460 million confirmed cases and 6 million fatalities have occurred worldwide. The emergence of complications associated with COVID-19, such as pneumonia, ARDS, and acute liver injury, accentuates the need for vigilance in preventing the spread of the virus and informing the public about the evolving global situation (Tian and Ye, 2020). The examination of primary information sources, such as epidemic dashboards, can facilitate a more comprehensive understanding of the impact of COVID-19 on societies.

The objective of this study is to assess the capability of the visualisation system design in the context of the ongoing epidemic. This study aims to identify and analyse any potential limitations in the information design structure and interactive visual components. Through an in-depth examination of the interaction process between participants and the dashboard, the objective is to enhance users' engagement with the dashboard, improve information readability, and optimise their overall user experience. By addressing these aspects, the study seeks to foster users' trust in the website's information transmission and enhance the effectiveness of its data dissemination configuration.

This investigation utilises the Epidemic Dashboard within Global Health Emergencies as a case study. 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 visualisation 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 utilisation of the system.
3. To examine the reading patterns of subjects and collect valuable evidence from comprehending the user's requirements and information-seeking tendencies when using the epidemic visualisation system.

In addition, the following research questions were investigated in the test:

a. How is the information on the dashboard, categorised 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 behaviour for information?
c. How to improve the existing outbreak data dashboards and promote the development of informative data visualisation techniques for data provision during global health emergencies?
d. What design solutions could be employed in the subsequent phase to ameliorate the design limitations identified from the existing maps?

To achieve the goal and tackle the research questions, the utilisation of screen recording functionality was implemented as a testing method to record the user's procedural actions and frequency of clicks. This methodology was considered an essential approach to assess the legibility of the visualisation system and monitor the participants' information search process. Further elaboration on the justification for choosing screen recording functional testing as the research methodology for this investigation will be provided in the next section.

5.2 Research Method

The utilisation of the screen recording feature was adopted as an ancillary instrument for acquiring data associated with computer performance amidst a study on human-computer interaction (Imler, 2011). For each participant, the length of time required to complete the task was recorded, and an examination of reading behaviours and tactics was executed through a combination of interactive click position data and mouse movement trajectory, with the mean duration serving as a metric (Kirsh, 2022). In the subsequent segment, the benefits of utilising screen recording in performance testing and the user behaviours and patterns that can be extracted from this methodology will be expounded upon.

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 the participants (Imler and Eichelberger, 2011). The researchers recorded and analysed 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 scrutinise the advantages of utilising screen recording in performance testing and explore the user behaviours 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, 2022). This constitutes a crucial aspect in the analysis of legibility and is often scrutinised 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 visualisation charts.

Interaction Intensity: To examine the correlation between interface layout and user interaction clicks in an interactive information visualisation system, it is necessary to analyse 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 analysed 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 utilisation of mouse tracking can furnish essential information on the comprehension of intricate and novel model frameworks by individuals (Konovalov and Krajbich, 2020), thus serving as a fundamental basis for the blueprint of upcoming visual interfaces. The recurrent patterns of mouse behaviour identified in the literature are subsequently synthesised, 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 behaviour, 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 et al., 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 and 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 utilised 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 categorised 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 characterised by lateral mouse movement within a paragraph (Ferreira et al., 2010). A comparative study utilising 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 characterised 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 visualisation, it is frequently observed in the application of vertical data tables (Mueller and 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 and 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 characterised 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 behaviour 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 5.1 presents potential interpretations for mouse behaviour 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 5.1 Mouse movement data and possible interpretations

Analysing the behavioural 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 behavioural patterns (Rotolo, 2016; Kortum and Acemyan, 2016; Katerina and Nicolaos, 2018; Leiva and Arapakis, 2020). Such information is pivotal for assessing overall usability.

5.3 User Performance Test

5.3.1 Scoping Test for Principle Evaluation

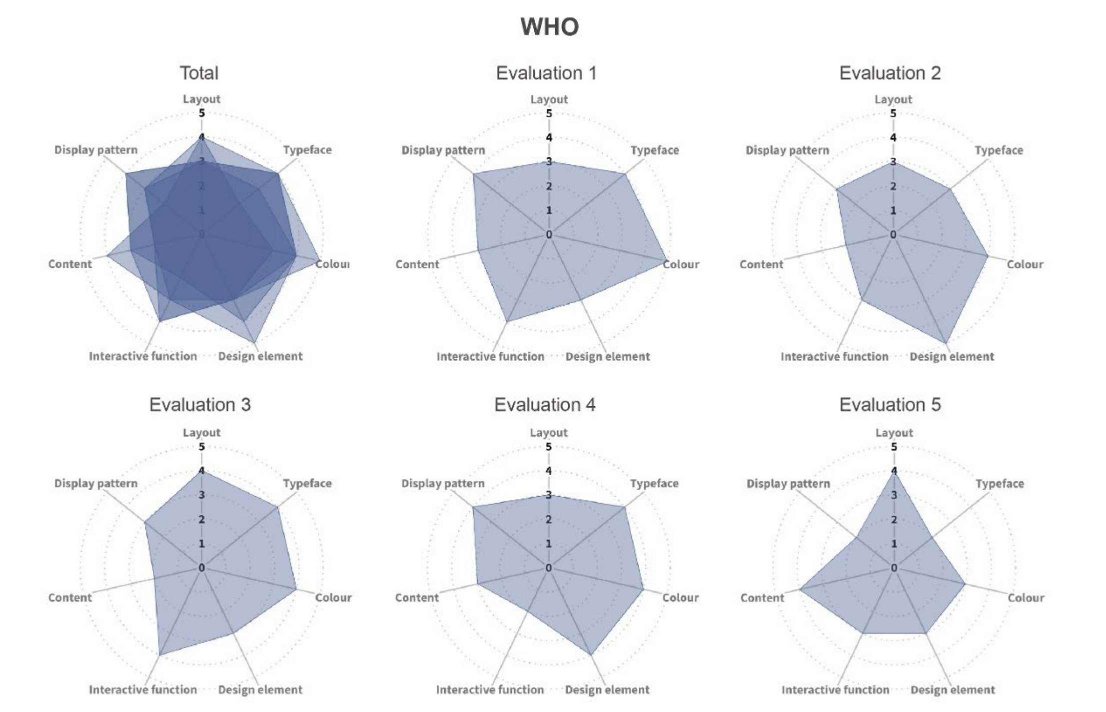
Amidst the current global health crisis (COVID-19), governments and media outlets face the daunting challenge of effectively communicating information about the health emergency's evolution to the public, including complex technological concepts and vast amounts of data. Data visualisation holds significant potential in conveying this information to society (Hanzl, 2007). Nonetheless, given the unfamiliarity and novelty of the content, there exists a potential risk of misconstruction and an unsatisfactory user experience. In summary, it is necessary to enhance the design of visual dashboards to facilitate the efficient dissemination of information and expertise (Pérez-Montoro, 2022).

When developing interactive dashboards, adherence to general design principles is crucial. Nonetheless, the design of many visual dashboards often prioritises presenting all data without considering the user's most important information or how the data is presented, leading to a complex information search process. Lauesen (2005) posits that interactive information visualisation systems ought to evaluate their design quality based on usability metrics such as efficiency, satisfaction, and ease of use. Besides these general usability factors, visualisation effectiveness also hinges on the user's ability to accomplish their objectives (Buono et al., 2005).

Two COVID-19 dashboards have been chosen for performance analysis, one disseminated by the World Health Organisation and the other by Johns Hopkins University. The following factors have influenced this choice:

1. The two selected dashboards exhibit similar data types.
2. Both of them adhere to similar operational standards and are exceedingly user-friendly for participants.
3. Despite having similar data, the presentation approaches, which encompass visual design and structural layout, are markedly distinct between the two dashboards.

Preceding the execution of the performance test, the experiment enlisted a cohort of five participants with design-oriented proficiencies, exhibiting an average age of 26.4 years. The primary objective of this preliminary assessment was to infuse a sufficiently unbiased theoretical foundation into the experiment. These participants meticulously evaluated the two dashboards across seven distinct dimensions, leveraging the design principles framework expounded in Chapter 3. The assessment entailed rating each dimension on a numerical scale ranging from 1 (limited alignment) to 5 (substantial alignment). The resultant evaluations will be instrumental in juxtaposing the divergences in rating outcomes between the two dashboards as per the design principles framework. This approach serves a dual purpose: firstly, it aims to illuminate disparities in the dashboard designs from a literature-based perspective via the integration of the principles framework; and secondly, it seeks to foster a comparative analysis between the outcomes of the participant performance tests in this phase, substantiated by the assessment within the principles framework, thereby further substantiating the credibility of the framework for case evaluations.



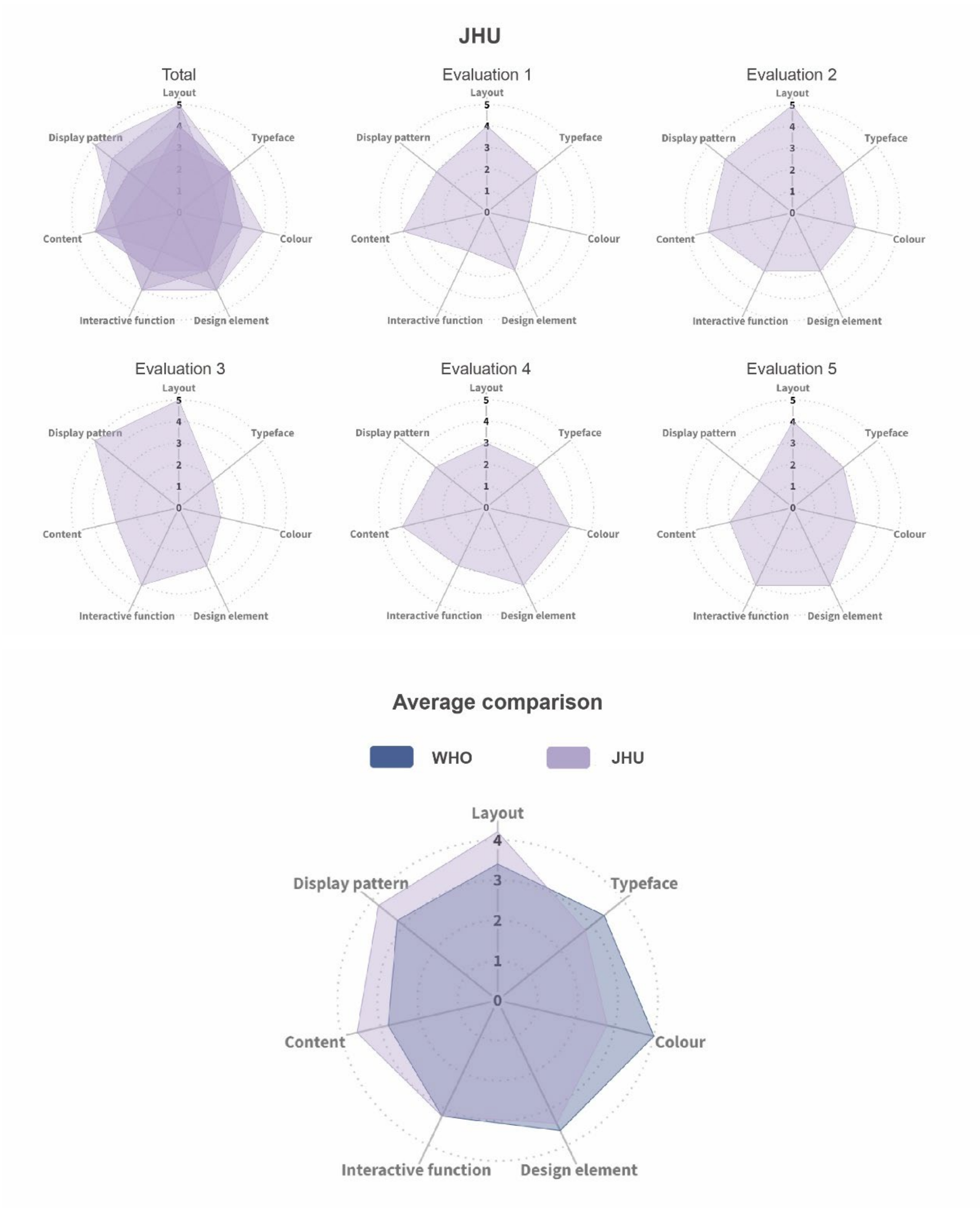


Figure 5.1 Participants' evaluation and comparison of each dashboard

The evaluation tests illustrated in Figure 5.1 reveal that both dashboards manifest specific design constraints pertaining to information structure and visual presentation. A meticulous comparison of the average evaluation scores discloses that the World Health Organisation (WHO) outperforms Johns Hopkins University (JHU) in dimensions such as colour utilisation, typography, and the incorporation of pertinent design components. This disparity implies that

WHO excels in crafting visual designs conducive to presenting specific information, spanning graphical as well as textual content. In contrast, JHU garners superior scores in terms of layout composition, component arrangement, and information content, indicating that WHO's holistic information layout, inclusive of component disposition and content coherence, is more proficient. The interactive functionality attribute elicits identical scores for both dashboards, suggesting the integration of a certain degree of interactive functionalities across the entire dashboard for both WHO and JHU. This comparative scrutiny of the evaluation framework effectively delineates the distinct design attributes of the two dashboards before embarking on the experimental phase, thereby subsequently substantiating the influence of these discrete attributes on user experience during the ensuing performance testing.

5.3.2 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 colour vision test (Hardy et al., 1945) to guarantee that all participants had a normal colour vision.

5.3.3 Test Environment, Materials and Test Settings

The took place indoors to prevent the impact of external natural illumination on the colour of the instrument panel. The task was performed by the participants utilising a computer system with a display resolution of 1920 x 1080 pixels. The dashboard utilised 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 will capture the user-generated usage data that transpires during the experimental sessions. Additionally, participants will be queried about their operational behaviours as they execute each task within the course of the study. In this investigation, the mouse motion data were examined utilising the motion frequency chart produced by the EV screen recording tool. Additionally, the usage of the SPSS computational system provides a more precise and dependable analysis by executing paired-sample t-tests for comparison between diverse variables.

