Validation of a heuristic set to evaluate the accessibility of statistical charts

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Abstract

A remote user test was performed with two versions (one accessible and another one non-accessible) of three types of web-based charts (horizontal bar chart, vertical stacked bar chart, and line chart). The objectives of the test were a) to validate a set of heuristic indicators for the evaluation of the accessibility of statistical charts presented in a previous work 7; b) to identify new barriers and preferences for users with low vision in the access and use of this content not previously contemplated. 12 users were tested, with a variety of conditions associated with low vision: low visual acuity (6 users), reduced central vision (2 users), reduced peripheral vision (2 users), blurry vision (1 user), sensitivity to light (3 users), Nystagmus (2 users) and color vision deficiency (CVD) (4 users). From a quantitative standpoint, accessible versions of charts were more efficient, effective, and satisfactory. From a qualitative point of view, results verify the relevance of heuristics H2, Legend; H3, Axes; H6, Data source (as data table); H10, Safe colors; H11, Contrast; H12, Legibility; H13, Image quality; H14, Resize; H16, Focus visible; H17, Independent navigation; related to the proposed tasks. As new observations, tooltips were highly valued by all users, but their implementation must be improved to avoid covering up significant parts of the charts when displayed. The data table has also been frequently used by all users, especially in the non-accessible versions, allowing them to carry out tasks more efficiently. The position and size of the legend can be a significant barrier if it is too small or appears in an unusual position. Finally, despite the limitations related to color perception, users prefer color graphics to black and white, so, to target all profiles, it is necessary to redundantly encode categories with colors and patterns as well.

Keywords

Low vision, Statistical charts, Data visualization, Web accessibility, User test

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1. Introduction and related research

The number of people with low vision worldwide is significant. Globally, in 2020, an estimated 43,3 million people were blind. On the other hand, it is estimated that 295 million people have moderate and severe vision impairment; 258 million have mild vision impairment; and 510 million have visual impairment from uncorrected presbyopia. Globally, between 1990 and 2020, the number of people who were blind increased by 50,6% and the number with moderate and severe vision impairment increased by 91,7% [1]. The same study predicts that by 2050, 61 million people will be blind, 474 million will have moderate and severe vision impairment, 360 million will have mild vision impairment, and 866 million will have uncorrected presbyopia.

Each disability affects visually impaired people in a different way, leading to an important variety of different user profiles [2]. Moreover, people with low vision use a wide variety of assistive technologies, among which screen magnifiers stand out, followed by others such as screen readers, zoom options integrated into web browsers, or high contrast settings. This great multiplicity of profiles, barriers, and assistive technologies involved, implies a significant difficulty in satisfying the specific needs of each group with a unique design.

Despite the higher prevalence of people with low vision, the scientific literature has essentially focused on blind people [3-4] thus making even more invisible a group that is little known to society. This profile presents significant differences to blind people, and it prefers to use their residual vision in their daily life as much as possible [5-6], even if it implies having to continuously adjust multiple aspects of the interface [5] or adopt uncomfortable or forced postures in front of the screen.

The lack of studies aimed at determining the needs and preferences of users with low vision calls for research in this area. In particular, research on statistical charts, content present in multiple key sectors such as education, research, communication, or business, among others, with a focus on this profile, is almost nonexistent.

To make up for this gap, the authors have created a set of heuristic principles to evaluate the accessibility of this type of data visualization [7]. The complete list of heuristics is shown in the table 1. These heuristics were validated against WCAG 2.1 [8] in previous research through the analysis of published charts in several contexts: digital media [9], public health information, [10] and scholarly articles [11], with good results. In this study, a second validation of the heuristic set with users is done because users contribute with a new perspective and identify problems that experts cannot always detect [12-13]. Special attention is paid to new possible barriers [14], and to the characteristics and needs of every specific profile [15].

