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Investigating user behavior in slideshows and scrollytelling as narrative genres in medical visualization

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ABSTRACT

In this study, we explore the impact of genre and navigation on user comprehension, preferences, and behaviors when experiencing data-driven disease stories. Our between-subject study (n=85) evaluated these aspects in-the-wild, with results pointing towards some general design considerations to keep in mind when authoring data-driven disease stories. Combining storytelling with interactive new media techniques, narrative medical visualization is a promising approach to communicating topics in medicine to a general audience in an accessible manner. For patients, visual storytelling may help them to better understand medical procedures and treatment options for more informed decision-making, boost their confidence and alleviate anxiety, and promote stronger personal health advocacy. Narrative medical visualization provides the building blocks for producing data-driven disease stories, which may be presented in several visual styles. These different styles correspond to different narrative genres, e.g., a *Slideshow*. Narrative genres can employ different navigational approaches. For instance, a *Slideshow* may rely on click interactions to advance through a story, while *Scrollytelling* typically uses vertical scrolling for navigation. While a common goal of a narrative medical visualization is to encourage a particular behavior, e.g., quitting smoking, it is unclear to what extent the choice of genre influences subsequent user behavior. Our study opens a new research direction into choice of narrative genre on user preferences and behavior in data-driven disease stories.

1. Introduction

Storytelling is a time-honored approach to share knowledge and communicate complex concepts to a general audience. Modern media enables the incorporation of data-driven storytelling with interactive graphics in a technique described as *narrative visualization* [1]. Used in various scientific fields, including astronomy [2], climate research [3], and cell biology [4], narrative visualization has shown the potential to communicate scientific insights to general audiences in a comprehensible and engaging manner.

While clear communication is important for sharing complex information with a general audience, it is critical in medicine, which can have severe consequences in cases of communication failure. Educating patients and their families on various conditions and options for treatment is vital for informed consent for any care, treatment, or services rendered by a healthcare provider. In the public health space, sharing relevant information in the right way can promote healthy behavioral changes, such as scheduling screening and taking preventative measures for the disease.

The field of medical illustration often takes responsibility for communicating medicine to patients and the broader public, appearing often in newspapers, television, and health organization websites. Medical illustrations and animations can depict normal and abnormal processes or treatments in a narrative that provides general information and facilitate engagement and empathy. However, these pieces are hand-crafted and not easily tuneable to different audiences and scenarios. Adopting methods from narrative visualization to tell data-driven disease stories may leverage the strengths of medical illustration while reducing production time and enabling the telling of more personalized, customizable disease stories.

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Research to date on the use and value of narrative medical visualization remains limited. Meuschke et al. [5] recently proposed concepts for designing data-driven medical stories about diseases in a narrative medical visualization framework that outlines several opportunities for further research. Effective visual methods to communicate medical data, such as volume images and measurements of blood flow data, to a general audience, require investigation. There is similarly little research on the most appropriate narrative genre and associated navigation strategy for interactive, data-driven medical stories.

Our prior work [6] explored a subset of these opportunities by discussing the design considerations for data-driven disease stories focusing on the story of a common congenital heart condition known as a bicuspid aortic valve (BAV). The data-driven aspect of this story is the use of blood flow visualizations to drive the story narrative. This extension expands upon our exploration of narrative genre and interaction design considerations in narrative medical visualization. We contribute a **second data-driven disease story** that affects a different system of the body and uses a different source of medical data and different interactive visualizations to drive the story. This additional story enables us to comparatively evaluate these design considerations on a more general level. Both stories have the same communication goal: to inform a general audience about the respective diseases, their risks, treatment methods, and methods of prevention. We present both stories in two narrative genres: the ***Slideshow*** genre and the ***Scrollytelling*** genre [7]. While both *Scrollytelling* stories are implemented similarly, the *Slideshow* stories differ in their degree of interaction within slides. This allows us to evaluate user interaction in more detail within a particular genre. We conducted a **comparative, between-subject user study** to evaluate the relative effectiveness of these genres in terms of **interaction, navigation, and transitions** of data-driven disease stories that provides a good proof-of-concept. This extension also includes data logs to evaluate which sections of the story users spend the most time in, to understand **user behavior** during a story experience.

2. Related work

In this section, we discuss foundational visualization considerations for broad audiences, describe essential aspects of storytelling and narrative visualization, and discuss current efforts in narrative visualization for medicine.

2.1. Visualization for broad audiences.

A broad audience can be defined as a group of people who differ in terms of age and culture, and who typically lack specific domain knowledge of a given topic [3]. When targeting such an audience, prior work has shown that data can be made more engaging and memorable when embedded in a narrative [8]. Memorability can also be encouraged with bespoke visualizations that are adapted specifically to the data of interest, rather than a more generic, e.g., scatter plot visualization [9]. Interactivity may also encourage more active user engagement with the data [3]. When visualizing complex data such as those from medicine, broad audiences also prefer design choices that support a clear, engaging, and understandable presentation of the information [10]. In line with the research mentioned above, our own work aims to apply these insights to effectively visualize complex medical data for broad audiences, using narrative-driven approaches, customized visualizations, and interactive features to enhance engagement and comprehension.

2.2. Visual data storytelling essentials

A visual data story consists of four essential components [11]:

1. **Story pieces**: The content and/or information that is conveyed through the story, e.g., through text or visualization.
2. **Structure**: The way the content of the story is composed to control the flow of the scenes and navigation through the story.
3. **Characters**: People or objects that can be either real or fictive who carry out actions in the story.
4. **Conflict**: Problem(s) or challenges that the characters must solve to build tension.