In order to comprehensively evaluate the design efficacy of dashboards employed for the presentation and dissemination of interactive information visualisation 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. The participants' interaction and information retrieval processes were systematically vocalised during the course of this assessment. The tasks encompassed the retrieval of targeted data from the dashboards of the World Health Organisation (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 randomised. The specific tasks and their corresponding research objectives can be found in Table 5.2.

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 5.2 Task details and corresponding research aims.

During these tasks, the examination of information layout, graphic presentation, colours, fonts, and interaction flow is further scrutinised 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 contributes to a better comprehension of the users' reading behaviour and the purpose of the interaction, augmenting objectivity in the results. For instance, when users utilise 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 perplexing and baffling, leading the user to read it multiple times (Nielsen, 2011); 2) the area encompasses several interactive features with ambiguous intentions, and the possibility exists for the user to speculate before utilising it (Lockton et al., 2010); 3) some elements of the area are more novel and appealing compared to others, luring the user's attention (Ferreia et al., 2010). It is conceivable that different understandings may arise in response to identical conduct. Henceforth, 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 and requisites of the respondents (e.g., via interviews) can enhance the knowledge of user behaviour before arriving at conclusions. Ultimately, to streamline surveys and gather supplementary data concerning user experience, the participants were mandated to fulfil a short questionnaire on their experience of locating information on the dashboard.

5.3.4 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 slightly higher average completion time of 123.5 seconds was observed for the JHU dashboard. It is evident that the time spent by participants is positively correlated with the intricacy of the exploration depth and task complexity, as a discernible upward trend in time consumption was noted in alignment with an escalation in exploration depth and task intricacy.

5.3.4.1 Task 1 Results and Analysis

Task 1 mandates participants to conduct a comprehensive search for fundamental epidemic information pertaining to a specific country (China) across two distinct dashboards. The requisites of this task encompass the retrieval of data encompassing the count of confirmed cases and fatalities. The objective was to examine the reading strategies utilised 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 5.2 Average usage time of the two dashboards in Task 1

In Figure 5.2, 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 discrepancy is attributed to the employment of different search strategies by participants while locating the correct answer on each dashboard. In the WHO dashboard, the majority of participants (80%) directly utilised the map tool to identify the relevant country or region. Conversely, the remaining 20% of participants utilised the search box to enter keywords such as "China," "China data," or "China epidemic" 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 was crafted for the complete JHU website rather than solely for the dashboard, thereby displaying interface details that were completely extraneous to the intended design structure and components of the dashboard. Consequently, users experienced perplexity and frequently had to retrace their steps during the search process, which was unhelpful for the original investigative aim of scrutinising the effect of the dashboard's design structure and components on users' information comprehension and navigation.

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 behaviour also accounts for the reading patterns observed in most of the participants.

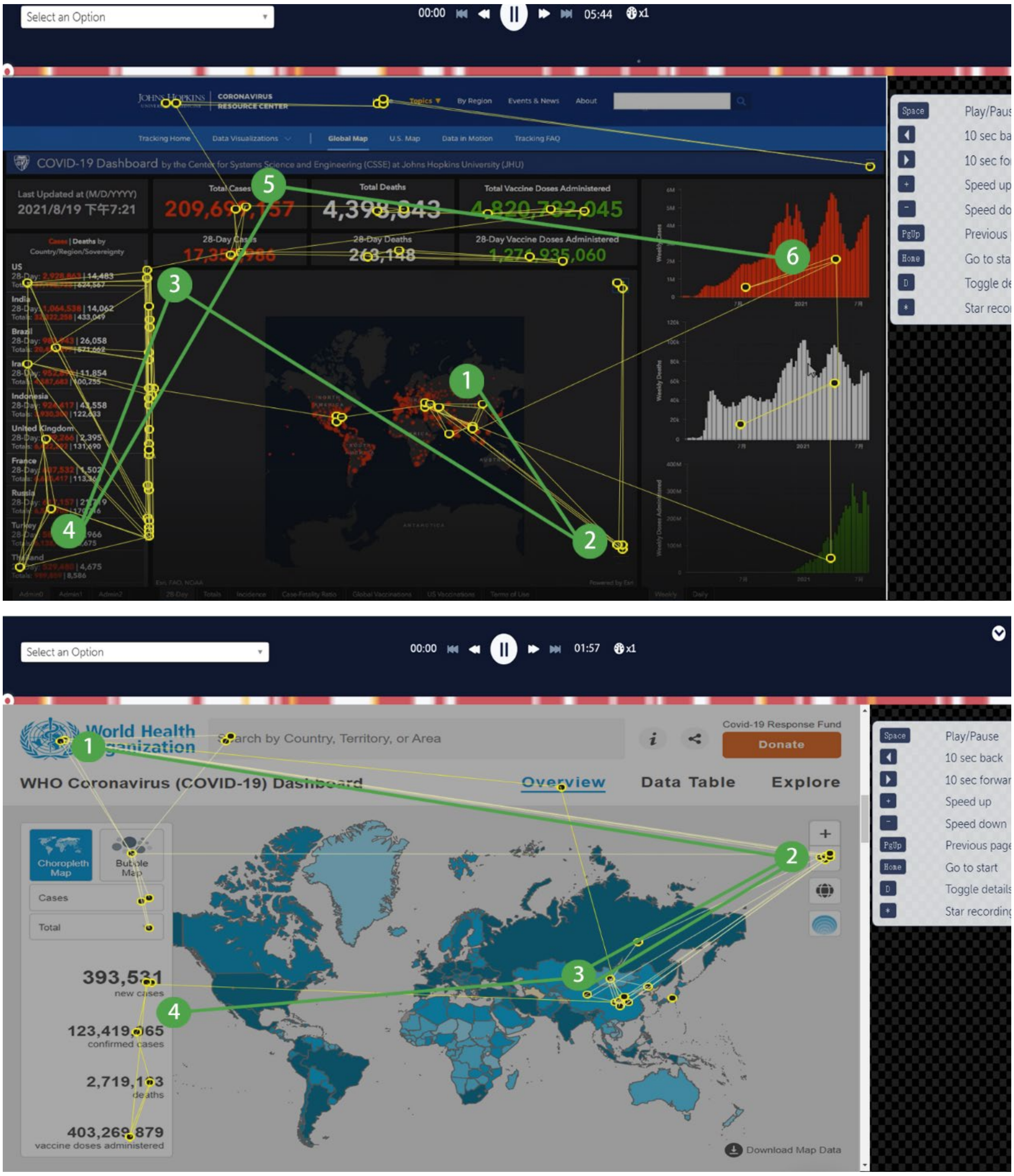


Figure 5.3 The representative reading behaviour of two dashboards in Task 1

In Figure 5.3, 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, adjust the map size through steps one to three to locate the target information on the map. Secondly, move 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 5.3, were more intricate and involved five distinct parts:

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 5.3), it was observed that the layout of data information had an impact on them. The frequent scrolling within the list highlighted the difficulty of information retrieval and emphasised 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). Similarly, 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 endeavoured 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.

5.3.4.2 Task 2 Results and Analysis

During Task 2, participants were tasked with locating the global confirmed case increment for November 1st, 2021, from the dashboard. This task aimed to assess the readability of data visualisation, which includes the interactive display structure of critical information (e.g., specific data) and the visual design. The correct answer to the task was 565,721. In the WHO dashboard, 24 participants (80%) found the correct answer. Of those, 83.3% utilised the "optimal" reading strategy, which involved pulling down the overall interface of 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 visualisation 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 visualisation, resulting in user confusion.

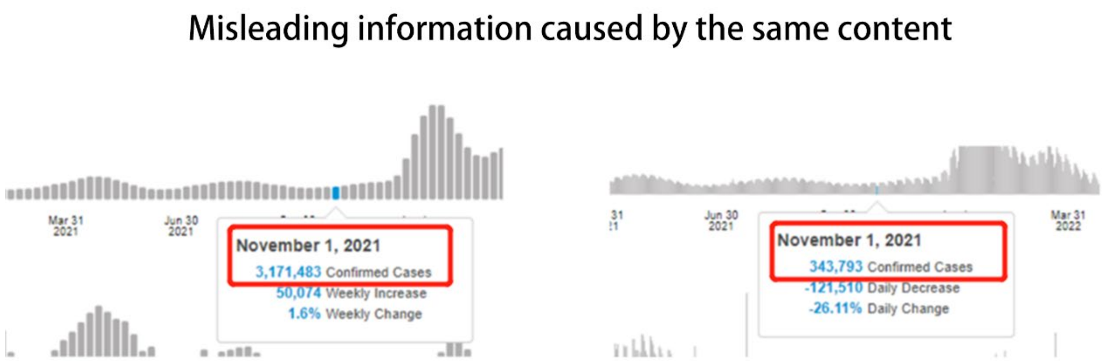


Figure 5.4 Misleading information present in the WHO dashboard in mission 2.

In Figure 5.4, the reading errors of the participant on the WHO dashboard were predominantly caused by a failure to discriminate between the temporal units of the data display (week/day). Figure 5.4 shows that the participant mainly relied on the interactive display of the date titles when placing the mouse on the visualisation 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 afforded an interactive function to switch the temporal units, the primary reason for the participant's reading errors was the small font size and buttons.

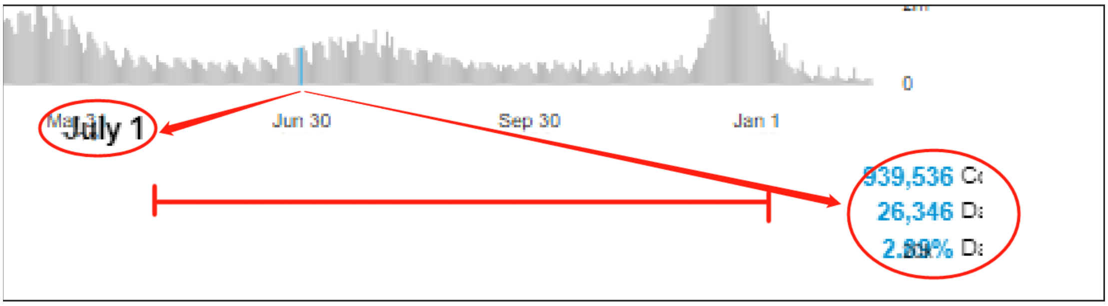


Figure 5.5 The poor impact of information design structure on users' reading strategies is shown in the WHO dashboard in Task 2.

Throughout the experiment, the instability of the dashboard system caused design predicaments, which negatively affected 13.3% of the participants (four individuals). Figure 5.5 delineates the various predicaments related to information presentation encountered by users while utilising the WHO visualisation. As depicted in the figure, the narrow azure area on the chart epitomises the data information anticipated to be observed on July 1st. However, the date display coincides with the original unit scale of visualisation and is at a specific distance from the actual blue area. When a user desires to view precise data, the display is further away on the right side, and the data units behind are about to vanish. This implies that the original data content will not be exhibited for some data dates closer to July (data after July). In such instances, participants necessitate investing more time in circumventing misleading information caused by design. This indirectly verifies that a well-structured visual design influences users' understanding of information.

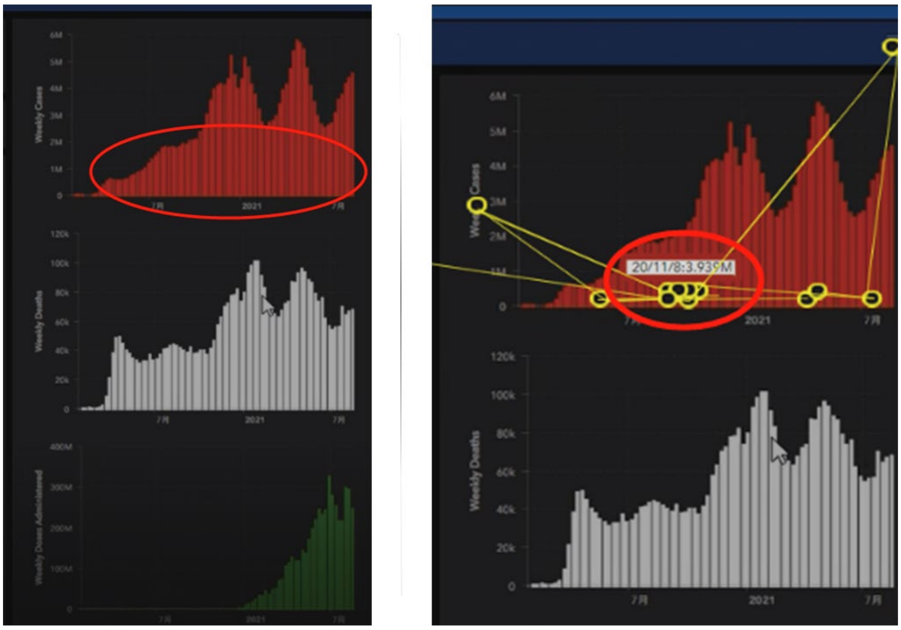


Figure 5.6 Representative mouse traces of the JHU dashboard in Task 2.

In Figure 5.6, 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 visualisations. 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 visualisations was too diminutive, and the interactive response was excessively slow, causing confusion and contributing to the error.

The reading behaviour suggests that the visualisation'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 visualisation 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 visualisation; however, only 20% of the participants (6 individuals) attempted to click and use it due to the button's small size and vague meaning. Additionally, JHU fails to offer any other design methods to assist users in quickly locating information.