Table 1. List of heuristics

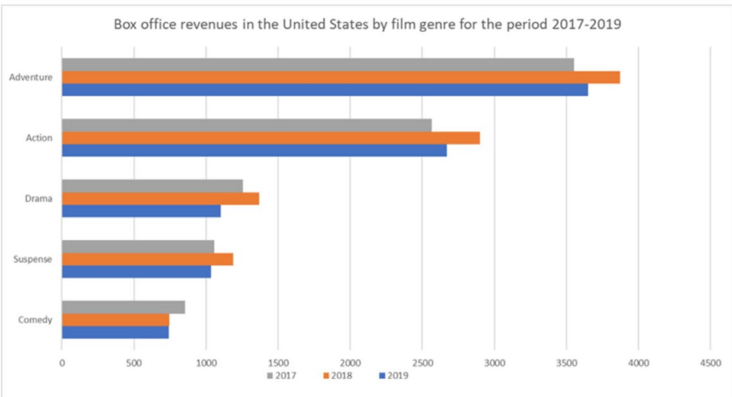
ID	Short name	Heuristic
H1	Title	Does the chart have a brief and descriptive title that helps users identify it among others appearing on the same page, as well as navigate between them?
H2	Legend	If the chart uses shapes, color or patterns encodings is there a legend to decodify them?
H3	Axes titles	If the chart needs axes, are they visible and have appropriate, concise and clear labels and titles?
H4	Caption	Does the chart have a caption helping understand it?
H5	Abbreviations	Are all the abbreviations in the chart expanded?
H6	Data source	Does the chart include information about its source (institution, date and URL of dataset)?
H7	Print version	Is there an optimized version for printing available?
H8	Short text alternative	Does the chart provide a text alternative that briefly informs about its contents and helps users decide if they want more information?

ID	Short name	Heuristic
H9	Long description	In case the text alternative does not adequately convey the information provided by the chart, does the chart provide a textual long description containing complete and structured information about the data?
H10	Safe colors	If the chart uses colors to provide information, is the color scheme safe for the different types of color vision deficiencies, including achromatopsia (total absence of color vision)?
H11	Contrast	Does the visual presentation of text and background have a contrast ratio of at least 4.5:1, and the non-text elements of the chart a contrast ratio of at least 3:1?
H12	Legibility	Is the text included in the chart legible (sans-serif font, font size of at least 16px or 12pt, line spacing of at least 1.5, no abuse of capital letters, bold or italics)?
H13	Image quality	If the chart is provided as a bitmap image, does the image have sufficient quality for a clear visualization and does it support a zoom of at least 200% without blurring or pixelation?
H14	Resize	Can the chart be zoomed up to 200% without an assistive tool and without loss of content or functionality?
H15	Without disturbing elements	Does the chart have any disturbing element like watermarks that hinder the visibility of the chart?
H16	Visible focus	When an element of the chart (lines, bars, points. . .) receives the focus, is there a visual indication of it?
H17	Device independent navigation	Is it possible to navigate between the marks and elements of the chart with keyboard, mouse and gestures?
H18	Customization	Is it possible to customize the chart (color scheme, contrast, typography. . .) with assistive technologies or with a resource-specific customization system?

2. Methodology

For the study, a series of synchronous, moderated, and remote user tests were carried out. The tests consisted of solving tasks for which users had to consult a set of web-based charts that had been created. In total, two different versions of three charts (horizontal bar chart, vertical stacked bar chart, and line chart) were generated: one accessible, created following the abovementioned heuristic guidelines [16], and another non-accessible version. The specific types of charts were chosen upon their popularity and adoption. The non-accessible charts were generated by Microsoft Excel (2019 MSO 16.0.10356.20006 Windows) using the tool's default options and generating an automatic export in HTML format (figure 1). Automated export of charts to HTML format using Excel involves converting the original vector image to a low-quality bitmap image. The export included the chart data table in text format.