Story pieces are composed of visualizations of the most important facts of the story to be communicated, e.g., with data [12]. Story elements such as labels, arrows, motion, audio, and textual explanations [13,14] typically complement these visualizations to emphasize the key story facts. We primarily use data visualizations, text descriptions, and icons in our data-driven stories. Story content can then be **structured** into a series of acts that are integrated into a story arc that defines the narrative progression of the story. Aristotle's tension arc is a common Western narrative visualization story structure [15], which divides the story content into three acts: (1) an introduction, (2) a climax, and (3) a denouement. These can be further divided into up to seven acts [16]. Both of our data-driven stories follow a five-act structure, namely Freytag's Pyramid. Story **characters** and the main story **conflict** may be introduced throughout these acts, with the conflict reaching a peak in the climax and reaching a resolution in the final act. Because our data-driven stories focus on disease, our characters are both patients and doctors, and the conflict comes from being affected by the disease while striving to live a healthy life. Each act further divides into scenes, which arrange into a story path. A story can be linear (having only one story path) or elastic (offering multiple optional story paths or branches diverging from a main path). We chose the latter to allow users to view additional information, such as an explanation of the medical imaging device used to make the diagnosis. Scene transitions require animation or interaction to progress along a story path [1].

2.3. Narrative visualization strategies.

Narrative visualization leverages these storytelling essentials with data. A given story structure with its various story pieces and scenes may be presented in several different styles, so-called **narrative genres**. Segel and Heer [1] discriminated seven genres: *Magazine Style, Annotated Chart, Partitioned Poster, Flow Chart, Comic Strip, Slideshow* and *Film/ Video/ Animation*. These genres are not mutually exclusive and can be combined. Our work uses the *Slideshow* genre for one of the two presentation methods for evaluation. In this genre, slides may be fully static, or contain animations. The sequencing and transition techniques for slides have been investigated in detail by Hullman et al. [17] and served as inspiration in our presentation design. The second genre that we investigated in this study, known as *Scrollytelling*, is a long-form article rich in images and multimedia that is common in online journalism. It is broadly thought to have been introduced in 2012 by the New York Times [18] and examined in detail by Seyser and Zeiller [7]. Recent work provides a more general overview of *Scrollytelling* techniques [19,20]. The *Slideshow* and *Scrollytelling* use fundamentally different navigational techniques. While in a *Slideshow*, users navigate between slides through discrete clicks or taps, *Scrollytelling* enables a continuous navigation experience by scrolling via either a mouse or trackpad.

The choice of narrative genre exerts some influence over the **interactivity** of the data-driven visual story, which ranges from *author-* to *reader-driven* [1]. A fully author-driven story, often intended for live presentations, consists of static visualizations in a linear story path with no interactivity. In contrast, fully reader-driven stories have no strict story path or ordering and exhibit extensive interactivity. It is debatable whether reader-driven stories belong to narrative visualization since the author cannot ensure that a message has been conveyed when the user has considerable freedom to explore the story.

Interactive visualizations lie between these two interaction strategies, combining and balancing aspects of both through a structured narrative with limited interactive elements. Segel and Heer [1] defined an *Interactive Slideshow* to follow an author-driven format to navigate between slides with reader-driven interactions available within each slide. Other hybrid interaction structures have also emerged. The *Martini Glass* structure begins a story in an author-driven format to ensure that the user views the intended content before opening up later in the story to allow for reader-driven free exploration. Our implementations of the BAV stories follow this approach.

Many additional elements enter into the design of narrative visualization related to genre and interactivity. Hullman and Diakopoulos [14] propose a framework to classify several of these elements. They differentiate multiple **editorial layers** of narrative visualization, starting with the data and continuing up to user interactions. They additionally describe rhetorical techniques, which include visual metaphors, individualization, and filtering. The narratives of data-driven stories can be expressed in different so-called **narrative design patterns**, e.g., *humans-behind-the-dots*, that align with the story author's messaging intent and target audience. Bach et al. [21] introduced eighteen narrative design patterns for telling data-driven stories. Edmonds and Bednarz [22] build on these works analyzing narrative visualization elements to derive a categorical classification of data-driven stories in terms of the strength and persistence of traditional narrative structures, e.g., Aristotle's tension arc. Current narrative visualization research focuses on story generation and story editing using machine learning techniques [23–25].

2.4. Narrative visualization for medicine.

While narrative visualization has become popular and accessible for information visualization [26,27], there is little research for combining medical visualization with narratives [5]. Research in this area focuses mainly on volume data, including Höhne [28], who presented a first approach for interactive exploration of volume data in the context of a museum exhibition, and Wohlfart and Hauser [29]'s authoring tool for generating interactive medical stories based on volume data. However, medical data also include non-spatial data, 3D models, and flow data that are important to tell data-driven disease stories. Our study uniquely includes these different data sources as the story pieces to our two stories.

Sallam et al. [30] studied the effect of data-driven medical videos on users' attitudes towards healthy lifestyle changes. Their findings indicate that such videos should convey concrete solutions to medical problems, and adapt the level of threat in the messages to the users' perception of risk. We incorporate these recommendations in both presentation styles of the two data-driven disease stories created for our study. Our work builds on the previously-designed stories for narrative visualization of aortic blood flow [6] and Cerebral Small Vessel Disease [31,32]. These stories follow some of the concepts proposed by Meuschke et al. [5], using the same tension arc as well as certain parts of their proposed template, e.g., the presentation of a patient. The main focus of this work, however, is to examine the narrative genre in terms of user behaviors, transitions, navigation, and interaction.

3. Medical background

In the following, we describe the medical background of our disease stories. We briefly introduce the disease itself as well as the data used for its diagnosis, which is used to build our data-driven disease stories.

3.1. Bicuspid aortic valve (BAV)

Cardiovascular diseases (CVDs) are a leading cause of death worldwide, with these numbers only increasing each passing year [33]. Early and accurate assessment of individual patient risk and disease severity is crucial for providing effective treatment. CVDs lead to deformation of the vessel geometry, which can cause quantitative and qualitative changes in blood flow [34]. To determine the severity of CVDs, physicians examine blood vessel morphology and internal blood flow [35,36]. One image modality used for this purpose is four-dimensional phase-contrast magnetic resonance imaging (4D PC-MRI), which allows for non-invasive measurement of patient-specific blood flow.

One specific type of CVD that 4D PC-MRI is particularly useful for evaluating is **bicuspid aortic valve (BAV)** disease, in which two of the three leaflets of the aortic valve are fused. The resulting change in blood flow can lead to aneurysm formation, which is a dilation of the vessel wall that can rupture and cause serious harm to the patient [37]. An aneurysm also increases risk of impaired heart function and aortic wall problems in patients with BAV, who require regular monitoring [38,39].