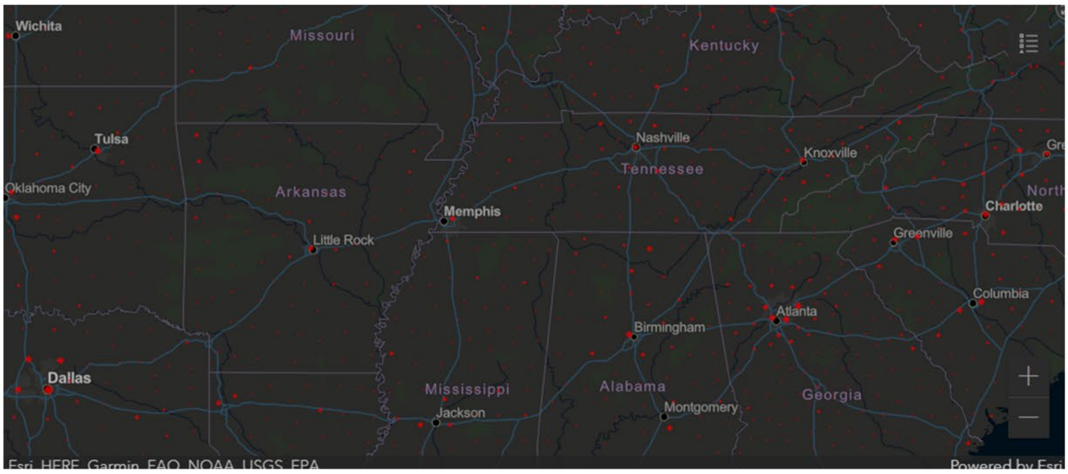
5.3.4.3 Task 3 Results and Analysis

Task 3 necessitated that the participants determine the aggregate number of confirmed cases in the United States on November 1, 8, and 15, 2020, using the dashboard. Unlike Task 2, the participants had to engage with the dashboard to locate the required data. The objective of the task was to observe the participants' "optimal" reading approach employed throughout the search process. Additionally, the aim was to scrutinise 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 behaviour 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 at a protracted mean duration of search (125.3 seconds). Nevertheless, owing to the preference for the cartographic tool in the information-seeking conduct of the participants, the investigation recognised a problem with the composition of information and interactive capacity of the dashboard maps, which may have resulted in perplexity and depletion of users' time.

Stage1: Initial

Stage2: Intermediate



Stage3: Detail

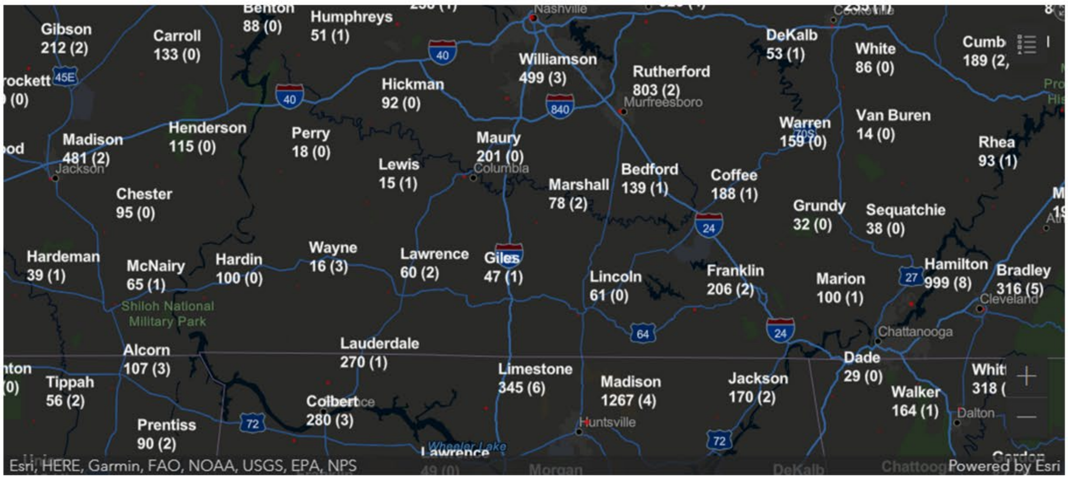


Figure 5.7 Three Stages of JHU Dashboard Map Display.

In Figure 5.7, the JHU dashboard's map display is showcased in various scales, categorised 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 swiftly. 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 perplexity prompts the participants to bypass the "preliminary" stage and expend more time exploring and locating the geography during the "intermediate" and "detailed" stages.

Figure 5.8 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 bewildering data display for participants. Figure 5.8 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 criticised the depiction of the crowded road network on the map, which did not help them to obtain relevant pandemic information. On the contrary, the colour contrast made it difficult for them to concentrate on finding information. Furthermore, this stage's "red dots" are too minute and easy to overlook. Figure 5.8 displays the obscurity of the "red dots" in the detailed stage of the map.

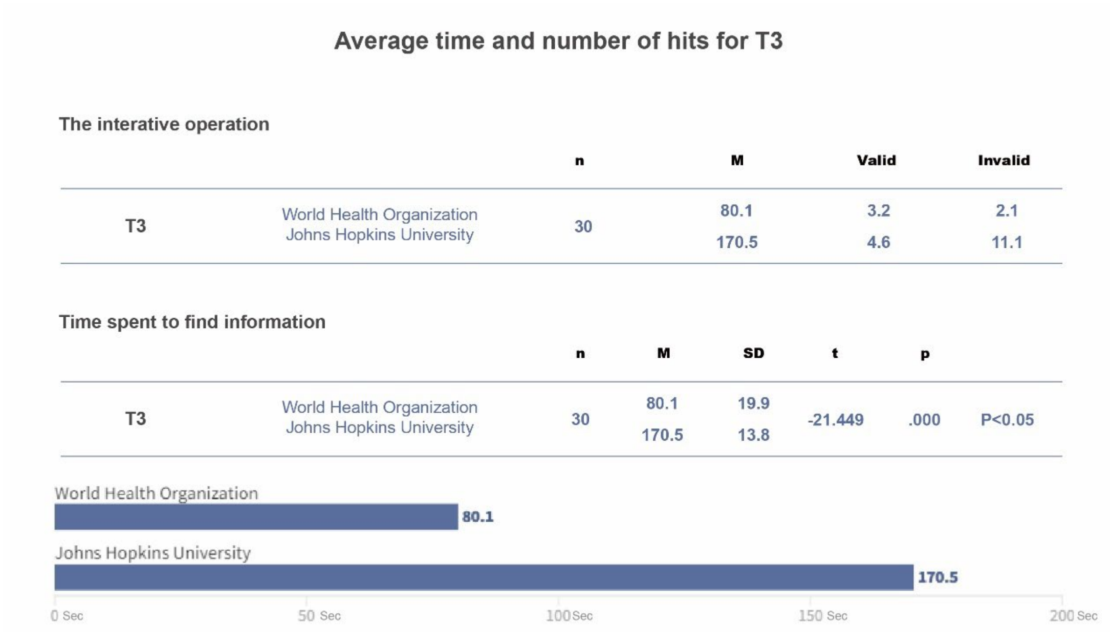


Figure 5.9 Comparison of the time and number of clicks for the two dashboards in Task 3

Figure 5.9 further investigates the impact of design constraints on user experience. Analyse 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 serve to demonstrate how the design limitations apparent within the JHU dashboard map not only result in the wastage of users' time but also have a detrimental impact on their overall user experience.

5.3.4.4 Task 4 Results and Analysis

Task 4 necessitates that the participants gather data pertaining to the present COVID-19 scenario in India and Germany utilising the dashboard. The individuals are obligated to generate strategy their personal reading techniques and furnish the investigators with their practical steps. The task encompasses an extensive corpus of data and intricate transitions among different segments of data, highlighting the users' propensities for transitioning while scrutinising different information, and the dashboard configuration and design effects 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 culprits being the monotonous flow created by the structural layout and the lack of annotations within the data visualisation. Figure 5.10 portrays the structure of the WHO dashboard homepage, where 36.6% of participants (11 individuals) opted to utilise 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.

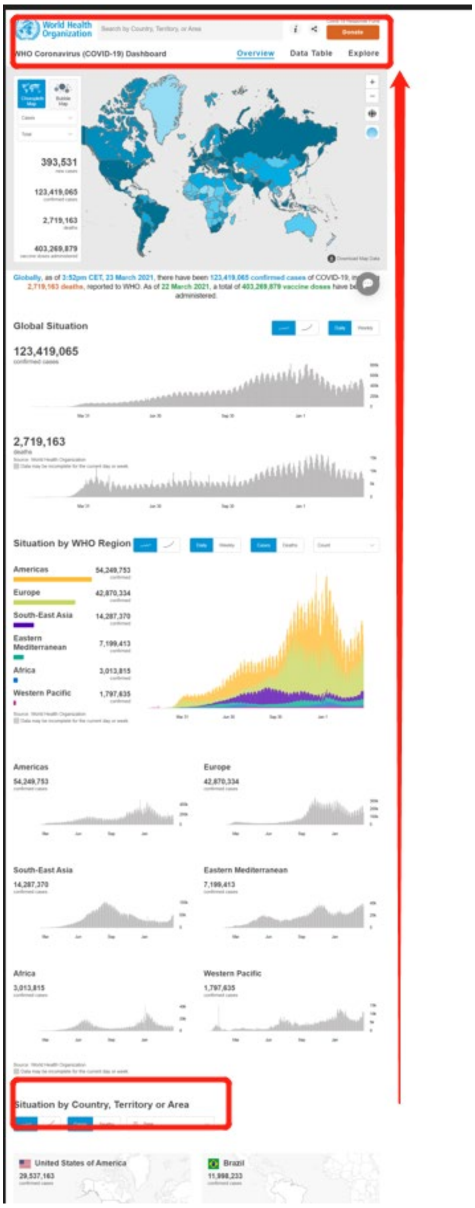


Figure 5.10 How far participants were able to find and compare information in the WHO dashboard pages.

5.3.5 User Perspective

Following the completion of the task, separate interviews were carried out to assess basic feedback from users who had utilised both dashboards. The obtained results provide insight into the users' evaluation and sentiments toward the respective dashboard.

5.3.5.1 Usage and Information Understanding about Dashboards

First, the interview process commenced with the gathering of information pertaining 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 was to comprehend the influence of distinct dashboard design types on the users' information comprehension and usage process while holding the content constant.

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 5.11 Participants' initial feedback on the two dashboards.

Figure 5.11 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 (24 out of 30 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 (20 out of 30 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 (13 out of 30 participants) found it relatively clear.

5.3.5.2 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.

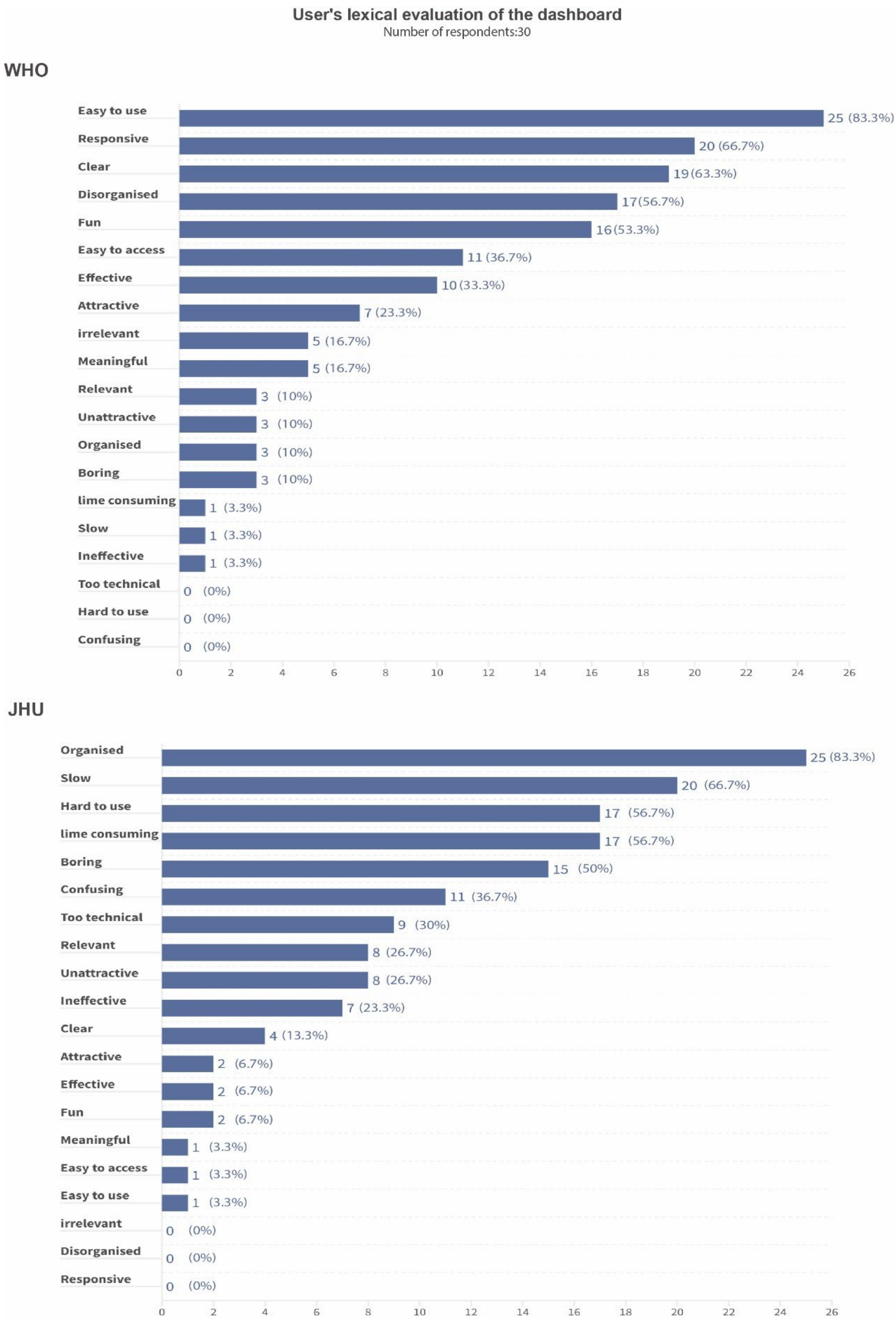


Figure 5.12 Choices of five words after using the WHO and JHU dashboards.

Figure 5.12 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 analysed 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 "Disorganised" but "Fun" (53.3%). In contrast, for the JHU dashboard keywords, 83.3% of participants acknowledged the dashboard to be "Organised". 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.

It is worth highlighting that in the evaluations of the WHO dashboard, "Easy to use" and "Disorganised" are both frequently used keywords among participants. However, to some degree, they are contradictory. Similarly, for the JHU dashboard, "Time-consuming" and "Slow" can be inferred through the average time taken in the experiment. However, comprehending the participants' user experience during the usage process is essential to understand the keywords "Hard to use" and "Organised" To acquire a deeper understanding of the dashboard designs, layouts, and functions that impacted the participants' user experience during usage, they were requested to provide distinct positive and negative effects of the two dashboards based on their user experiences.