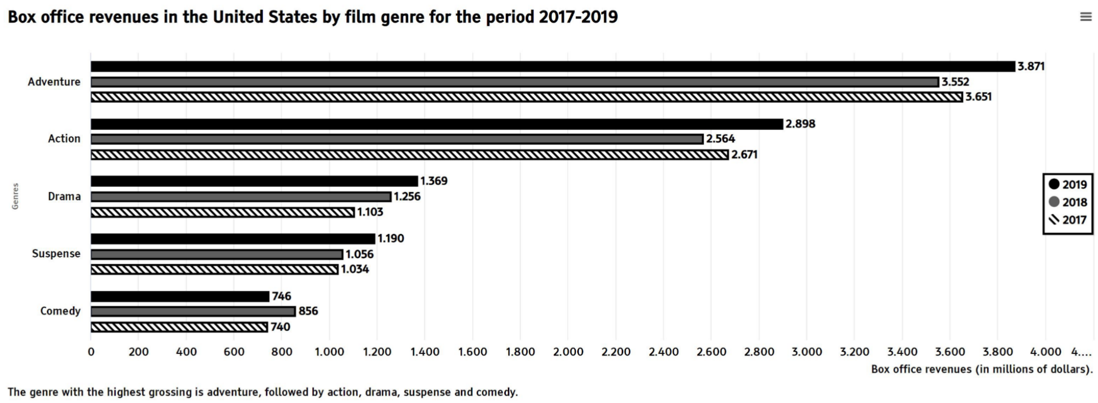
Figure 1. Non-accessible bar chart created with Excel.



Box office revenues in the United States by film genre for the period 2017-2019			
Genres	2019	2018	2017
Comedy	740	746	856
Suspense	1034	1190	1056
Drama	1103	1369	1256
Action	2671	2898	2564
Adventure	3651	3871	3552

The accessible versions were created using the Highcharts JavaScript library (v. 8.0.0), including many of its accessibility options: screen reader support, keyboard navigation, the use of patterns as an alternative to color, a visual indicator when a mark of the chart receives the focus, and a table with the chart's data, as well as a tooltip functionality that complements the legends, providing information on the value associated with each mark when the focus points to it (figure 2). All charts, questions and the results of the test are available online. For each chart, five identical tasks were proposed for both versions, based on scenarios and fictitious data, modifying only the values represented in each version of the chart.

Figure 2. Accessible bar chart created with Highcharts library.



Genres	2019	2018	2017
Adventure	3871	3552	3651
Action	2898	2564	2671
Drama	1369	1256	1103
Suspense	1190	1056	1034
Comedy	746	856	740

Bar chart tasks, objectives and heuristics related:

- Which genre and in what year did cinema get the most box office takings? Objectives: compare bar chart lengths by reviewing the entire chart.
- Which genre and in what year do the ticket sales approach 3 billion? Objectives: understand grid marks, compare bar chart length versus grid within the entire chart.
- In what year does the Drama genre generate most sales? Objectives: search for a specific datum by reviewing a category.
- In what year does the Action genre generate most sales? Objectives: search for a specific datum by reviewing a category.
- Between the Drama and Suspense genres, which of the two grossed the most ticket sales in 2017? Objectives: find and compare two specific marks by focusing on a part of the chart.

Heuristics related: H2, H3, H6, H10, H11, H12, H13, H14, H16 and H17.

Stacked bar chart tasks, objectives and heuristics related:

- How many shoes were sold in September 2019? Objectives: search for a specific bar on the timeline and look for the specific category in the stacked bar.
- In which month of 2018 were less shoes sold? Objectives: understand year encoding; compare bar lengths of one category by reviewing the entire chart.
- Considering the two-year sale, in what month were the most shoes sold? Objectives: compare total bar lengths by reviewing the entire chart.

- Between the two years, in what month did sales closer to 1000 shoes occur? Objectives: understand grid marks, compare bar length to grid in the chart.
- In what month is there the biggest difference between 2018 and 2019? Objectives: understand year encoding; compare the two categories in the stacked bar within all bars; do some calculations.