3.2. Cerebral small vessel disease (CSVD)

Cerebral small vessel disease (CSVD) describes a range of disorders resulting from the malfunction of tiny blood vessels in the brain that are destructive to the surrounding brain tissue [40]. It is more common than stroke, occurring 6–10 times more frequently, and is the most frequently observed incidental finding on brain imaging studies [41]. Over time, CSVD can lead to motor and cognitive dysfunction and greatly increases the risk of dementia. CSVD is diagnosed using magnetic resonance imaging (MRI), which can show different kinds of brain lesions that indicate the severity of the disease. Biometrics data, such as patient blood pressure, is also useful in diagnosis.

Though affecting a substantial proportion of the population, most people have never heard of CSVD. As such, it is a ripe topic for meaningful scientific education and outreach. Additionally, preventing early-onset or serious CSVD later in life is straightforward at the individual level by maintaining a healthy lifestyle and monitoring one's blood pressure regularly.

4. Story authoring

For the BAV story, we used 4D PC-MRI data acquired before and after BAV treatment. We used the software *Bloodline* [42] to generate visualizations of the aorta and internal blood flow. The CSVD story uses MRI data from the brain and segmentation masks of the lesions as well as tabular data capturing patient risk factors from the University Hospital Magdeburg. We supplemented the stories with photos, illustrations, and icons. A detailed description of the visual elements in the stories, as well as the design process, can be found in the works of Kleinau et al. [6] and Mittenentzwei et al. [31].

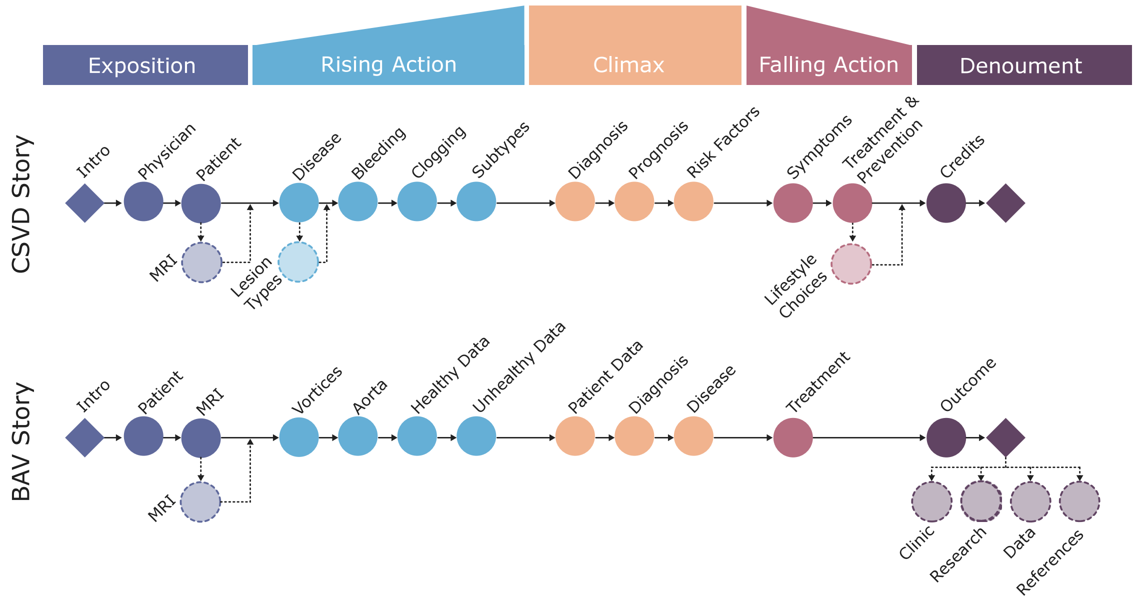
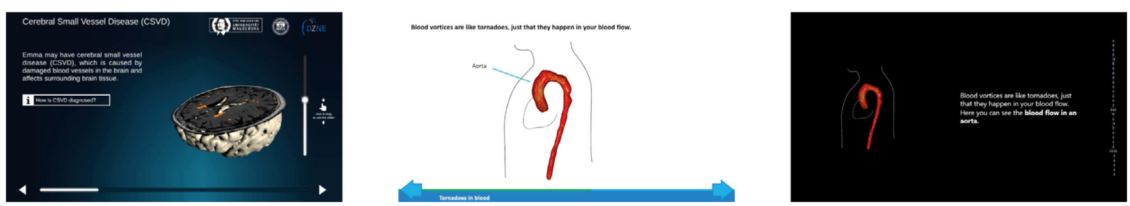


Fig. 1. Structural overview of the CSVD and BAV stories. The graphs represent the higher-level structures of the two stories embedded in Freytag's Pyramid. Diamond-shaped story nodes mark the start and end scenes. Each circular story node represents a thematic section (act) within the respective story. Downward branches and dashed lines indicate optional paths that users can voluntarily visit.



(a) CSVD Slideshow (b) BAV Slideshow (c) BAV Scrollytelling

Fig. 2. Excerpts of the stories implemented using different tools where (a) shows the CSVD *Slideshow* in Unity, (b) the BAV *Slideshow* in PowerPoint, and (c) the Scrollytelling version of the BAV story in ScrollyVis.

4.1. Comparison of story boards

Both stories follow a similar structure by using Freytag's Pyramid, see Fig. 1. The CSVD story has multiple optional branching paths at its beginning and end, while the BAV story follows a martini glass structure more closely, with most branching paths at its end. These optional branches offer in-depth or additional information on selected aspects of the story, e.g., the functioning of MRI or additional disease information. Offering optional paths in the story allows the users to determine the level of detail of the story, making it suitable for a wider range of users. This is necessary to make this disease information accessible to a general audience.

Both stories incorporate a short explanation of MRI as well as a fictional patient as the main character. While the BAV story uses a stylized cartoon character who is neutral in terms of age and gender, the CSVD story contains a more realistic depiction using photographs. The CSVD story also contains a supporting character in the form of the treating physician.