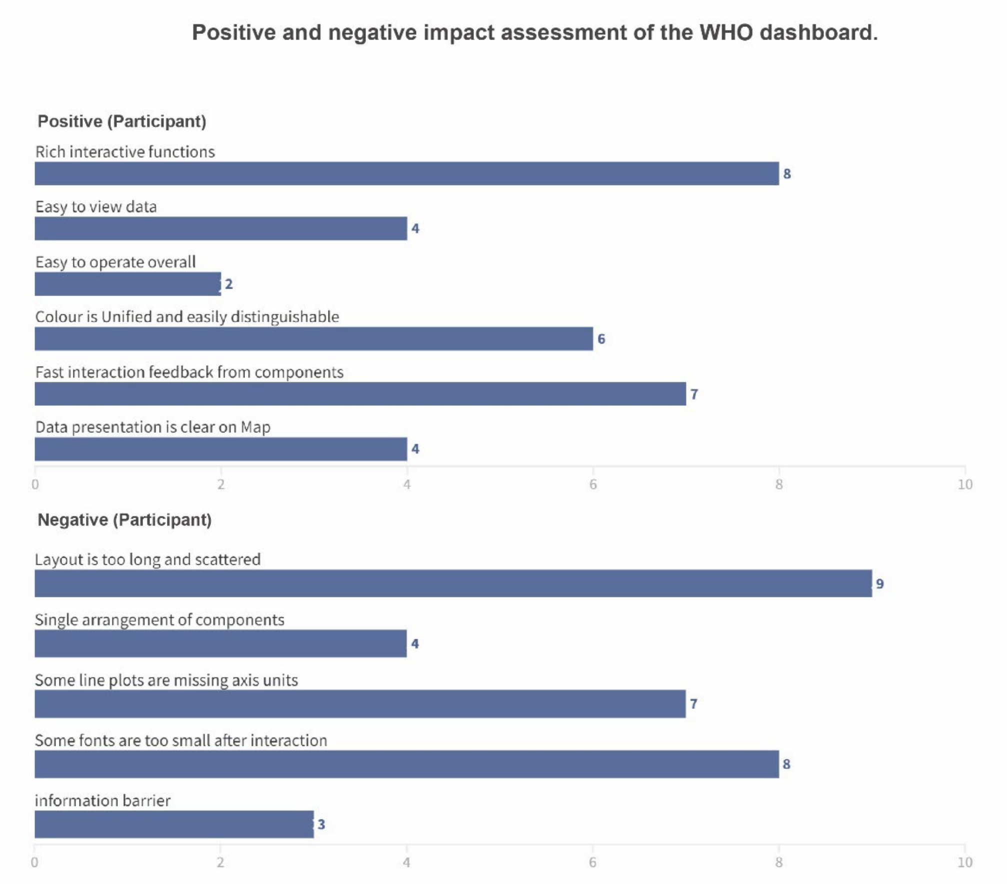


Figure 5.13 Users evaluate the positive and negative effects of the WHO dashboard during use.

Figure 5.13 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 (14 out of 30 participants) believed that the positive effects of the dashboard primarily derive from its various visualisation 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 (9 out of 30 participants) evaluated the colour combination positively, noting that the dashboard utilises fixed colours (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 colours "uniform" (6 out of 9 participants) and "easy to distinguish" (3 out of 9 participants). Moreover, 36.6% of participants (11 out of 30 participants) found that the presentation area of the visualisation tools (charts and maps) in the system provided "clear data" (4 out of 11 participants) and "timely interaction feedback" (7 out of 11 participants), thereby reducing the time required for users to view the data. On the negative aspect, it was noted that 30% of the respondents, comprising 9 out of 30 participants, espoused the belief that the "dispersed layout" (6 out of 9 participants) and "single" (3 out of 9 participants) were principally attributable to the elongated design structure, which culminates in a protracted visual movement for users whilst navigating through the information search and comparison process. According to Few (2013), when information cannot be displayed on a single screen, it disrupts user cognition due to data refresh, thus impeding the swift identification of information within the structure. Moreover, 26.6% of the participants (8 out of 30 participants) opined that there were certain "font sizes not suitable for reading" while interacting with visualisation tools. 6% of participants (2 out of 30 participants) further contended that, in certain circumstances, the information generated via mouse interaction with visualisation tools could obscure the original interface content. The preceding analysis reveals that the participants' perceived usability of the WHO dashboard stems from its adept handling of information identification. This proficiency primarily arises from the judicious manipulation of colour within the visual design, coupled with the effective design and presentation of information within the visual components. These strategies collectively facilitate users' capacity to differentiate and interact with specific data during their engagement with the dashboard. This effectiveness is congruent with the successful integration of information design elements, including colour and typography, as delineated 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. This feedback underscores the criticality of cultivating coherent relationships and interactions among diverse visual elements, an imperative that resonates within the overarching framework of the dashboard's design principles.

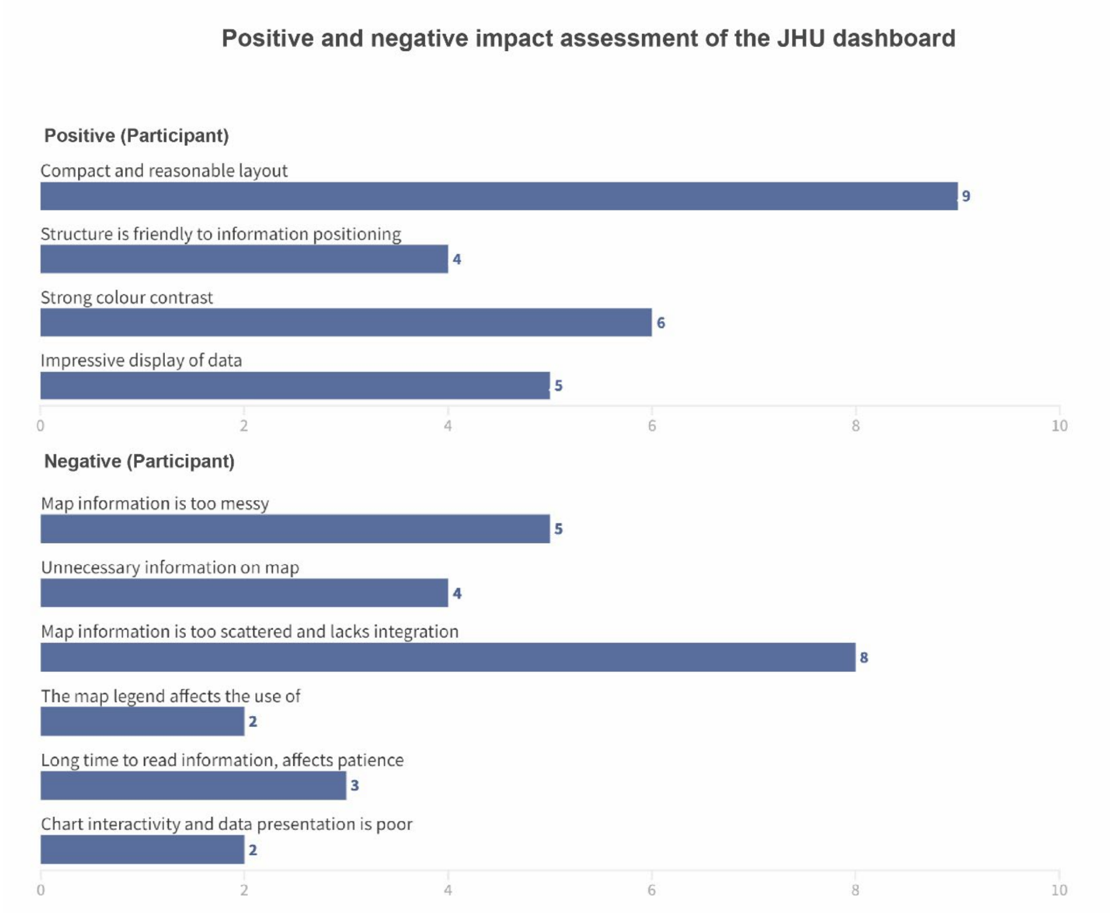


Figure 5.14 Users evaluate the positive and negative effects of the JHU dashboard during use.

Figure 5.14 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 favourably perceived by the participants. Of them, 43.3% of participants (9 out of 30 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 colour 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 visualisation 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 summarise, the participants' keyword selections and feedback underscored their favourable 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' suboptimal experiences with the JHU dashboard predominantly stemmed from the design aspects of information representation within the visualisation 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 pertinent information on the dashboard, more time was required to locate detailed information and comprehend it thoroughly. Significantly, these observations are consistent with the initial assessment of the JHU dashboard conducted at the outset of the experiment, which indicated that the JHU dashboard adhered more closely to the principles outlined in the framework concerning layout composition, component presentation, and information content.

5.3.5.3 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 opined that such a design would be effective in improving the utilisation of interface space and reducing time cost caused by excessive interface layout. Furthermore, interactive features (3 participants) or design layout (6 participants) were proposed to assist users in filtering and searching for specific information. Additionally, 20 of participants suggested modifications to the map tool in the dashboard, as it represented the users' "best" choice in the experiment. Some of these modifications included defining different countries and regions through colour instead of individual red dots (8 participants) and minimising the impact of unnecessary information on the map, such as detailed highways (6 participants), providing map legend explanations (2 participants), and enhancing information transparency generated by interaction to reduce information blockage (4 participants). Seven participants suggested the adoption of fixed colours for important information types, which would increase their representativeness and reduce user-defined information. Furthermore, 3 participants suggested reducing the saturation of colours, as high saturation brings strong contrast, making the dashboard "impressive," but also causing users to experience visual fatigue easily during use. In addition, some participants (2 participants) suggested increasing the font size generated by interaction to aid users in reviewing specific information in the visualised chart. Two other participants suggested that the visualised chart clearly specify data units and measurement values, such as the x and y axes. Figure 5.15 presents the participants' design suggestions for the dashboard.

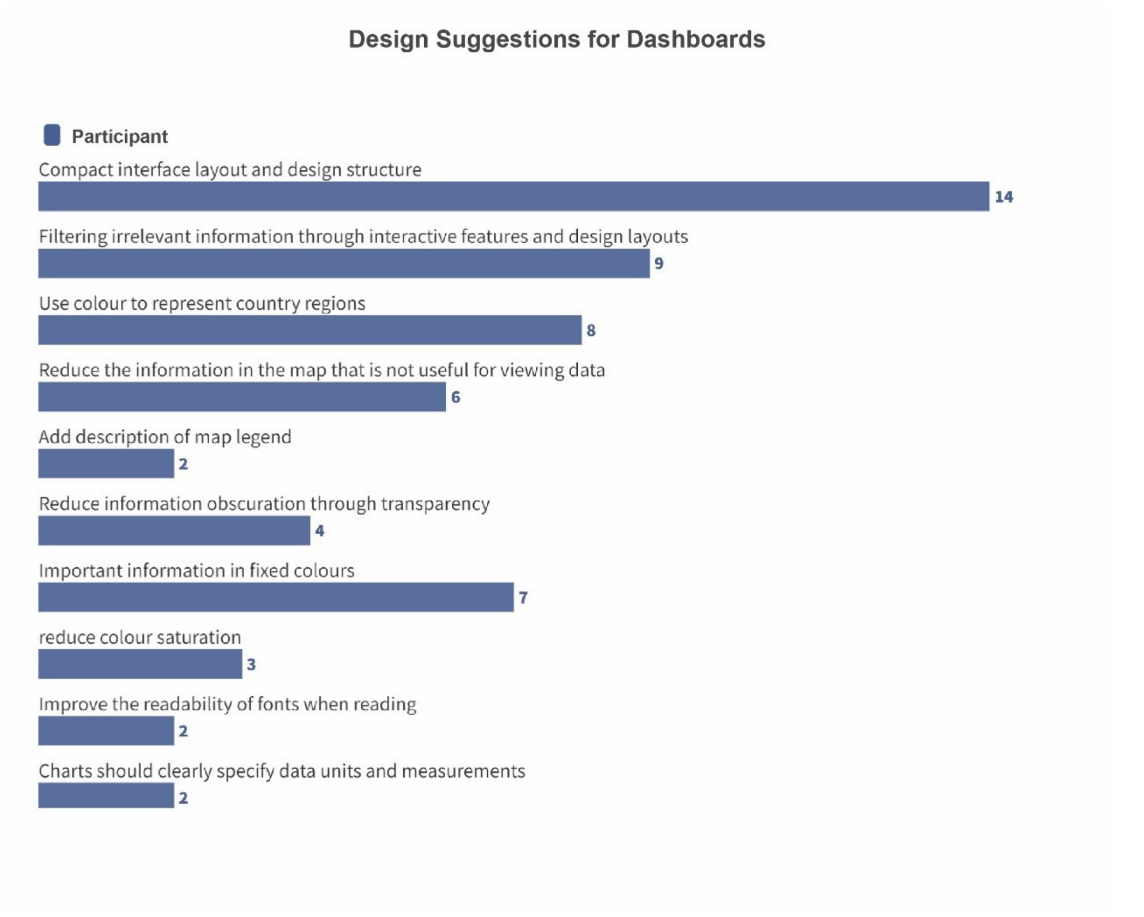


Figure 5.15 Design Suggestions for Dashboards from Participants.

5.3.6 Summary and Discussion

To determine the design factors that affect reading strategies and legibility in dashboards, an experiment was conducted to measure the reading performance of users in two different types of dashboards through various tasks, 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 analyse users' information search behaviour, thereby gaining a deeper understanding of the issues related to information structure and visual elements. Additionally, the design suggestions provided by the 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 information structure and visual design from the testing. A more comprehensive analysis of the users' information search behaviour may aid in improving the design based on the user's usage habits and user experience.

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, economising 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 and owing to the absence of fixed navigation at the top, the 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 utilisation 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, the 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 utilisation 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, 2003; Tan et al., 2013).