Heuristics related: H2, H3, H6, H10, H11, H12, H13, H14, H16 and H17.

Line chart tasks, objectives and heuristics related:

- In what month and airport have more flights been flown? Objectives: locate higher value by reviewing the entire chart.
- In what month has El Prat Airport had the highest number of flights? Objectives: understand category encoding; locate higher value of a specific category by reviewing the entire chart.
- In what month has Barajas Airport had the lowest number of flights? Objectives: understand category encoding; locate lower value of a specific category by reviewing the entire chart.
- Which airport had the highest number of flights in October? Objectives: understand categories, compare two specific point values on a section of the chart.
- In which month and airport were the number of flights nearest to but not higher than 50.000 flights? Objectives: understand grid marks, compare points to grid by reviewing the entire chart.

Heuristics related: H2, H3, H6, H10, H11, H12, H13, H14, H16 and H17.

Basic metrics related to effectiveness (percentage of completion per task), to efficiency (time per task), and to satisfaction (measure of expectations, with a simplified 5 points Likert scale) were collected during the test. Qualitative measures focus on detecting the barriers encountered by users and on analyzing the strategies and workarounds used by users to overcome the barriers they face. After the test, users were asked for their favorite version of each chart, and informal comments were promoted. A total of 12 users were recruited from the Asociación Discapacidad Visual de Cataluña: B1+B2+B3 (Visual Disability Association of Catalonia, Spain), and with a snow-ball system from the early contacted users. Initially, tests were planned to be held in B1+B2+B3 offices, but due to access restrictions during the Covid pandemic, they were repurposed as remote tests. Because of COVID and the change of plans, many of the users contacted refused to participate after initially accepting, also due to the barriers expected to be encountered in the use of videoconferencing platforms.

On the other hand, remote tests allowed users to answer the tests from their own homes, with their personal computer equipment and assistive technology, with the ideal setup. Consent forms were sent to participants prior to the session so they could read, print, and sign them. Before starting each task, the moderator read the explanation, asked for questions from the participants, and explained subsequently.

The sample was composed of 58.33% men and 41.66% women. 83.33% of the users had higher studies and only two users (16.66%) had middle school and elementary school studies, respectively. The age of the participants was between 18 and 79 years, the average being 42,3 years. The sample includes a variety of conditions associated with low vision: low visual acuity (6 users), reduced central vision (2 users), reduced peripheral vision (2 users), blurry vision (1 user), sensitivity to light (3 users), Nystagmus (2 users) and color vision deficiency (CVD) (4 users). Table 2 shows a detailed description of each user.

3. Results

Table 3 shows the average percentage of solved tasks for the accessible and non-accessible versions of each chart (effectiveness), the average efficiency in seconds by type of chart and version and, finally, the median value.

The accessible version of the stacked bar chart and the line chart present greater effectiveness (88.33% and 93.75%) than the non-accessible versions (81,67% and 87.50%). On the other hand, the non-accessible bar chart shows a higher effectiveness than the accessible one (98.33% vs. 91.67%).