4.2. Genre implementation

We used the *Slideshow* and *Scrollytelling* narrative genres to create the stories described above. We wanted to investigate **which navigation method is easier** for a broad audience to use, whether the resulting **transitions are perceived as pleasant**, and whether the **amount of interaction is enjoyable**. Furthermore, we wanted to investigate the influence of the navigation method on **user behavior**, e.g., if users tend to spend more time within the story of a certain genre. The implemented prototypes can be found via the following hyperlinks for BAV Slideshow, CSVD Slideshow, BAV Scrollytelling and for CSVD Scrollytelling.

4.2.1. Slideshow-based navigation

The first implementations were based on a traditional *Sildeshow*, where users interact by clicking to navigate through the slides. To create the *BAV Sildeshow* we chose *Microsoft PowerPoint*. The CSVD *Slideshow* was implemented using the game engine *Unity*. Each slide contains a *navigation bar* and a *progress bar* which orients the user to where they are in the story, and how much remains in case they are struggling to follow along. To access additional information, the user can click on *underlined text comments* in the BAV story or *animated icons* in the CSVD story.

To visualize blood flow in the BAV story, the animations created with *Bloodline* are converted to GIFs and inserted into the stories. This ensures that the videos play automatically, so that there are no missed video experiences. The motion from the video also draws the user's attention to the blood flow. The CSVD story contains static MRI data. *Animated icons* are used to indicate interaction possibilities with the visualizations, such as rotation and clipping on 3D models.

PowerPoint's feature to move to the next slide when clicking on any non-interactive slide elements makes accidental switching between slides very likely. Another challenge was overcoming PowerPoint's slide show aesthetics when using other transition techniques such as more gradual transitions. This was often just possible through careful slide design. For gradual transitions, slides were kept nearly identical with minimal changes, which, combined with morphing or inconspicuous slide transitions, creates a visual effect of continuous change within a slide.

In summary, using PowerPoint brought some limitations to the story design, compared to Unity. The interaction functionality of PowerPoint mainly consists of different slide transitions while Unity is specifically designed to create interactive media and thus offers more possibilities for including interactions within slides. However, to create a *Slideshow* in Unity, the story author has to have basic coding knowledge. Furthermore, a powerful game engine like Unity is not intuitive for inexperienced users, and may often be overkill. Using PowerPoint to create a *Slideshow* is much quicker and easier for users who have no experience with game engines or coding. However, exploiting the functionalities of PowerPoint to create a narrative *Slideshow* is still complicated and time-consuming.

4.2.2. Scrollytelling-based navigation

We used the *ScrollyVis Editor* [43] to re-create both stories using the *Scrollytelling* genre. The main interaction method here is scrolling, but some click interactions are added to enable selection of story path branches. While the content of each of the two stories is identical in both genres, one main difference in interacting with the story is how the user deviates from the main story path via these branches. In *Scrollytelling*, the users must actively decide whether they want to go an optional path or not. Branching in the *Slideshow* is integrated into a scene as a highlighted interactive comment or *animated icon*. The visual design of the ScrollyVis implementation follows a dark theme, see Fig. 2(c). This was a design standard predefined by the editor, which was previously evaluated in a user study [43].

A main feature within the ScrollyVis Editor is the navigation tree on the side to follow the progress of the story, similar to the progress bar in PowerPoint. In addition, the implementation of the text structure differs between the *Slideshow* and *Scrollytelling* genres. In PowerPoint and Unity, slide text can be displayed sequentially in an animation, so that multiple text items can be displayed at the same time. ScrollyVis takes care of building text by scrolling instead so that a maximum of one text block is displayed at a time. Furthermore, interaction with elements inside the story (such as rotating a 3D object) only works through scrolling. The only exception is videos that contain play and pause buttons.

The ScrollyVis editor does not have an option for including GIFs. We used videos instead to include animations that were inserted as GIFs in PowerPoint as well as advanced interaction techniques (such as clipping a 3D model) used in Unity. When a new video in ScrollyVis appears, it starts automatically. It can be paused at any time by scrolling further down or using the pause button. This makes the videos more interactive than the GIFs, but less interactive than the Unity story implementation.

5. Evaluation

We conducted a user study to investigate the influence of different genres and topics in terms of interaction, navigation, and transitions in the context of our specific use cases. We focused on the following aspects and defined three research questions (RQs):

Interaction. The stories offer different amounts of interaction ranging from GIFs and videos to rotation and clipping of 3D objects. Therefore, RQ1 investigates: "How does interaction influence usability throughout the story?". We investigated if participants preferred a certain amount of interaction and how the amount influenced the time they spend in the story.

Navigation. Our stories offer two main strategies for navigation, vertical navigation via scrolling and horizontal navigation using clicking. Furthermore, optional story branches can be accessed in different ways. Based on these options, RQ2 investigates: "Is vertical navigation, via scrolling, or horizontal navigation, using clicking, more efficient for visual storytelling?". By comparing different navigation techniques, we explore if participants prefer one technique over another and if they influence the paths participants take through the story.

Transition. Our stories are rather complex, covering several aspects of diseases that most participants are unfamiliar with. Thus, RQ3 investigates: "To what extent do the genre-specific transitions influence the usability and aesthetics of the story?". We investigated if transitions between story sections were found pleasant and if users were able to follow the central theme in the different story versions.

5.1. Study design and participants

The study was performed with 85 participants (51 male, 31 female, 3 nonbinary), with an age range from 8 to 61 years (mean age: 27.32). Most participants had a high school diploma, a bachelor's or master's degree. We acquired participants at the *Long Night of Science*, a university event aimed at the general public. Additional participants were recruited through invitations and announcements to university students. We screened out students enrolled in medical courses. We conducted a between-subject design study in which each participant interacted with one of the two story implementations. We divided participants so that 22 viewed the slideshow implementation and 23 the scrollytelling implementation of the BAV story. The CSVD versions were viewed by 20 participants each.

All implementations were presented on two Wortmann Terra All-in-One-PC 2211 with an Intel Core i3 with 3.4 GHz, 8 GB RAM, an Intel HD Graphics 2500. Each PC had a 21.5" touchscreen with Full HD (1920×1080) resolution.