Another observation made during the experiment regarding the design pertains to the hindrance in promptly locating information due to the arrangement of the country list in the JHU dashboard. It was noted by the participants that the list was arranged based on the total data of the country's epidemic 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 organising the list based on total data does not accurately reflect the current stage of the epidemic 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 organised, presented, and arranged in various ways to cater to the needs of individuals. Therefore, an interactive way to arrange the information list can be incorporated to fulfil 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 pertinent information, the individuals still opted to dedicate a substantial amount of time searching for information in the map legends. This conduct signifies that users are inclined to employ and rely on the map component when accessing dashboard data and expect to locate the information they require directly in the map component, rather than exploring other aspects of the system. This user conduct emphasises 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 and Ruas, 2009). In the present 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 summarise the data for users through the "red dots" in the map component. Moreover, the participants also reported that the explanation of the "red dots" in the map legend was unwieldy and not explicit enough, which led to the necessity of repeated comparisons to the legend. Fareed et al. (2020) contend 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, necessitating users to reposition the mouse. The issue of information overlap refers to the transient information produced during interaction but not overlapping (Hunt and Cavanagh, 2011), and this problem is also widespread in many existing visualisations. 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 utilise an untested design scheme and instead conduct first testing of the design (Brasseur, 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, colour schemes, display styles, etc.

Another aspect of visual design quality arises from the implementation of chromatics in the visualisation of data in dashboards. In the course of the experiment, positive feedback was obtained from the participants regarding the utilisation of colour and its fixed correlation with significant data in the WHO dashboard. Nevertheless, the participants still reported encountering issues with the chromatic scheme while attempting to locate information. During Task 2, the participants conveyed that the contrast of colours 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 colours 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 colour can augment their concentration and circumvent ocular strain (Sleeper, 2019).

In summation, the experiment serves as a comprehensive investigation into user performance within diverse dashboard types, encompassing tasks such as reading time and interactive interactions. This inquiry is further enriched through the meticulous analysis of users' information-seeking behaviours, 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. The participants' approach to utilising the dashboard to acquire information can be distilled into two principal stages. The initial step involves swiftly 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 scrutinising the visual components. Notably, the experiment underscores the substantial impact of design on users' information retrieval behaviours. Elements encompassing dashboard structure, layout, arrangement of information lists, map components, interactive features, and more, collectively influence users' ability to swiftly locate data while potentially introducing challenges in the information search process. Observations gleaned from the experimental process reveal the interplay between design and user behaviour. Aspects such as structure, layout, the arrangement of information, and interactive components significantly impact the speed and accuracy with which users locate information. The insights derived from participants' feedback and the observed design limitations provide invaluable direction for dashboard improvement. A comprehensive analysis of users' information-seeking behaviours enables a design refinement process that harmonises with 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 colour schemes. Recommendations from participants suggest enhancing the user experience by refining visual design attributes, encompassing aspects like transparency, colour schemes, and display styles. Additionally, the issue of colour application in data visualisation is highlighted, underscoring the significance of considering colour saturation and brightness in design to enhance user attention and mitigate visual strain. These findings effectively address the research questions posited at the commencement of the experiment.

5.4 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 analysing different layout and visual design elements in the dashboard. Dashboard designs that limit users' information-seeking behaviour 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 design were identified pertaining to information design and visual design elements that impact the location of user information. Concretely, based on the findings of all tasks, the layout structure of the dashboard was among the factors affecting the user's macro-level information categorisation. The visual elements resulted in a protracted interface length in the absence of interaction, and the location of user information necessitated frequent page scrolling and shifting. The configuration of the information list caused bewilderment in the user's search for the target information, and the logic did not correspond to the user's requirements. The utilisation of visualisation 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 visualisation interactions, and data overlays incorporated into the design led to unproductive reading time for the user and multiple misunderstandings. The findings highlight the necessity to reinforce the layout structure and information design that impact the user's ability to locate information. Additionally, during testing, another visual design problem was discovered regarding the impact of the colour scheme on the user's ability to view information. In Tasks 2 and 3 of the JHU dashboard, the intense colour saturation and brightness of the visual components negatively influenced the user's viewing experience of the data. As suggested by the participants, the colour system necessitates 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.

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 behaviour 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 recognising 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 summarising 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 optimise the usability and effectiveness of dashboards.

6 Conclusion

This chapter outlines the study's objectives, consolidates key research discoveries that address the research questions, and highlights the theoretical, practical, and methodological contributions to the existing body of knowledge. In conclusion, it outlines potential study limitations and outlines prospects for future research endeavours.

6.1 Overview of the Research

This study endeavoured to establish a comprehensive framework to articulate guiding principles for interactive information visualisation. It aims to synthesise and compile material related to the visual and interaction design factors that influence the presentation of information and user understanding when visualising as an integrated entity. This work covers two main design areas: information communication and visual interaction. In the area of information communication, the framework contains design principles related to information design that influence the creation of infographics and data visualisations. These principles encompass concepts such as Gestalt theory, panel styles, and information architecture. Visual interaction, on the other hand, mainly contains design elements that influence the user interaction process. These include structural layout, colour schemes, interaction design and related aspects. In addition, this study presents design recommendations that aim to enhance the synergy between information presentation and visual components in visualisations, thereby facilitating mutual support within the system architecture. As described in Chapter 1, interactive information visualisations constitute typical information design material. They involve data visualisation, user exploration and the completion of an information finding journey through interactive manipulation (Liu and Stasko, 2010). However, the exploration and evaluation of the design of interactive information visualisation systems from an information design perspective is still relatively rare in relevant usability studies. This lack is particularly evident in interactive dashboards designed for public use during global health emergencies. In order to address this critical gap and fulfil the research objectives articulated in Chapter 1, this study adopts an evaluative, experimental and application-oriented approach to assessing dashboards deployed during pandemics, all of which are underpinned by a user-centred approach. At the same time, a framework of design principles tailored to interactive information visualisation emerged, tested by empirical findings and existing scholarship.

The first objective of this research is dedicated to testing the integration of information and interaction design theories within the field of visualisation systems, with a particular focus on their usefulness in the context of global health emergencies. To achieve this goal, an extensive literature review was conducted covering relevant research work and design principles within the fields of information design and interaction design as they relate to information communication and user perception. The literature review was accompanied by interviews with participants who were actively involved during the epidemic, with the aim of elucidating their needs and gathering valuable feedback. This multifaceted approach combined comprehensive literature research and user insights, culminating in a robust framework of design principles. The principles were developed with the explicit purpose of empirically assessing the accessibility of interactive information visualisation systems. The framework covers these seven aspects, including everything from visual system structure layout, colours, font typography, design elements, interactive features, information content, and visual components, which together cover a large number of design elements required to effectively present information, while meeting the requirements of both visual communication and interactive features.

The second objective of this study was to identify design constraints that have an impact on the legibility of interactive information visualisation systems. In addition, it seeks to investigate how these constraints affect an individual's approach to reading speed and accuracy of comprehension. In order to achieve this objective, a framework of design principles derived from the literature review and interviews was exhaustively evaluated and applied in the case studies outlined in Chapter 4. Through case studies, public visualisation systems applied during previous outbreaks were critically assessed based on the seven assessment dimensions created by the principles framework. The assessment was designed to gather information and visual design related limitations in the case studies that affect the effectiveness of information communication, as well as to measure the effectiveness of the application of the principles framework. Therefore, the data derived from this assessment helped to explore the manifestations of visual design limitations (e.g., unclear colour schemes, crowded textual content, image quality issues, disjointed and misaligned layouts etc.) and their impact on the effectiveness of information presentation in visualisations. Subsequently, performance experiments featuring mouse tracking were conducted with the explicit goal of identifying design constraints that affect an individual's reading strategy, speed and accuracy. Both the case evaluations and performance trials apply to the third objective, which is to explore and develop effective visualisation design solutions (e.g., dashboard layouts, visual rendering of cross-component elements, and stylistic considerations) that enhance the usability and aesthetic appeal of information visualisations. The main experimental findings include:

- Visualisation components that are interactively linked (where information changes through interaction) should be tightly packed to allow users to view changes between data in a timely manner.
- When users are looking for information in a dashboard, they are more likely to recognise information with a high colour contrast, but when this type of information dominates a single visualisation, it affects the user's ability to look at it for long periods of time.
- Recommendations for the design of information presented in post-interactive layouts, especially for interactive layouts combining graphics and text.

The final objective of this study was to synthesise the insights gained from the experimental results and user interviews to provide a comprehensive summary and set of design recommendations for a prospective visualisation system in the context of global health emergencies. This objective delves into several key areas explored during the experiments and interviews. Firstly and most importantly, it investigated the impact of data presentation on the likelihood of dashboards becoming confusing when users attempt to access information. Key information design limitations revealed through mouse movement analysis included instances of confusion associated with information layout conventions, manifested as structural layout complexity and a lack of clarity in visual communication conveyed through dynamic map representations. These included the long component layout of the dashboard that resulted in the need for the user to swipe through the page, and the presentation of irrelevant information in the map that was not relevant to the dashboard and thus interfered with reading comprehension. These design limitations in turn translated into increased time spent on information retrieval and comprehension. Furthermore, it was found that through careful examination of mouse movement data, including analysis of movement trajectories and viewing durations inferred from mouse click frequency, it became clear that specific design constraints inherent in dashboards could be identified by discerning the reading behaviour of users. The final aspect of this objective revolves around exploring effective user-centred information design methods aimed at improving the readability of dashboards.

6.2 Contribution to Knowledge

This study investigated the effectiveness of interactive information visualisation systems in global health information design and interaction design. This section discusses the key findings and related contributions to knowledge to highlight how they enhance the application of existing design principles and contribute to future research. The following section discusses theoretical definitions that may contribute to the design of interactive information visualisations, findings that may enhance the effectiveness of information presentation, and key findings for information visualisation optimisation.

Firstly, this research endeavours to develop a comprehensive framework of principles suitable for interactive information visualisation systems. This work involves a careful synthesis and aggregation of a large body of literature, covering the fields of information communication and visual interaction. The synthesis entails a thorough examination of various domains including, but not limited to, Gestalt Theory, Colour Theory, Typographic Layout, Interaction Design, User Perception and Dashboard Design (both component design and display media). This iterative process includes the compilation, analysis and summarisation of academic publications. It is necessary to critically assess these publications, scrutinising the rigour of the methodologies employed, the robustness and applicability of the statistical results and the accuracy of the interpretation of the results. It is worth noting that the literature provides very little in the way of design principles that can be directly derived or generalised for visualisation in dashboards related to the presentation of information under visual interaction, especially in the field of interactive information visualisation systems as information material. In summary, the literature review begins by critically analysing the research covered, then draws in research relevant to information materials in the context of global health emergencies, and finally distils it into detailed design principles that can be applied to interactive information visualisation systems. These principles were explicitly organised into seven distinct areas based on information dissemination and visual interaction, namely: layout, colour, type layout, design elements, content, interactive features and component presentation. The judicious categorisation of these principles facilitates their application and enhances the prospect of generating effective design solutions. Furthermore, this research makes a significant contribution to the field of interactive information visualisation through the extensive compilation and interpretation of literature. The resulting framework of principles is an valuable resource not only for graphic visualisers but also for port coding engineers, enhancing their ability to optimise and enhance design output.

Secondly, the project implemented a framework of principles for case studies of public visualisations during past epidemics. The findings highlight the effectiveness of applying research-based design principles in enhancing the visualisation of information and data presentation. The findings presented in Chapter 4 highlight a significant trend: cases that integrate broader design principles in the average threshold algorithm consistently exhibit higher design performance levels. While this result may be intuitively obvious, the need for research must be emphasised in an effort to ensure that the development of a framework of principles is both comprehensive and effective in practical application. Therefore, substantiating its framework with empirical evidence is crucial for research efforts. In the absence of clear empirical evidence, one can only speculate that adhering to these design principles can enhance the effectiveness of interactive information visualisation system designs. Nonetheless, the results of the evaluation study firmly validate its utility as a basis for subsequent research investigation. Furthermore, it is worth noting that the underlying structure of the principle framework is essentially based on the constituent design elements of the visualisation system. Significant determinants that have a critical impact on the design are initially discovered through rigorous evaluation studies and subsequently become the direction of subsequent experimental research. It is important to emphasise that this assessment is primarily concerned with the effectiveness of the design, not the content. Therefore, given the widespread use of interactive information visualisation across different communication domains, these findings remain highly relevant. The evaluation data shows that for both graphic designers and coding engineers, compliance and self-checking against the principles categorised in the Principles Framework can significantly improve the effectiveness of communicating information through visualisations and make them aware of the impact of user reading in future designs. and cognitive design limitations.

Thirdly, the User Performance Experiment is a compelling demonstration of the integration of mouse-tracking technology for assessing the impact of information and interaction design in interactive information visualisation dashboards on information accessibility and user engagement. The experiment highlights the transformative potential of information design within the interdisciplinary field of dashboard design evaluation, thanks to the application of mouse tracking technology. The experiment effectively validated that mouse movement data can intuitively reflect the design of interactive information visualisation dashboards based on user reading behaviour. This approach is based on practical user-centred arguments. If a user encounters confusion while exploring a dashboard due to unclear information presentation or visual design constraints, the mouse trajectory and dwell time can pinpoint specific areas that cause user confusion. More importantly, experiments have shown that specific design constraints within a system can be identified more effectively through comprehensive analysis of mouse paths and feedback from users. For example, examination of user reading behaviour in the experiment showed that participants invested a significant amount of time reading and interacting with the information presented by the map component in the dashboard, which was evident from their mouse movements. The large number of mouse movements pinpointed the map component as the user's 'area of interest', and the duration of time invested meant that there were design constraints that prevented other participants from accessing or understanding the information. Timely user feedback and post-experiment interviews helped to elucidate these design constraints on the user experience. This also underlines the premise that mouseover data should not form the sole basis of user behaviour analysis; instead, it is recommended that this be supplemented with qualitative data (e.g., participant feedback) to enable designers to develop a nuanced understanding of the user's reading process and reduce potential analysis bias. Furthermore, research has shown that participants tend to show a tendency to prioritise the exploration of the most engaging areas of a visualisation system, contrary to the findings of Nielsen and Pernice (2010), who suggested that readers tend to start their information consumption from the top. This observation proves that general static visualisation paradigms exhibit a different behaviour than the public when using dashboard material. This behaviour can reasonably be attributed to the tendency of users to selectively engage with component areas with rich design elements and high visual complexity during self-navigation, as reflected in their mouse movements. These areas inherently convey a high level of importance within the dashboard and tend to engage users to explore more information through interactive engagement. Such user behaviours became apparent in the experimental setting through the user information retrieval process and mouse movement trajectories.