Table 2. Information of participants in the user test

ID	Gender	Age	Education	Condition	Assistive technology
1	M	18	Middle School	Ocular albinism, nystagmus and low vision with visual acuity 1/10 with the best correction.	Browser's zoom and Windows high contrast mode.
2	M	70	Bachelor's Degree	Glaucoma with 30% visual impairment in the left eye and visual acuity in the right eye, movement of the hand and left eye 0'35 130º-1'25-0'45+4 R-0'5	Windows magnifier and high contrast mode in combination with handheld Magnifying Glass.
3	M	30	Bachelor's Degree	Ocular albinism with visual acuity of 10%.	Windows magnifier.
4	M	58	Bachelor's Degree	Glaucoma with visual acuity 0-10.	Handheld Magnifying Glass.
5	F	26	Bachelor's Degree	Brain injury affecting peripheral vision and reduced central vision at long distance with 70% visual field involvement.	Browser's zoom.
6	M	26	Bachelor's Degree	Stargardt's disease and visual acuity of 5% and difficulty in the perception of all colors.	Zoom and inverted colors in MacOS.
7	M	79	Bachelor's Degree	Wet macular degeneration.	Windows magnifier and high contrast mode in combination with handheld Magnifying Glass.
8	F	51	Bachelor's Degree	Stargardt's disease with visual acuity of 7%, and difficulty in color perception.	Windows magnifier.
9	F	76	Elementary School	Achromatopsia and high myopia with visual acuity of 15%.	Browser's zoom.
10	M	23	Bachelor's Degree	Juvenile retinoschisis.	Windows magnifier and browser's zoom.
11	F	28	Bachelor's Degree	Multifocal chorioretinitis.	Browser's zoom.
12	F	49	Bachelor's Degree	Bilateral central nystagmus of unknown etiology. Difficulty perceiving certain colors.	Windows magnifier and high contrast mode in combination with screen reader.

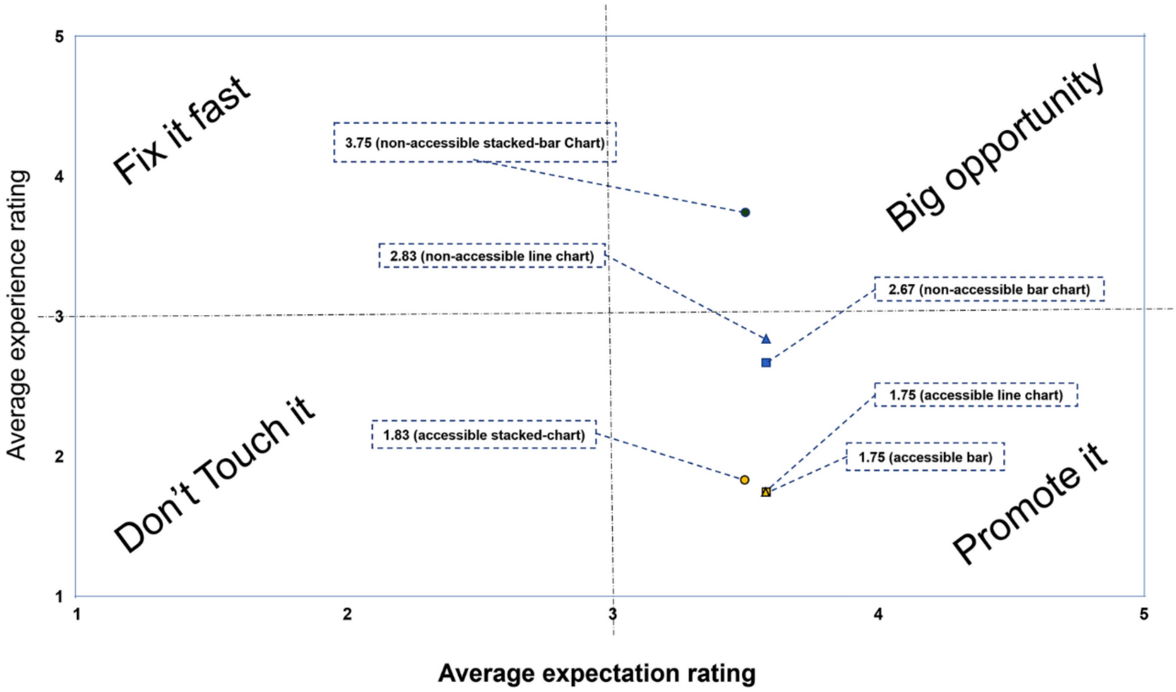
Table 3. Effectiveness and efficiency by chart type and version