Participants used touch input only to interact with the story during the study. After experiencing the story, participants were asked to fill out a qualitative questionnaire. This questionnaire contained questions regarding participant demographics, user experience of the navigation types (clicking and scrolling), and knowledge checks to verify if the intended messages were received. The results of the knowledge checks did not differ from the findings in the prior work of Kleinau et al. [6], where almost all of the participants answered most questions correctly. We are not able to draw conclusions to evaluate our stories in terms of interaction, navigation, and transitions from the knowledge checks. Therefore, we do not discuss the results further in this paper.

We logged the time each participant spent at each story node. In the *Slideshows*, a story node is a single slide while in the *Scrollytelling* implementations a story node describes one element that can be faded in and out via scrolling (e.g., a text or image). To improve the comparability of results, we aggregated the measurements of multiple story nodes for *Scrollytelling*. For instance, in the *CSVD* story, we aggregate time spent in all story nodes that relate to the explanation of MRI. This includes text as well as video story nodes. Data logs are not available for all participants, due to errors when mapping the time measurements to the questionnaire results, e.g., because participants did not enter the correct ID. 10 data logs that cannot be mapped to a questionnaire were excluded from this analysis.

The times for the first and last node were excluded for every participant because the stories were often idle in these positions, either when waiting for the next participant or while a participant filled out the questionnaire. Furthermore, data logs that were

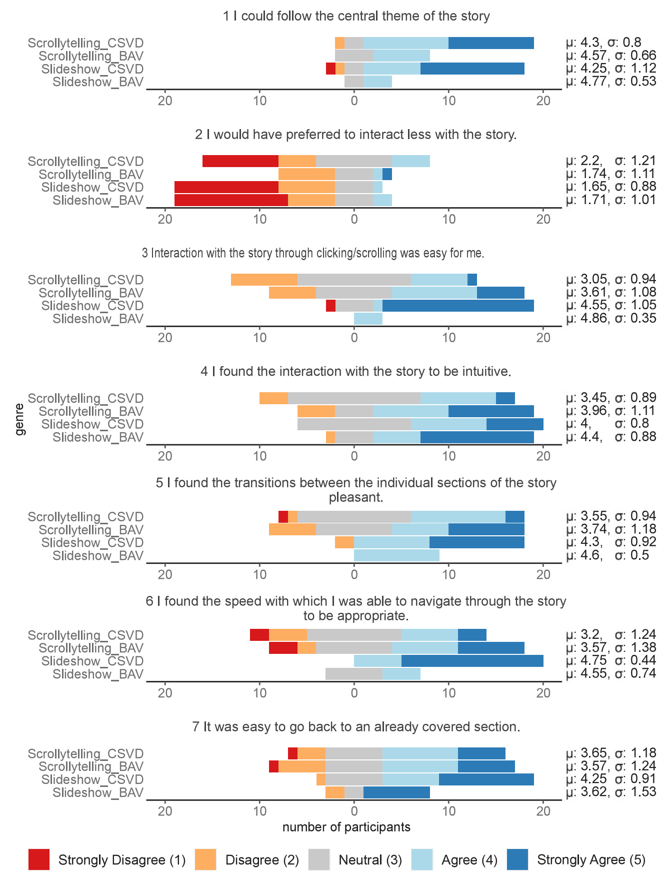


Fig. 3. Participant responses to usability questions for the *Slideshow* and *Scrollytelling* versions of the BAV and CSVD stories. We parameterized the responses to the Likert scale, by giving them numbers from one to five, to calculate the mean (μ) and standard deviation (σ) per story version for each question.

recorded after the last visit to the end node were excluded. Participants must terminate the story at the end node to obtain the ID needed to complete the questionnaire. Thus, the data logs that were saved after visiting the end node are most likely caused by to participants going back in the story to complete the questionnaire or provide qualitative feedback on specific aspects of the story. In the *Scrollytelling* version of the *BAV* story, one outlier was excluded. This participant had more than twice as many slide transitions as the other participants.

We also observed participants navigating the story and documented what issues emerged using the *think aloud* method [44]. The questionnaires and study data are included as supplemental material.

5.2. Results

In this section we discuss the results of our user study in terms of interaction, navigation and transitions within the limits of our use cases.

5.2.1. Interaction

Our first question pertained to the relationship between interaction of the genres and story usability (RQ1). Participants rather disagreed when asked if they would prefer to interact less with the story (Fig. 3, statement 2). They generally agreed that it was easy to interact with the story through scrolling or clicking, with higher agreement when clicking (Fig. 3, statement 3). It is noticeable that the *CSVD slideshow* was rated the best. The interaction with the CSVD story was rated to be intuitive, with slightly higher agreement in the *Slideshow* (Fig. 3, statement 4).

Additionally, participants reported that the interaction with the *BAV Slideshow* was sometimes perceived as sluggish, with buttons not always responding immediately when pressed. When interacting via scrolling, we found that users needed more guidance. Participants struggled at first to understand that they should scroll to interact with the story. Some described this interaction as not very intuitive. Some participants were unsure when to continue scrolling when a video was shown, as the video started again when it was finished. One participant proposed to automatically show accompanying texts when a video is shown.

The participants spent a considerable amount of time at the first story nodes, which contained interactive or animated content, such as a blood flow animation video in the BAV story and nodes titled “MRI” and “Disease” in the CSVD story, see Fig. 5. However, the participants did not stay as long at later nodes with interactive or animated content.