Finally, the essence of this study lies in the effectiveness of information presentation in interactive information visualisation, and for this reason, the results of this study extend their applicability to different domains that focus on information exchange and visual presentation, i.e. the investigation and implementation of usability in interactive information visualisation. In particular, the study emphasises the effectiveness of design in facilitating information exchange. This includes the emphasis on information prioritisation and navigational soundness in data visualisations based on user-centred layout structures, as well as the readability and effectiveness of information presented visually in dashboards during interaction. To this end, the utility of the framework of design principles generated through this research extends beyond the immediate scope of designing interactive information visualisation systems for emergency situations. It has the potential to serve as a guiding resource for dashboard design research in various fields, providing a summary of empirically validated best practices. In addition, the versatility of these design principles allows them to be applied to a range of other applications. For example, these principles can be judiciously applied to the field of financial data analytics to improve the quality of data visualisation components, as good visual design allows information to be effectively presented with interactive linkages. Similarly, these principles can be applied to the sharing of educational resources between design engineers with specialist knowledge, as a sensible layout structure can maximise the readability of information and user perception. In addition, the principles are useful in tailoring principles for other design outcomes with similar characteristics, such as interactive maps and web design. This versatility emphasises the enduring value of the principles derived from this research and their potential to contribute to the advancement of various design fields.

6.3 Limitations of the Study and Future Research

6.3.1 Limitations of the Study

This research project acknowledges a limitation of the Chapter 4 case evaluation experiment. In the case evaluation, the study evaluated seven aspects that affect information delivery and user usability across cases over different periods of time. However, the study acknowledged some subjectivity in the process, as the assessments were conducted by a single researcher. Ideally, more evaluators should be added and all evaluation scores should be averaged to improve the convincingness and fairness of the evaluation. This problem is remedied in Chapter 5's range testing. The number of evaluators was increased from one to five people with design experience, and the evaluation scores for various aspects of the dashboard were averaged. This minimises subjectivity in the evaluation process, and mean scores are more convincing and better illustrate differences in the design of different dashboards.

Another limitation concerns the nationality composition of the participants in the first round of questionnaires in the project. Due to the sudden nature of COVID-19 and China's movement restrictions in local areas, the researchers' questionnaire experiment was conducted during the Wuhan lockdown. Due to the inability to predict the spread of the virus (that is, the severity of the epidemic in other countries is not as severe as that in Wuhan, China), and the need for first-hand information from users, all questionnaire participants recruited were from China, and most of them were from Wuhan. This may result in users' information needs and habits being affected by national cultural differences. In future studies, recruitment conditions will be extended to the global public, but may still result in certain limitations to the research materials.

6.3.2 Future Research

In generalising the findings of this study to other public health crises and individual healthcare settings, consideration needs to be given to how to ensure that the findings are accurately representative of different populations. This includes more in-depth research on individual responses across cultures, social contexts and economic conditions to ensure the universality and effectiveness of the information visualisation design. For example, through collaboration with international organisations, healthcare professionals and communities, field surveys and interviews are conducted across cultures and geographies to gather more comprehensive data and insights. To ensure the accuracy and applicability of the findings, future studies should also employ a variety of research methods, including quantitative and qualitative analyses, as well as field observations and experiments. This will help reveal the preferences, cognitive differences, and differences in the usage experience of information visualisation design among different populations, which will guide further design and promotion efforts. In addition, in order to make the research results more widely available globally, various dissemination channels need to be utilised, including academic journals, conference presentations, social media and online collaboration platforms. Also, research data and tools can be shared through open access to facilitate wider collaboration and knowledge exchange. More than that, future research needs to work towards ensuring the universality and effectiveness of information visualisation design, taking into account the diversity and needs of different populations. This will help to better address public health challenges globally and improve people's understanding of and ability to cope with health information.

The findings of this thesis also benefit the field of information visualisation research itself. Many visualisation models or systems developed within the discipline often lack a foundational framework of design principles. Consequently, the results derived from experiments in this field frequently prioritise the viability of the model itself while neglecting the essential aspect of user experience during experimentation (e.g., Morgan et al., 2018; Li and Ma, 2018; Bernasconi and Grandi, 2021). It is worth noting that improving the effectiveness of information visualisation may make a substantial difference in experimental results. Thus, it is advisable for researchers to incorporate the framework of principles devised in this project into their experiments. This can enable a more accurate assessment of the potential and limitations associated with diverse forms of visualisation. Additionally, the applicability of the principle framework to various experiments and researchers should be contemplated in future research endeavours. Furthermore, there is room for further exploration of experimental approaches concerning the legibility of visualisation tools for data presentation to address the limitations of potential research methods encountered in this study. For example, future experiments could simulate the ability of users from different cultural backgrounds to receive and understand information through different terminals. This could help to check whether there is a relationship between the presentation of information visualisations and external factors. Furthermore, the integration of certain techniques into future studies, such as EEG technology, is expected to extend empirical research on users' sensitivity to emotional aspects of information design.

Moreover, forthcoming research endeavours will explore the application and enhancement of interactive information visualisation in prospective settings, encompassing public health and healthcare field. Interactive information visualisation has witnessed widespread utilisation throughout the COVID-19 pandemic, and its efficacy in presenting and disseminating interactive data has resulted in favourable changes in public behaviour, augmenting comprehension and attentiveness to pertinent information during the crisis (Budd et al., 2020; Padilla et al., 2022). Elevating the quality of information presentation within these visualisation systems can notably expedite user information orientation, enhance retention, and influence user perceptions. As the current study demonstrates, the way in which individuals access outbreak information through interactive information visualisation systems has the potential to influence compliance with public health directives and potentially reduce the recurrence of outbreaks. Future research is therefore encouraged to delve deeper into the effectiveness of optimising interactive information visualisations in different contexts and cultural environments, and to test whether they do indeed have a substantial and positive impact on user behaviour. Using dashboards (an important medium for information visualisation during the COVID-19 pandemic) as a communication tool and case study in this research, it is necessary to apply a design principles framework to redesign these dashboards. Subsequently, it could be investigated whether public education using these enhanced infographics would increase vaccination rates or improve adherence to social distance measures compared to the less effective original design. Although the immediate pressures of the COVID-19 pandemic have waned, most regions today still have crisis events of varying severity and the continued dissemination of public health information remains relevant. Therefore, the potential application of the results of this project holds great promise for future public health communication efforts.

In conclusion, there is a need for an in-depth study on the presentation of information visualisation on alternative electronic platforms. In today's world, more and more people are accessing information through highly portable and convenient terminals such as smartphones (Sarwar and Soomro, 2013; Siuhi and Mwakalonge, 2016), and more convenient digital terminals are becoming particularly evident in Asian countries. This shift has led to an increase in the facilitation of information interactions via finger-operated touchscreens, thus narrowing the gap between users and the information displayed on their screens (Jacucci et al., 2010; Hinckley et al., 2016). Therefore, upcoming research will focus on establishing direct interactions with users by customising visual display terminals and presentations to accommodate the information needs inherent in public health scenarios between countries that may be due to cultural practices. This will require customising visual display terminals and presentations to harmonise with the prevailing environment. Design solutions will focus on conveying information that is compatible with user behaviour, which may vary from one electronic terminal to another. Based on the findings of this paper, the principles of information design in interactive systems will be extended to facilitate the development of customised interactive information visualisation designs for various terminal platforms.

6.4 Conclusion

In summary, this thesis interprets interactive information visualisation systems developed in global health emergencies over the last few years, based on the principles of information design and interaction design. It provides new design insights and theoretical perspectives for better public use and understanding of data. To this end, interactive information visualisation systems applied in COVID-19 pandemics and previous health crises were selected, evaluated and tested. Evaluation of these cases focused primarily on the effective application of a framework of design principles, while user performance testing focused on the impact of these principles on user reading speed and information search accuracy. Limitations and relevant information design approaches are summarised through analysis of user behaviour and feedback, with the ultimate aim of improving the readability of visualised information.

Design principles are recognised as a means of enhancing information visualisation. Therefore, a comprehensive review of relevant research publications was conducted, resulting in the creation of a framework of design principles based on seven key aspects of interactive information visualisation. Starting with information and interaction design aspects that affect information dissemination and user perception, principles were collected for structure, colour, typography, design elements, interactive features, content and display modes. Subsequently, the applicability of these principles was explored in the context of global public health, and examples of practical visualisation systems from different epidemiological periods were evaluated, which showed that the more principles that were applied, the more effective the system's visualisation design output was. This approach to evaluating visualisation as a whole of information systematically assesses aspects of the whole system and makes it easier to distinguish specific system components that affect user perception and information dissemination.

This study provides new recommendations for the layout of information presentation in interactive information visualisation systems in health emergencies. It was found that layouts that minimise or avoid mouse scrolling (e.g., compact layouts) are more effective in helping users read and compare information in a visualisation system. Such layouts better reflect the advantages of interaction in synchronising information presentation, i.e., displaying information comparisons after user interaction. In addition, research has shown that information presented interactively in a visualisation component appears more cohesive when it is tightly arranged, and that the layout should be tailored to the specific visualisation choices and provide appropriate visual cues to prevent overlapping of important information.

In addition, this study analysed an information visualisation dashboard in health emergencies using mouse-tracking techniques to assess the quality of information dissemination in user operations. Various practical conclusions were drawn from the design and analysis of the mouse tracking tests. It was found that data reflected in user mouse behaviour should not be relied upon exclusively, but should be supplemented with qualitative data such as mean time, number of clicks and user feedback. This approach helps designers to understand more accurately the process by which users read information and interact with the system, thereby reducing potential bias in analyses. Importantly, it has been observed that users' perceptions do not always correspond exactly to their behaviour. Therefore, design improvements to meet user needs must be based first and foremost on a well-researched framework of design principles, and not solely on subjective preferences or aesthetic considerations.

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Appendix

Communication of viruses to the public – the Novel Coronavirus (2019-ncov)

You are being invited to participate in a survey conducted for doctoral research and the University of Leeds (UK) to investigate the importance of information visualization as an effective means to communicate guidance on the transmission and prevention of deadly viruses to the public in a global health emergency. This questionnaire will focus on the outbreak of the novel coronavirus (2019-ncov).

Your help is much appreciated and your participation in this study is entirely voluntary and you can withdraw at any time during the questionnaire. All answers are anonymous.

We believe there are no known risks associated with this research study. However, as with any online related activity, the risk of a breach is always possible. To the best of our ability your participation in this study will remain confidential, and only anonymised data will be published. We will minimise any risks by retaining all the data digitally in a project folder on a drive on the University of Leeds' servers, which can only be accessed by authorised staff associated with this project.

The entire questionnaire will take approximately 15 minutes to complete.

If any issues arise, please bring them to the attention of the researcher: Jiacheng Yue (sdjyu@leeds.ac.uk).

We would like to thank you very much for taking part in this project. Your collaboration is very much appreciated.

1.Please confirm that you understand your participation in this study and that you give permission for the members of the research team to access the anonymised responses and publish the results in academic papers and reports. *

- ◯ I confirm

2.What is your nationality? *

3.What is your gender? *

- ◯ Female
- ◯ Male

Appendix 1 Information Sheet (Online Questionnaire)

4.What is your current age? *

- ◯ Under of 18
- ◯ 18~24
- ◯ 25~30
- ◯ 31~40
- ◯ 41~50
- ◯ 51~60
- ◯ Above 61

5.What is your education level? *

- ◯ Primary school
- ◯ High school/ secondary school or equivalent
- ◯ Vocational/ technical school or college
- ◯ College/ university graduate
- ◯ Some postgraduate education
- ◯ Postgraduate or professional degree

6.Which city and country were you living during the Coronavirus outbreak (mostly during January and February 2020)?