Chart	Average percentage of solved tasks	Average Efficiency (time in seconds)	Median efficiency (time in seconds)
Accessible bar chart	91.67%	21.30	14
Non-accessible bar chart	98.33%	44.58	21
Accessible stacked bar chart	88.33%	23.20	19
Non-accessible stacked bar chart	81.67%	33.38	29
Accessible line chart	93.75%	25.56	15.5
Non-accessible line chart	87.50%	23.48	15

In terms of efficiency, the accessible versions of the bar chart and the stacked bar chart are superior to the non-accessible versions (21.3 and 23.2 seconds vs. 44.58 and 33.38 seconds). However, the non-accessible version of the line chart presented greater efficiency compared to the accessible version (23.48 vs. 25.56 seconds). It must be considered that the floating windows of the video conferencing tool sometimes overlapped with the charts, forcing some users to spend part of the time moving them, with a negative impact on the time count.

It must also be considered that in the line chart, the time required for one of the users, far above the average, has increased the overall time count. In terms of satisfaction the comparison between expectations and experience [17] is clearly favorable, being in the quadrant of “promote-it” (figure 3), meaning that the users got better results than expected and as such, were very satisfied, while in the case of non-accessible charts the comparison between expectations and experience puts the experience in the quadrant of “big opportunity” (figure 3), meaning that the expectations are so low that small improvements can bring great results.

Figure 3. Measure of expectations with accessible and non-accessible charts.



When asked which version of each chart users found easier to use, most users preferred the accessible version over the non-accessible one (86,11% vs 13,89%), reinforcing the satisfaction results, except for user 7 (stacked bar chart), user 8 (line chart), user 10 (bar and line charts), and user 11 (both bar charts).

3.1. Observations

The use of color (H10) in the non-accessible versions of the three charts has been a barrier for users 6, 8 and 9. In these three cases, the accessible version, with greater contrast and with patterns as an alternative to color, has allowed them to complete the tasks in a shorter amount of time. However, some users preferred the use of colors instead of the white, black, and grey version of the accessible version (1, 2 and 7). In particular, user 11 has highlighted that the absence of color and the interactivity (H17) implemented had not benefited him. The same user also highlighted that the use of patterns confuses him.

Among the magnification options (H14), we find two differentiated strategies depending on the user: a) use of the operating system’s magnifying glass or screen magnifier; b) use of the browser zoom. In the first case, resizing means losing certain parts of the chart and, with them, important information to carry out the proposed tasks. This situation has been the case for users 1 and 2 (could not locate the legend) (H2). In those cases, when the task involves making a comparison between data, they are forced to memorize the first value and look for the second by scrolling through the screen. In the second case, on the other hand, the accessible version adjusts its size to the window width after applying the zoom, allowing users to see the entire chart on the screen, but not certain elements that accompany it, such as the table with the data source (H6) or the legend (H2). Thus, the accessible versions facilitate comparisons within the chart. In this sense, tasks focused on comparing data have been performed better with the accessible versions of the charts.

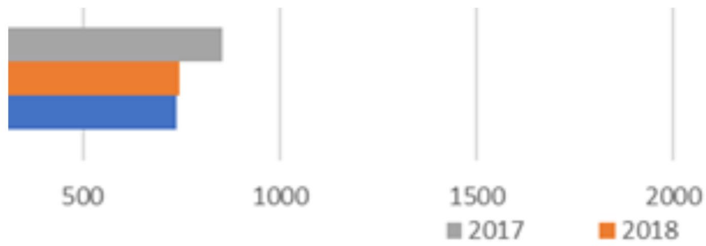
In the accessible versions of the charts, a tooltip functionality has been implemented to provide the value of the selected mark (bar or point) as an alternative to legends (H2). Tooltips have been useful for all users, except for user 9 who has preferred to use the data table (H6). This functionality, used by almost all users, has been highly valued by users 1, 3 and 5, while users 6 and 8 in the interaction with the line chart have highlighted the fact that the tooltips obscured the chart preventing them from following the lines and seeing the marks, especially after magnifying the screen. In this case, the accessible chart does not meet the dismissible requirement associated with the success criterion 1.4.13 (Content on hover of focus) of the WCAG 2.1 [8], which could solve the difficulty mentioned by users.