5.2.2. Navigation

We next discuss participant behaviors related to RQ2, which investigates the different navigational methods for the respective *Slideshow* and *Scrollytelling* genres. Fig. 5 shows how participants navigated through the stories. On average, participants stayed 5 min 34 s (min: 3 m 40 s, max: 8 m 50 s, σ: 1 m 23 s) in the *CSVD Slideshow*, 4 min 18 s (min: 2 m 38 s, max: 6 m 41 s, σ: 1 m 11 s) in the *BAV Slideshow*, 6 min 13 s (min: 2 m 37 s, max: 9 m 54 s, σ: 1 m 50 s) in the *CSVD Scrollytelling*, and 7 min 5 s (min: 2 m 46 s, max: 12 m 23 s, σ: 2 m 21 s) in the *BAV Scrollytelling*. We were not able to find any differences between subgroups defined by gender, age, and education. The *CSVD* story offers more optional story branches in the beginning compared to the *BAV* story. Fig. 5(a) and (c) show that many participants took these branches, leading to the time lines being spread wider along the *x*-axis of Fig. 5. Since the *BAV* story follows the Martini Glass structure, most participants follow a rather linear click-path of the story until several optional branches are offered at the end, see Fig. 5(b) and (d). Only a few participants chose to view the optional story branches at the end of the *BAV* story, while the optional information in the beginning and middle of the story were more frequently viewed. Some optional paths at the end of the story were not visited at all. Fewer participants viewed this additional information in the *BAV Slideshow* compared to *BAV Scrollytelling*. Participants viewing the *CSVD Slideshow* and the *BAV Scrollytelling* versions were more likely to go back in the story, showing in the more frequent appearance of jagged lines in Fig. 5(a) and (d). Only a few participants decided to go back to multiple story nodes. Across all participants, the average time spent on the same story nodes in each story version is similar.

Participants’ comments about the *Slideshow* mainly concerned navigation. The transitions between slides were stated as *good-looking* by one participant and *too slow* by another. Participants noted that navigation from left to right was aligned with the reading direction. Participants wanted an option to switch directly between non-adjacent slides, such as an interactive menu bar to switch to specific scenes. Many participants felt that the scrolling speed was too slow. One participant did not recognize they could scroll up again. Some participants only scrolled on the right side of the screen, while scrolling was possible everywhere.

Some participants did not understand that they should keep scrolling after clicking on story nodes (see Fig. 4(b)) at branching points at the story and expected something to happen directly. The graph on the side describing the structure of the story was appreciated; participants wished they could navigate directly with it.

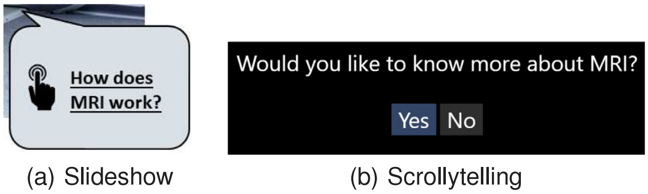


Fig. 4. Interaction design for deviating from the main path for the (a) *BAV Slideshow* and (b) *BAV Scrollytelling* version of the story.

5.2.3. Transition

We next discuss participants' ratings on story transition aesthetics and usability (RQ3). For all stories, most participants agreed that they could follow the central theme of the story (Fig. 3, statement 1). The answers for both versions of the *CSVD story* include a noticeably larger span. The transitions between the individual sections were also rated slightly more pleasant in the *Slideshow*, but still with high ratings for both (Fig. 3, statement 5). The navigation speed was perceived as appropriate, with a higher agreement in the *Slideshows* (Fig. 3, statement 6). It was additionally perceived as slightly easier to go back to an already covered section in the *Slideshows*, however, due to an implementation error, for the *BAV Slideshow* the answers of the first 10 participants could not be included in this question (Fig. 3, statement 7).

Logging the transitions users triggered while navigating the stories, we are able to see that users revisited previous story nodes more frequently in the *Scrollytelling* implementations. The difference is especially noticeable for the BAV stories. An average of 3.17 (σ: 4.41) transitions to previously visited nodes were made in the *BAV Slideshow* and 10.43 (σ: 14.13) in the *BAV Scrollytelling*. Users transitioned 7.75 (σ: 9.6) times to previously visited story nodes on average in the *CSVD Slideshow*. In contrast, 8.58 (σ: 9) transitions were made on average in the *CSVD Scrollytelling*.

Overall, participants reacted positively to all stories. Multiple participants stated they would like to look at such stories in their free time. Feedback included that the story was fun, and that it reminded them of digital information boards in museums, where the length of the story was remarked as reasonable. Some participants wanted more detailed information, e.g., how specific steps of the BAV therapy worked, or a more detailed explanation of terms like 4D PC-MRI. The visualizations of the blood flow in the aorta were hard to recognize for some participants, and differences before and after treatment were recognized by vessel shape rather than blood flow. In both stories, smaller technical problems were discovered, such as confusing zooming behavior.

Slide numbers in the *BAV Slideshow* were commented by one participant as unnecessary and were confusing when they jumped through the additional slides. The arrows used for navigation in the *BAV Slideshow* could be included better in the overall slide design. One participant was confused by additional arrows not used for navigation but to highlight parts of the visualizations in the story. The structure of some slides of the *CSVD* story was not clear. This is because they were thought to be too crowded with charts and text. This led to participants not knowing how to interact further with the story, which might be connected to the negative rating in Fig. 3 (statement 3). Participants with more slide transitions rated the transitions as slightly less intuitive and pleasant in the questionnaire.

6. Discussion

We explored two concrete use cases for narrative visualization in medicine by creating patient-centered stories about *BAV* and *CSVD*. Our study exposes a number of interesting results to probe further in terms of story interactivity, navigation, and transitions. In the following, we discuss our research questions in context of our results.

6.1. Discussion of research questions

RQ1: How does interaction influence usability throughout the story? Most users did not wish to have fewer interaction possibilities, see Fig. 3 (statement 2). These results do not seem to be influenced by the topic or genre. Apart from the *CSVD Scrollytelling* having slightly more participants who wished to interact less, there is no noticeable difference between the stories that mainly used videos (*Scrollytelling*), GIFs (*BAV Slideshow*) or 3D interaction (*CSVD Slideshow*), see Fig. 3 (statement 2). This means that it might be less important how many interaction possibilities a story offer, as long as these are embedded well in the overall flow of the story.

In the *Scrollytelling* implementation of the *BAV* story, many participants stayed rather long at the first story node ("Vortices") containing the blood flow animation as a video, see Fig. 5(d). The same can be seen for the nodes "MRI" and "Disease" in the *Scrollytelling* version of the *CSVD* story, see Fig. 5(c). However, Fig. 5 does not show that participants stayed as long at later story nodes with interactive or animated content. This might be caused by participants needing more time to familiarize themselves with the video implementation, or by a greater level of curiosity when encountering the first animated story content.