[请选择省份 ▾] [请选择城市 ▾] [请选择区/县 ▾]

7.What is your present occupation? *

- ◯ School students
- ◯ Government / government officials / civil servants
- ◯ Enterprise managers (including grassroots and middle and senior managers)
- ◯ General Staff (office/office staff)
- ◯ Professionals (e.g. doctor/lawyer/sports/journalist/teacher, etc.)
- ◯ Ordinary worker (eg factory worker/manual worker, etc.)
- ◯ Business services staff (e.g. sales staff/shop staff/waiters, etc.)
- ◯ Self-employed/contractors
- ◯ Freelancer
- ◯ Farming, forestry, animal husbandry and fishery labourers
- ◯ Retire
- ◯ No professional
- ◯ Other Professionals (please specify) ________

Appendix 2 Information Sheet (Online Questionnaire)

8.Were you infected with the novel coronavirus(2019-ncov)? (This question is optional)

- ◯ I was infected with novel Coronavirus
- ◯ I now have novel Coronavirus
- ◯ I have not been infected with novel Coronavirus

9.How interested were/are you in knowing in detail about the new coronavirus (2019-ncov)? *

◯ 1 ◯ 2 ◯ 3 ◯ 4 ◯ 5

Not very interested Very interested

10.How did/do you seek information about the novel coronaviruses (2019-ncov)? (You can select more than one) *

- ☐ Look the daily news in the public media for information on the virus
- ☐ Use the Internet to search for information
- ☐ Consult trusted organisations such as Government, WHO (Work health Organisation), Institutions where you work
- ☐ Discuss with friends and family to get relevant information
- ☐ Other ______

11.What are the things that concern(ed) you the most about the new coronavirus (2019-ncov) itself? (You can select more than one) *

- ☐ What does the virus look like
- ☐ The cause of widespread and infection in people
- ☐ The target group more susceptible to be infected
- ☐ The symptoms of infected people
- ☐ Whether there is a cure
- ☐ Whether experts are working on producing a vaccine
- ☐ Ways to avoid and prevent infection by the virus
- ☐ How it compares with previous coronaviruses (such as SARS)
- ☐ Other more clinical and detailed information (such as mutation of virus and route of infection)
- ☐ Other ______

Appendix 3 Information Sheet (Online Questionnaire)

12.During an outbreak of a new coronavirus, what information are you most concerned about? (You can select more than one) *

- ☐ Total number of new cases, deaths, cures per day
- ☐ The measures and announced by the government
- ☐ The effect of the measures
- ☐ State of the city (traffic/supplies/cases)
- ☐ Special hospital locations
- ☐ Medical resource(team and experts)
- ☐ Case data from other countries and related news
- ☐ Transparency of material donations
- ☐ Refute rumors
- ☐ Preventive measures
- ☐ Disease knowledge
- ☐ Real-time growth of the epidemic trend map
- ☐ Other ______

13.During the outbreak, governments strongly advised people in Wuhan to stay at home and people travelling from Wuhan to self isolate themselves. In these situations, what do you think is the best way to spread the information and why? *

- ○ Through the government and the community to inform every household, to ensure that information is available
- ○ It is convenient and fast to circulate information through the network

14.List any omissions in the information you have found about the new coronavirus (2019-ncov)? *

- ○ Yes ______
- ○ No

Appendix 4 Information Sheet (Online Questionnaire)

15.What type of medium do you prefer to use when looking/reading information? (You can choose more than one) *

- [ ] Mobile phone

- [ ] Television

- [ ] Ask people

- [ ] Newspapers

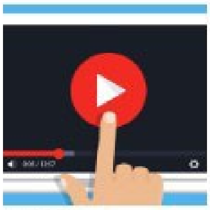
- [ ] Computer

- [ ] Other

17.What type of information communication do you think is most appropriate for the current phase of the epidemic? (You can choose more than one) *

- [ ] Visual information such as information graphics and data visualisation

- [ ] Basic text information



- [ ] Video

- [ ] Print based information

- [ ] Environmental information

- [ ] Other

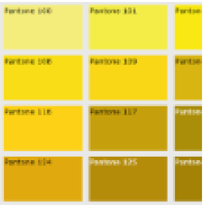
Appendix 5 Information Sheet (Online Questionnaire)

19.Nowadays, there are many infographic to disseminate data information about COVID-19 (2019-NCOV)? (Click on the "infographic" to see an example) *

20.Which colour palettes do you think are appropriate for showing the virus information? (You can select more than one) *

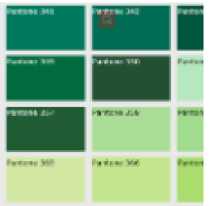
☐ Red

☐ Blue



☐ Yellow

☐ Orange



☐ Green

☐ Purple

☐ Other

22.If you came across visual information (e.g. information graphics and data visualisation), what were the POSITIVE aspects? *

23. If you came across visual information (e.g. information graphics and data visualisation), what were the NEGATIVE aspects and how could they be improved? *

24.What do you think of this Interactive information visualisation? (Click to view the example) *

○ 1 ○ 2 ○ 3 ○ 4 ○ 5

don't make sense — I like it that way

26.Can you give some examples of visual information that you remember? (You can paste links to any websites)

27.Overall, was information about the new coronavirus (2019-ncov) easy to find? *

○ 1 ○ 2 ○ 3 ○ 4 ○ 5

Not very easy Very easy

28.Overall, was information you found about the new coronavirus (2019-ncov) clear and easy to understand? *

○ 1 ○ 2 ○ 3 ○ 4 ○ 5

Not very clear and easy t Very clear and easy to un

29.Overall, was information you found about the new coronavirus (2019-ncov) helpful? *

○ 1 ○ 2 ○ 3 ○ 4 ○ 5

Not very helpful Very helpful

30.Overall, was information you found about the new coronavirus (2019-ncov) communicated in an effective way? *

○ 1 ○ 2 ○ 3 ○ 4 ○ 5

Not very effectively Very effectively

31.Overall, did the information you found about the new coronavirus (2019-ncov) grab your attention due to its design? *

○ 1 ○ 2 ○ 3 ○ 4 ○ 5

Not at all Very much so

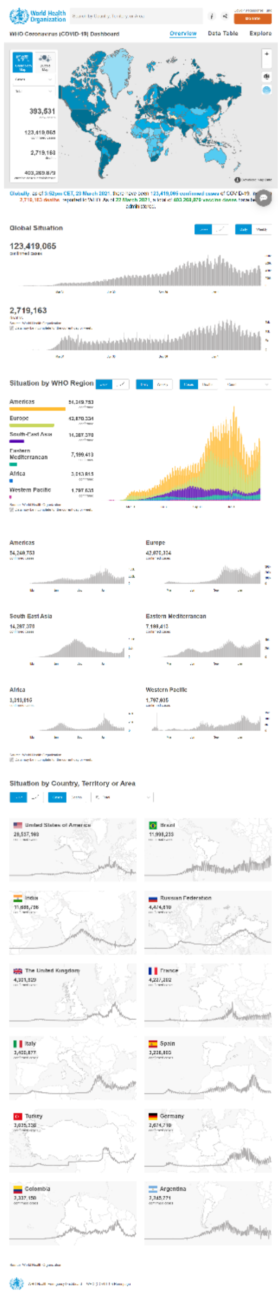
33.Any further comments about the way information was communicated and designed?

34.Would you like to leave your email address to help with my research in the future? *

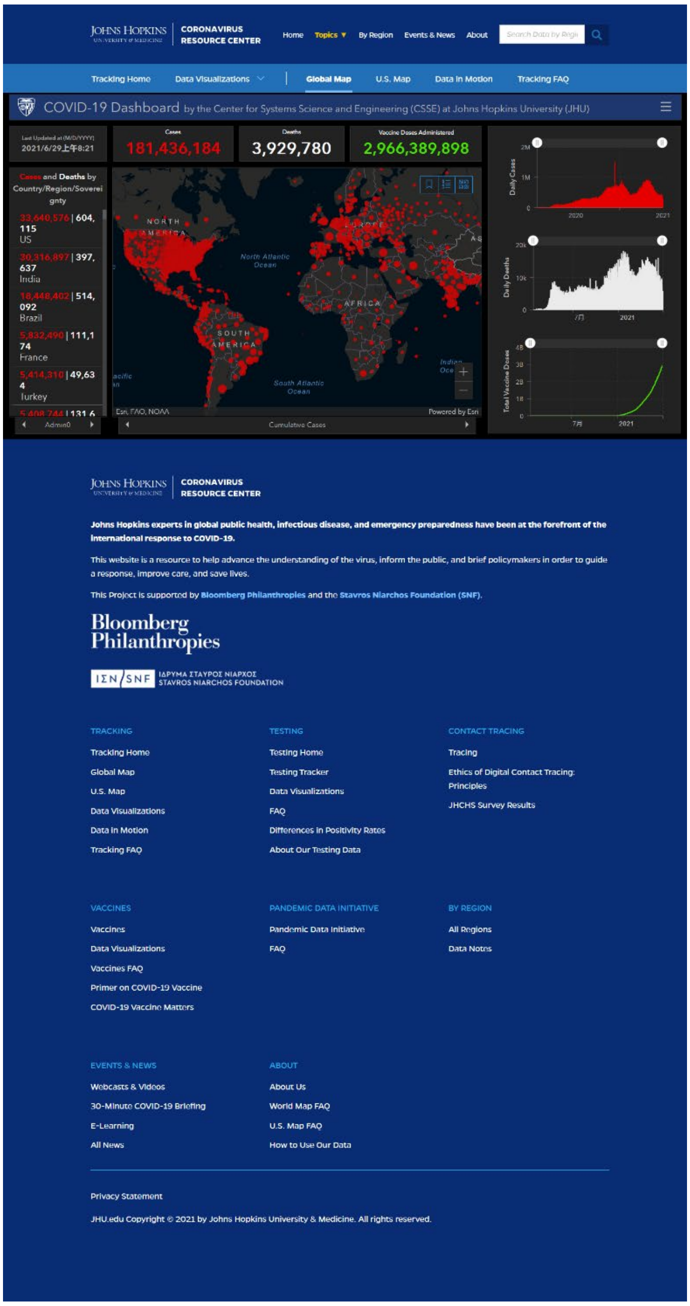
Appendix 6 Information Sheet (Online Questionnaire)

Classification	Description	Reference
Layout	Ensure that the system layout reduces page switching and scrolling interaction so that the same type of data exists in the same page space	Nielsen, 2002; LePage & Andrew, 2020; Few, 2006; Bach et al., 2018; Pettersson, 2019
	Important data and information should appear in the most conspicuous position on the screen. Reject the second click or operation (swipe or click)	Nielsen, 2002; Few, 2006; Bach et al., 2018; Hullman & Bach, 2018; Zheng et al., 2021
	Use a clear and simple layout structure and avoid useless decoration. It not only does not help users understand the meaning of the data faster, but it will directly affect the speed at which users understand the data	Few, 2006; Pettersson, 2019; Murray 2017; Bladder et al., 2011
	Place related objects (such as images and explanatory text) together so that users can explain that they are grouped	Few, 2006; Hick, 2009; Lechner, 2014
	Ensure that the overall system (e.g., content style, framework, general information) is reflected in the overview instead of too much detail and precision).	Nielsen, 2002; Few, 2006
	Get an overview of the entire collection in the layout system (e.g., main options, data map information, etc.)	Nielson, 2002; Shneiderman, 2008
	Use similar layouts in different pages of the system to effectively reduce the cognitive burden of users	North and Shneiderman, 2003; Bach et al., 2022; Roberts 2007
	The arrangement of the layout should be meaningful based on the test environment so that users can understand the meaning between components	Concen et al., 2022; In & Lee, 2017; Andrade, 2019
	Make sure that the layout structure of the entire system caters to the components so that they can be well integrated.	Bach et al. 2022; Few, 2006; Nielsen, 2002
Font	Choose simple fonts and avoid design elements that may draw unwanted attention or reduce the legibility of information	Black, 1990; Hartley, 1994
	Use 14 to 16 point font size for body text	Chapman, 2019; Tiao, 2017
	Display text in a simple, uncluttered style to prioritise text readability	Few, 2006; Bernard, 2002; Amdur, 2007
	Use a typeface design that is more suitable for the screen to display text in the system	Bernard et al., 2002
	When using font weights, put good readability first	Robinson, 1985
	Under different terminal display, the font size between desktop text and mobile text should be kept at about 38% to achieve the premise of optimal reading	Kennedy, 2018
	Use line spacing of 1.5 or 2 to optimise the legibility in a block of text	Bernard, 2002
	Justify text to the left to optimise legibility of online text	Schalk, 2007
Colour	The connection between colour and content is not just a decorative tool, but in line with the meaning of information transmission	Hartley, 2004; Few, 2005
	When using colour you must fully understand the background. Reject the presence of complementary colours (such as backgrounds, graphics, and text) that do not conform to colour harmony	Moore et al. 2005; Pettersson, 2019
	Display relevant information using the same or gradient colours, and the maximum number of gradients shall not exceed 4 colours	Wesley & Moore, 1999
	When defining different types of information, ensure that the colours are clearly different, so that the difference in colour is clear.	Pettersson, 2019
	Use colour to draw attention and accent colours to bring out the most important information.	Wichmann et al., 2002; James, 2014
	Limit the colour to 2 or 3 tones (no more than 5) to reduce visual clutter, changing chromaticity and value	Few, 2006; Stone, 2006
	Visual presentation contrast ratio of colour brightness to text and images of at least 4.5:1	Webaim, 2021
	Create enough contrast between foreground and background colour to optimise visual legibility	Few, 2006; Hick, 2009; Lechner, 2014
	Ensure strong colour contrast between variables and emphasise important statistics	Stones & Gent, 2015
Element	Clarify the functions of icons and buttons to reduce user confusion caused by excessive decorative meanings	Few, 2006
	Maintain a consistent design style (the same function button should not have multiple design styles)	Heller and Illc, 2001; Kimball, 2013; Heller 2013
	Avoid trying to include too much information in one chart, use animations optional and user-user-controlled to make the chart more simplified	Nielsen, 1992; Few, 2006; Lechner, 2014
	Use simple histograms to clearly display information. Avoid using stacked or three-dimensional histograms to interfere with the viewing of information	Gillian & Bichmer, 1994; Few, 2006
	In order to make the measurement meaningful, we must know the content to be measured and the expression unit of the measurement. If a measurement method is not the clearest and most effective way to convey what the dashboard viewer should understand, then the measurement method is flawed	Nielsen, 1992; Few, 2006; Tijus et al., 2007
	Ensure strong colour contrast between variables and emphasise important statistics	Stones & Gent, 2015
	Avoid using complex image backgrounds on chart, ensure consistent styles between chart of infographics	McCready, 2016
	Ensure that the graphics clearly represent the information they are visualising	Stones & Gent, 2015
	By displaying the selected content in each menu, clearly mark where the user is in the system and where they can go (menu formats should be fixed and easily visible)	Tognazzini, 1992;
		Few, 2006
	Designing visually good media components can convey information clearly and effectively without distracting people. (e.g., have enough fitting space and interval to display data in the chart)	Few,2006;
		Hicks, 2009
Content	Consistency should be maintained in system interface design and operation sequence (e.g. the content or display of the same attribute should use the same color, terminology)	Tognazzini, 1992;
		Shneiderman et al., 2016
	When appropriate, the instructions for use of the system should be visible or easily retrieved (e.g. reduce cognitive burden for users search through fuzzy matching)	Nielsen, 1992
	Data should not contain irrelevant information or rarely needed information (e.g., useless decorations. It cannot help users understand the meaning of data faster, on the contrary, it will directly affect the speed of users' understanding of data)	Few, 2006
	Metadata should exist to explain the source, purpose, intent, and other context of the data	Chapple, 2009
	Allows the user to see the exact values in the table and minimizes the data format and presentation of the content	Few, 2013; Sawyer, 2021;
		Bach et al., 2018
Interactive function	The system should let users understand what is happening through appropriate feedback within a reasonable time (e.g., display a progress bar to feedback the loading of the system; Corresponding actions performed through feedback messages, etc.)	Nielsen, 1992; Hicks, 2009;
		Dorman, 2013
	Interactive functions should be clear and easy to operate (e.g., clearly mark the zoom in and zoom out buttons on the map; clear filters around the diagram)	Nielson, 1992; Shneiderman, 2008
	Highlight all buttons and functions (e.g., through colour, background, font size and thickness, etc.)	Nielsen, 1992
	Save the history of user operations to support undo and restore operations	Mayhew, 1992; Shneiderman, 2003
	Allow users to share and download system data to facilitate presentation and sharing on various platforms (e.g., social media or link format etc.)	(Nielsen, 1992; Shneiderman, 2003)
Display pattern	The presentation of the data in the system should use the same interactive scene (e.g. the data pop-up or way, format or layout), even if the presented data is different	Nielson, 1992
	The value should be adjusted in time with the relationship between the items (under the same interface, if the data is adjusted, the corresponding map and table should be changed in a consistent manner to correspond to the display of the data)	Mayhew, 1994; Nielsen, 1992;
		Shneiderman, 2003
	Keep the display simple, merge multiple system pages to reduce the frequency of users repeatedly jumping to view	Nielsen, 1992; Few, 2006
	Incorporate 'see & point' techniques rather than 'remember & type' (e.g., place the display content and related interactive functions in the same place where the system page is visible)	Shneiderman et al., 2016
	Users can easily open and find the location of the system to ensure the basic operation of the system (e.g. the open, enter information, execute or cancel)	Mayhew, 1992; Nielsen, 1992; Shneiderman, 2003
	Place related objects (e.g. images and explanatory text) together so that users can understand that they are grouped	Nielson, 1992; Hicks, 2009
	Avoid clutter. Information should appear in a natural and logical order (e.g. present information in an orderly sequence, logical structure, timeline, or prioritized by importance)	Norman, 1988; Mayhew, 1992; Nielson, 1992
	Ensure proper support for mapping different data attributes to visual variables including position, color, texture, motion, etc.	Nielson, 1992; Ware, 2019