All users have followed the strategy of following the axes (H3) and the marks with the cursor pointer.

When bitmap images (Excel exports) were resized, the problem of their low quality was more pronounced, creating legibility problems (H12) for users 2, 3, 4, 5, 6, 7, 8 and 9 (figure 4). For user 2 there was even a problem differentiating the bars of the first chart due to the poor quality of the image. Specifically, he stated "it seems to be missing pixels". Insufficient contrast (H11) between the text color used by default by Microsoft Excel and the background has also been a barrier for these users even after being resized.

In all these cases, the users have solved the tasks using the data table (H6) available, not the chart. In all cases, users have initially used the chart to solve the tasks. Only when they have been unable to find the answer, they have used the data table to find it, or they have used it to confirm their answers before verbalizing it (users 5, 6 and 7). User 6 was the only one to recognize that he preferred to consult the table rather than the chart in all cases. Users 7, 8 and 9 (the last one due to poor color perception) found that their efficiency improved when using the data table after the first task and has used it more frequently since then.

Figure 4. Detail of the low quality of the non-accessible bar



All users except user 9 (who has used the data table exclusively) have frequently used the legend to be able to interpret the data (H2). In the different tests we have seen problems locating the legend if it is not at the bottom of the chart or if it is off the screen due to the applied zoom. We have also observed difficulty in differentiating the data series if the color was not sufficiently distinguishable (H10) or the size of the legend was not sufficient.

In accessible versions of the bar chart and the stacked-bar chart, when a data series receives the focus (H16), the rest of the bars are displayed with less contrast to highlight the active element. This has been a barrier for user 10, who has expressed that it has confused him.

4. Discussion and limitations

The paper describes the results of an ongoing study that aims to verify a list of heuristics with users. The relative small number of users does not allow to statistically validate the results nor to generalize them to the whole population, but the authors consider that the insights collected with this first approach are relevant and give light to barriers and priorities.

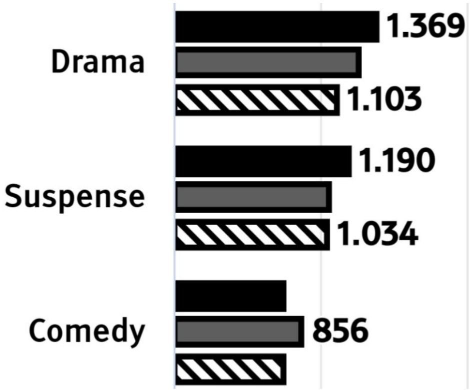
The test is proof that in most cases, users prefer to solve tasks using the chart, even if it is not accessible, instead of using the data table. This confirms the results of other studies in which the use of the residual vision was preferred over other strategies [5, 6].

The tooltips, which, as we have highlighted previously, have been highly valued by all users, have been shown to be useful for: a) giving direct access to the data associated with each mark, avoiding forcing users to consult the data table; and b) serving as an alternative or complement to the legend. However, tooltips generated by Highcharts library do not comply with the accessibility recommendations of WCAG 2.1 and part of the literature [18, 19] , as it is not possible to hide them in case of overlay with other elements.

The order of the bars was key to interpret the time series data for users 3 and 4. The recommendation of sorting the axes chronologically is also cited in the literature [20, 21].

Users 1, 2, 4, 5, 7, 10, 11 and 12 solved the tasks using the browser zoom set between 110% and 200%. In the accessible version of the charts, this means that content needs to reflow to avoid horizontal scrolling, clipping, or overlapping of elements. This functionality associated with the responsive web design technique is implemented by the Highcharts library, but in some cases, it has presented some unexpected behavior that has involved accessibility problems, such as some labels disappearing (see figure 5).