RQ2: Is vertical navigation, via scrolling, or horizontal navigation, using clicking, more efficient for visual storytelling? In general, interaction to navigate the *Slideshow* was considered easier and more intuitive than scrolling, see Fig. 3 (statements 3 and 4). This may be because clicking remains a more common and familiar way of navigating *Slideshows*. The slow scrolling speed negatively impacted the user's perception of scrolling, see Fig. 3 (statement 6). This might also be a reason why participants stayed longer in the *Scrollytelling* implementations. The study results in favor of clicking rather than scrolling could be interpreted to mean that clicking is the more favorable interaction mode. However, there are multiple ways to implement scroll-based storytelling and our evaluation considers only one of these.

The problem of participants not realizing that they should scroll after decision nodes could be solved by displaying the continuing text directly when a decision is made. The influence of scrolling speed is another open question that this study does not address. Simply assessing scrolling as less intuitive does not account for the success of scrolling in digital articles and social media [45]. Additionally, interaction via scrolling led to an increased number of people revisiting previous story nodes. This might be caused by the story nodes being smaller components of the visualization, e.g., a single text block or an image instead of a whole slide. This may make users feel that returning to an early point of the story takes too much time or effort. However, returning to an previously-covered section was rated more negative for the *Scrollytelling* implementations compared to the *Slideshows*, see Fig. 3 (statement 7). This might be caused by the slow scrolling speed, making it cumbersome to go back multiple sections of the story. All story versions contained an interactive view, where the participants were asked to make the correct diagnosis for the patient based on the information presented previously. All four plots in Fig. 5 show that many participants went back to previous story parts to look up the relevant information before making a decision. This implies that this kind of quiz inside a story can be used to draw the users' attention to certain information.

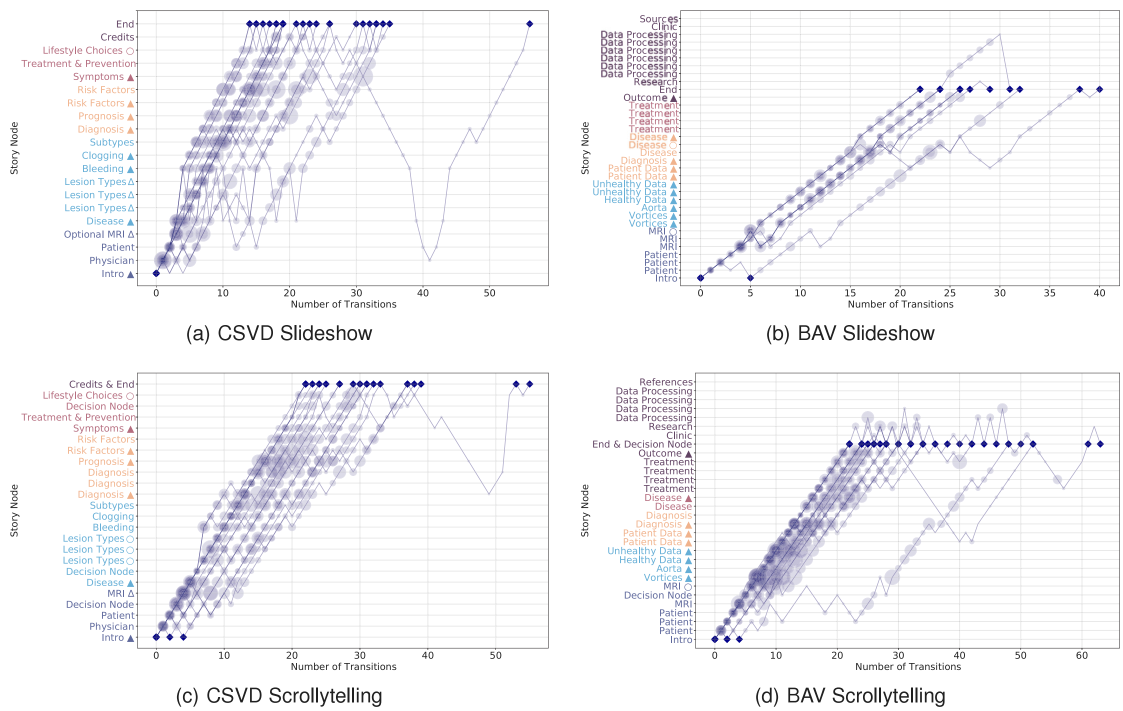


Fig. 5. Logging of the click paths of the participants, for (a) the *CSVD Slideshow*, (b) the *BAV Slideshow*, (c) *CSVD Scrollytelling*, and (d) *BAV Scrollytelling*. Each line represents a participant. Darker areas indicate that the data of multiple participants overlap. The size of the circles shows how long a participant stayed at a certain node of the story. The *x*-axis shows the number of transitions between different views in the story, e.g., changing a slide in the slideshow. The *y*-axis shows the different (aggredated) story nodes, their color-coding indicating to which part the story node belongs in the Freytag's Pyramid, see Fig. 1. Story nodes containing interactive visualizations or animations are marked by a triangle ▲, and optional story branches are marked by an empty outlined circle ○. Story nodes that are interactive and optional are marked by an outlined triangle △. The time spent at the first and last story nodes is excluded because the stories were often idle in these positions. Instead, we mark these nodes with a diamond glyph of fixed size.

The optional story branches after the end node of the *BAV* story were visited by very few participants, while optional information within the story was viewed more frequently. This may be because the optional branches were poorly integrated into the main story line. Additionally, these branches are not part of the patient's story, and therefore may be of less interest to users. On average, participants stayed longer in the *Scrollytelling* stories than in the *Slideshows*. This matches our other observation that participants tend to revisit previous story nodes more often when using *Scrollytelling*.

Participant comments suggest that further research is needed into the impact of slide numbers as a navigational aid. Slide numbers may contribute to visual clutter with poor aesthetics.