Appendix 7 Interactive information visualisation principle framework



Appendix 8 Dashboard lab materials used by participants in performance testing (1)



Appendix 9 Dashboard lab materials used by participants in performance testing (2)

The opinion of public to dashboard – the seeking and understanding COVID-19 data

You are being invited to participate in a survey conducted for doctoral research and the University of Leeds (UK) to investigate the importance of information visualisation as an effective means to communicate guidance on the transmission and prevention of deadly viruses to the public in a global health emergency. This questionnaire will focus on the participants' opinions of operational and visual in the existing COVID-19 dashboard.

Your help is much appreciated and your participation in this study is entirely voluntary and you can withdraw at any time during the questionnaire. All answers are anonymous.

We believe there are no known risks associated with this research study. However, as with any online related activity, the risk of a breach is always possible. To the best of our ability your participation in this study will remain confidential, and only anonymised data will be published. We will minimise any risks by retaining all the data digitally in a project folder on a drive on the University of Leeds' servers, which can only be accessed by authorised staff associated with this project.

The entire questionnaire will take approximately 10-15 minutes to complete.

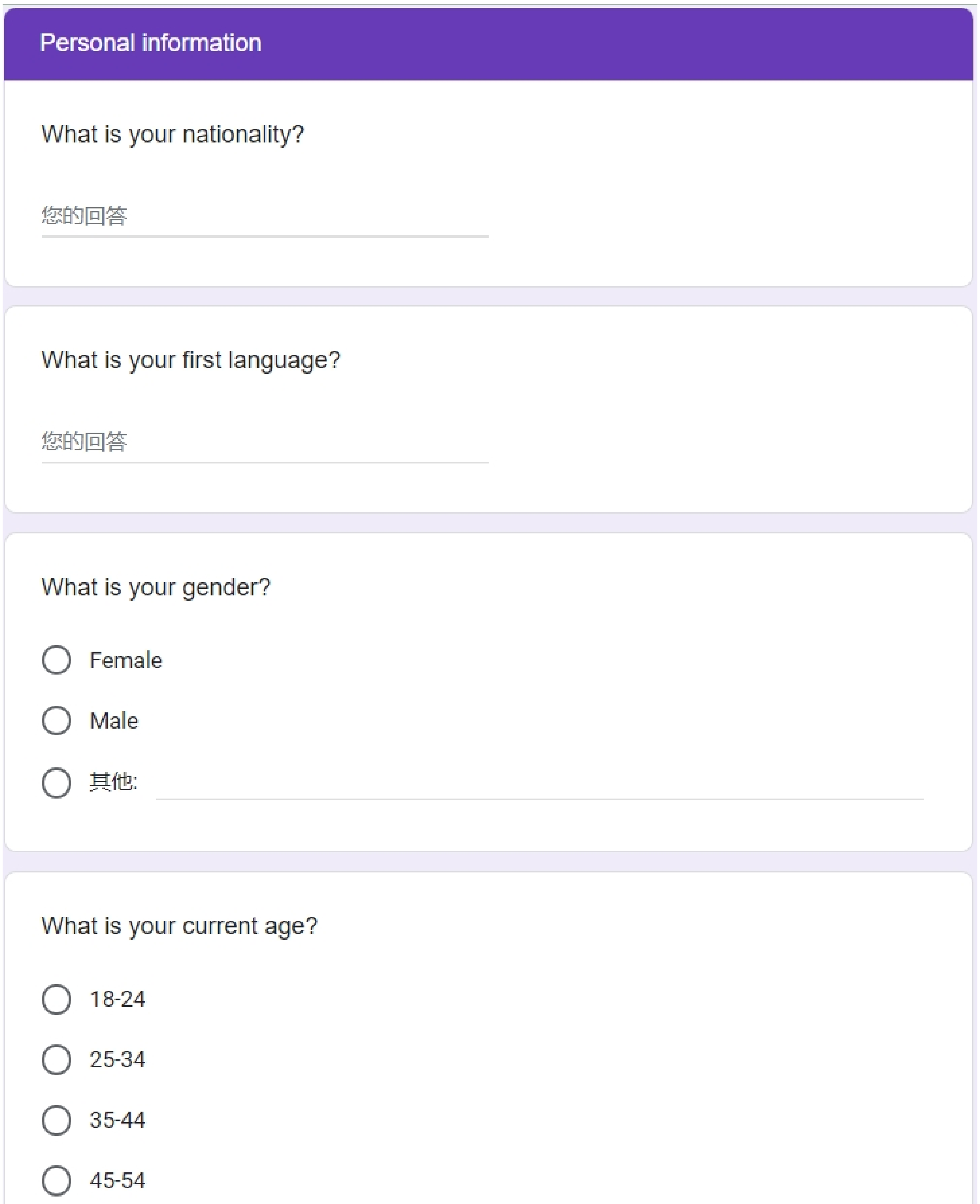
If any issues arise, please bring them to the attention of the researcher: Jiacheng Yue (sdjyu@leeds.ac.uk).

We would like to thank you very much for taking part in this project. Your collaboration is very much appreciated.

Please confirm that you understand your participation in this study and that you give permission for the members of the research team to access the anonymised responses and publish the results in academic papers and reports.

○ Yes

Appendix 10 Interview questions after user performance test



Personal information

What is your nationality?

您的回答

What is your first language?

您的回答

What is your gender?

- Female
- Male
- 其他:

What is your current age?

- 18-24
- 25-34
- 35-44
- 45-54

Appendix 11 Interview questions after user performance test

- 55-64
- 65-74
- 75+

Have you used any interactive visualisation dashboards to seek COVID information before?

- Yes
- No

Experience and opinion about the COVID-19 dashboard WHO(World Health Organization)

How easy is it to FIND COVID-19 data information with the WHO dashboard?

	1	2	3	4	5	
Not very easy	○	○	○	○	○	Very easy

How easy is it to UNDERSTAND the Covid data information with the WHO dashboard?

	1	2	3	4	5	
Not very clear and easy to	○	○	○	○	○	Very clear and easy to

Appendix 12 Interview questions after user performance test

In the process of finding and then understanding the information on the WHO dashboard, what are the POSITIVE aspects of your experience as a user? List up to 3.

您的回答

In the process of finding and then understanding the information on the WHO dashboard, what are the NEGATIVE aspects of your experience as a user? List up to 3.

您的回答

Please choose 5 keywords from the picture that you think represent your experience with WHO dashboard

- ☐ Fun
- ☐ Boring
- ☐ Clear
- ☐ Confusing
- ☐ Easy to use
- ☐ Hard to use
- ☐ Effective
- ☐ Ineffective
- ☐ Organised

Appendix 13 Interview questions after user performance test

- [ ] Disorganised
- [ ] Attractive
- [ ] Unattractive
- [ ] Meaningful
- [ ] Too technical
- [ ] Responsive
- [ ] Slow
- [ ] Relevant
- [ ] Irrelevant
- [ ] Easy to access
- [ ] Time consuming

Are there any further comments and suggestions regarding the design of the WHO dashboard?

您的回答

The experience and opinions for existing COVID-19 dashboard JHU(Johns Hopkins University)

How easy is it to FIND COVID-19 data information with the JHU dashboard?

1 2 3 4 5

Appendix 14 Interview questions after user performance test

Not very easy ○ ○ ○ ○ ○ Very easy

How easy is it to UNDERSTAND the Covid data information with the JHU dashboard?

	1	2	3	4	5	
Not very clear and easy to understand	○	○	○	○	○	Very clear and easy to understand

In the process of finding and then understanding the information on the JHU dashboard, what are the POSITIVE aspects of your experience as a user? List up to 3.

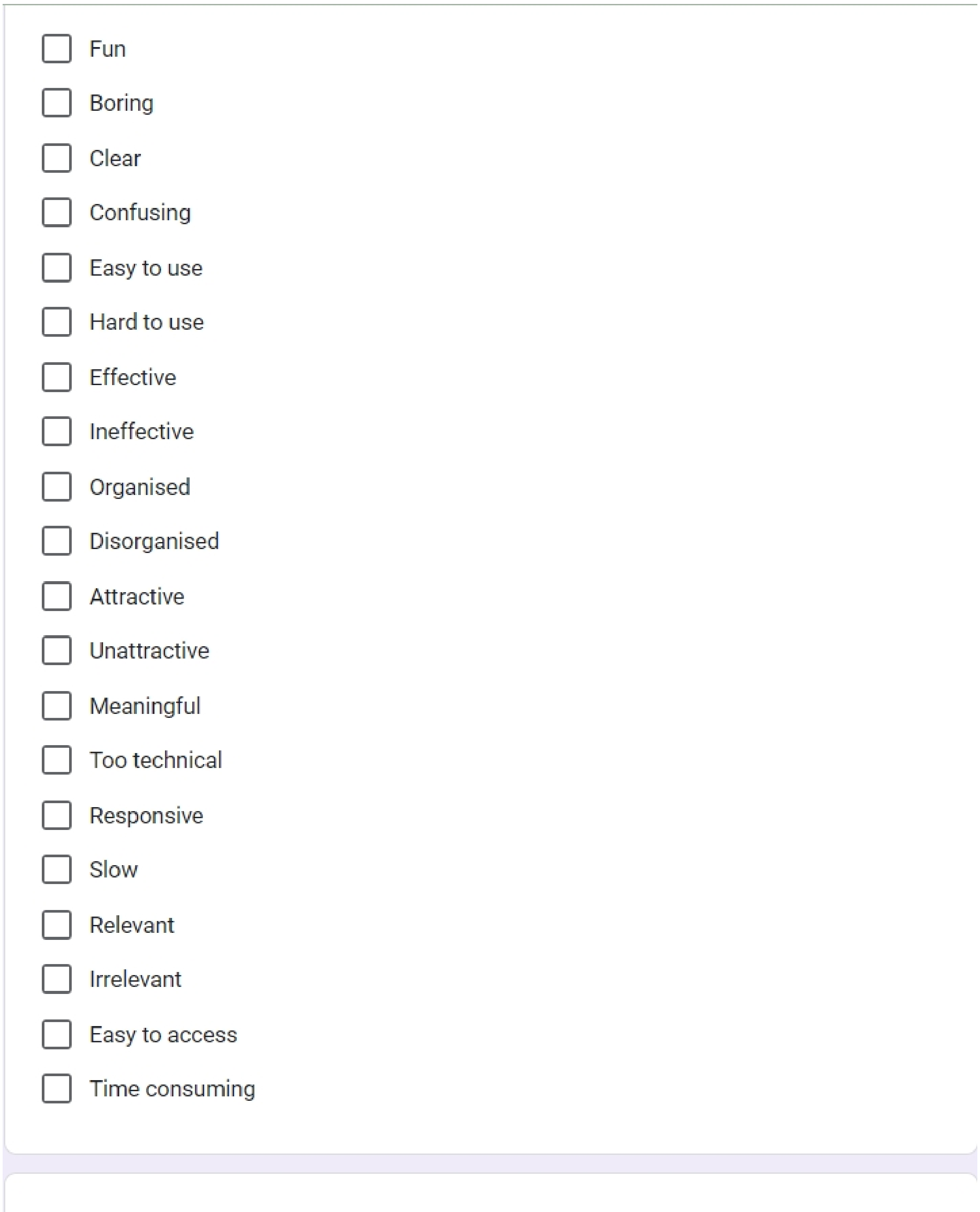
您的回答

In the process of finding and then understanding the information on the JHU dashboard, what are the NEGATIVE aspects of your experience as a user? List up to 3.

您的回答

Please choose 5 keywords from the picture that you think represent your experience with JHU dashboard

Appendix 15 Interview questions after user performance test


- [ ] Fun
- [ ] Boring
- [ ] Clear
- [ ] Confusing
- [ ] Easy to use
- [ ] Hard to use
- [ ] Effective
- [ ] Ineffective
- [ ] Organised
- [ ] Disorganised
- [ ] Attractive
- [ ] Unattractive
- [ ] Meaningful
- [ ] Too technical
- [ ] Responsive
- [ ] Slow
- [ ] Relevant
- [ ] Irrelevant
- [ ] Easy to access
- [ ] Time consuming

Appendix 16 Interview questions after user performance test