Figure 5. Detail of the accessible bar chart showing the absence of some labels



Currently, Excel does not provide accessible defaults for creating a new chart. However, it is possible to create fairly accessible charts. Exporting charts to non-Microsoft formats like HTML is also very problematic in terms of accessibility properties. Only an expert author will be able to create a moderately accessible chart. Our focus has been about fundamentally in visual perception and not so much in understanding the chart. For this reason, we have tried to make the charts easy enough to understand for all users regardless of their educational level. In this sense, no substantial difference has been noted between the results of users with the lowest level of education and the rest of the users.

5. Conclusions and future work

The results have allowed us to verify the relevance of the heuristics: H2, Legend; H3, Axes; H6, Data source (implemented as a data table); H10, Safe colors; H11, Contrast; H12, Legibility; H13, Image quality; H14, Resize; H15, Without disturbing elements; H16, Focus visible; and H17, Independent navigation.

The legend (H2) is essential to understand the data. Its position and size, as well as the colors (H10) and contrast (H11) used, can negatively influence the effectiveness and efficiency if they are not designed following accessibility guidelines. On the other hand, labelling the values directly in the chart marks or implementing tooltips are even better alternatives. For users with CVD, it is essential to use safe color combinations or patterns to differentiate the marks. However, the combinations based on white, black and grey produce an effect of visual saturation in certain users, especially in those who preserve the perception of color. Considering the suitability of color to encode categories 22 and that some users prefer it over monochrome interfaces, a possible conclusion of the test is the need to redundantly encode categories with colors and patterns as well, to target all profiles.

Of equal importance to the legend are the titles of the axes (H3). Both have been used by all users to understand the data. Using vertical text on the y-axis does not seem to have been a problem for any user. But, on the contrary, low-quality images of text hinder the legibility of the legend and axes text (H13).

Providing access to the data source as a table (H6) allows users to have a highly efficient, fully text-based alternative when the task involves searching for a particular datum. Also, as observed during the test, it is useful to verify an answer before delivering the task.

Another common barrier has been insufficient image quality (H13) of non-accessible charts to cope with demanding resizes (up to 500%) (H14). In such cases, legibility (H12) is compromised and the use of charts in vector format is the best alternative because they can be enlarged as much as necessary without losing quality 23. Another of vector charts' advantages is their complete integration with the Document Object Model (DOM), that grants the ability to manipulate and customize them as any other HTML element and makes them compatible with assistive technology [24, 25].

Other works highlight the difficulties that users with low vision experience when interacting with screen magnifiers [26-28] , because they only have a partial view of the page they are interacting with, and this can cause loss of context since not all the elements necessary to interpret or interact with the content are displayed on the screen. This is a common issue when interacting with a chart whenever the task requires comparing data. This requirement seems to lead to designs with reflow, to avoid horizontal scrolling, clipping, or overlapping of elements (H14), but this only worked for users using browser zoom and not for those using screen magnifiers with magnifications much greater than 200%.

The heterogeneity of needs and preferences among participants leads to test personalization techniques (H18) as a key factor to ensure the best accessibility in the greatest number of possible situations. However, as other works point out 4 one single method of adapting the presentation of the charts may not be sufficient to meet all the requirements for people with low vision.

In these tests, authors decided to start with simple charts. With more complex charts it might be possible to find a larger number of barriers (this was even mentioned by users 2 and 8). In future research authors will test how complexity affects the barriers encountered by the users and also the effect of customization options (H18), to allow users to hide or show the marks desired at a given time.

The main line of future work is trying to recruit new users, to cover most low vision profiles to continue reviewing the list of heuristic indicators and improve it by refining the guidelines and doing a new iteration in the definition and scoring of the heuristic set. Further work is required to plan other types of tasks that allow validating some of the heuristics not contemplated in this study (H1, Title; H4, Caption; H5, Abbreviations; H7, Print version; H8, Short text alternative; H9, Long description; H18, Personalization).

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