RQ3:To what extent do the genre-specific transitions influence the usability and aesthetics of the story? The questionnaire results show that topic had a larger influence on how easily participants were able to follow the story compared to genre, see Fig. 3 (statement 1). The *CSVD* stories were rated very positively. However, following the story was rather hard for a few users, especially in the case of the *CSVD Slideshow*. This might be due to the *CSVD Slideshow* introducing more interaction within slides, which might have distracted participants from following the story content. This also matches our prior observation that the interaction with the *CSVD Slideshow* was difficult for some participants, see Fig. 3 (statement 3).

The implementation used for scrolling in this work deviates from scrolling in online news pages by first fading out a scene before showing the next one. This might have caused the story to be perceived as unintuitive, leading to participants rating the transitions of the *Scrollytelling* versions as slightly less pleasant, see Fig. 3 (statement 5). The transitions of the *BAV Slideshow* (implemented in PowerPoint) received the best rating, see Fig. 3 (statement 5).

The number of user comments on transitions indicates a sizeable impact of ease of navigation on the quality of interaction. Our evaluation highlights the importance of easy and fast transitions between neighboring slides, and ways to transition directly between non-neighboring ones.

6.2. Discussion of study design

Conducting the study as part of a larger event meant that participants were not required to take the time to complete a questionnaire, which may bias our results in favor of people enjoying our story. This would influence our general study results but does not affect the comparison of the two genres, as the bias applies to both cases. However, in future studies participants opting out of the questionnaire should be counted and reasons collected. Our results present a proof-of-concept for creating and evaluating the role of narrative genres on user preferences and behaviors in data-driven disease stories. However, the ease of implementation and results were greatly impacted by the chosen software and its technical limitations.

The results of our study are based on only two stories. This came with tradeoffs, e.g., regarding the choice of transitions and interaction opportunities. We created a storyboard that could fit both genres, *Scrollytelling* and *Slideshow*, to allow the implementation of the same story in both genres. This means that we were only able to explore a small part of a larger design space. In contrast to *Slideshows*, where it is common for the content of an entire slide to change, *Scrollytelling* often uses advanced techniques to create more sohphisticated transitions [19]. Therefore, our results do not provide fully generalizable insights but a starting point for further research in this area.

The development of our stories highlighted the need for specialized software that could, for example, support story design in multiple languages or provide easy-to-implement navigation controls to generate multiple story paths or switch directly between slides. In addition, the consistent integration of different media related to their style was a challenge that affected the perceived quality of the results. A corporation with professional designers who work, for example, for the New York Times, could further improve the story interface in terms of fonts, color scales, and layouts. However, the focus of our proof-of-concept centered on narrative genre interaction, navigation, and transitions, as well as lessons that can be learned for similar projects.

7. Conclusion

We presented an evaluation for how narrative visualization and different interaction, navigation, and transition techniques can be used to explain medical data to the general public. In the following, we summarize our major lessons learned and derive implications for the design of and future research into data-driven disease stories. Since we only explored two use cases for the genre implementations, which cover only a small part of the design space, the generalizability of our results is rather limited. Instead, our work focuses on deriving initial lessons learned and providing many options for future work. Future generalizations will require a larger set of stories implemented using a broader range of the available design space, such as different transition styles.

We implemented the stories in a *Slideshow* genre with standard clicking interaction, and in the *Scrollytelling* genre via scrolling interaction. Study results show a preference for interaction via clicking, however, it may be that the scrolling interactions were not sufficiently optimized. It would be interesting to compare other interaction styles, such as a continuous data story when scrolling, instead of showing and hiding content. Different scrolling speeds should also be explored in future studies to improve ease of use. In addition, *Slideshow* formats can be compared with other genres, such as data comics and data videos.

We mainly followed the Martini Glass structure for the BAV story but optional paths at the end of the story were rarely viewed. Based on our study results, we would therefore suggest including optional paths wherever possible throughout the story rather than at the end. Further studies are needed to evaluate how optional paths can be included in a story and what kind of optional information should be presented. The degree of interaction within the data visualizations had little influence on the users. Stories with GIFs (*BAV Slideshow*) and videos (*BAV Scrollytelling* and *CSVD Scrollytelling*) received similar results for usability and data logs compared to the *CSVD Slideshow* containing the possibility to rotate and clip 3D objects. Providing the users interactive tasks, such as providing a diagnosis, can be used to draw their attention to certain information presented in the story. However, we cannot say if this interaction is perceived as entertaining (e.g., following the principle of gamification) or if it leads to higher engagement or memorability. This presents an opportunity for future work.

Many users commented on the quality of transitions and navigation elements. These elements have a high impact on how enjoyable users find the story. News sites can be an important inspiration for addressing many of the negative comments made by study participants, and we advise authors of future stories to consider the techniques used by popular media outlets. For example, if participants do not realize they are supposed to scroll at the beginning of the story, having text that only partially appears at the bottom of the screen could remedy this issue. Following the suggestion of many of our participants, navigational elements should be included to allow transitions to non-adjacent story nodes. Further studies are needed to investigate how the quality of transitions and navigation can be improved in different genres, leading to a more seamless and engaging story experience. While prior work focuses on visualization-to-visualization transitions for *Scrollytelling* of information visualizations, future work is needed to investigate those transitions for scientific visualizations, as well as between scientific visualizations and information visualizations.

CRediT authorship contribution statement

Sarah Mittenentzwei: Conceptualization, Methodology, Software, Formal analysis, Investigation, Writing – original draft, Writing – review & editing, Visualization. **Laura A. Garrison:** Conceptualization, Methodology, Writing – original draft, Writing – review & editing. **Eric Mörth:** Conceptualization, Software, Writing – original draft. **Kai Lawonn:** Writing – original draft. **Stefan Bruckner:** Conceptualization, Writing – original draft. **Bernhard Preim:** Conceptualization, Methodology, Writing – original draft, Writing – review & editing, Project administration. **Monique Meuschke:** Conceptualization, Methodology, Writing – original draft, Writing – review & editing, Project administration.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

We have shared our data online:

Evaluation Data and Additional Material (Original data) (Author Website)

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Appendix A. Supplementary data

Supplementary material related to this article can be found online at https://doi.org/10.1016/j.cag.2023.06.011.

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