Touch Screen Exploration of Visual Artwork for Blind People

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ABSTRACT

This paper investigates how touchscreen exploration and verbal feedback can be used to support blind people to access visual artwork. We present two artwork exploration modalities. The first one, attribute-based exploration, extends prior work on touchscreen image accessibility, and provides fine-grained segmentation of artwork visual elements; when the user touches an element, the associated attributes are read. The second one, hierarchical exploration, is designed with domain experts and provides multi-level segmentation of the artwork; the user initially accesses a general description of the entire artwork and then explores a coarse segmentation of the visual elements with the corresponding high-level descriptions; once selected, coarse segments are subdivided into fine-grained ones, which the user can access for more detailed descriptions.

The two exploration modalities, implemented as a mobile web app, were evaluated through a user study with 10 blind participants. Both modalities were appreciated by the participants. Attribute-based exploration is perceived to be easier to access. Instead, the hierarchical exploration was considered more understandable, useful, interesting and captivating, and the participants remembered more details about the artwork with this modality. Participants commented that the two modalities work well together and therefore both should be made available.

CCS CONCEPTS

• **Human-centered computing** → **Accessibility systems and tools**; *Touch screens*; • **Applied computing** → *Arts and humanities*.

KEYWORDS

Art accessibility, Blindness, Touch screen, Audio feedback.

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1 INTRODUCTION

Being able to take part in cultural life and appreciate art is among the provisions of the Universal Declaration of Human Rights [5, 50] (Article 27). Legislators worldwide have enacted laws and regulations to ensure that such provisions reach all individuals, including people with disabilities [40]. However, such regulations are seldom enforced [29] and, as a result, participation to cultural life by individuals with disabilities is still far from being at the same level of the general population [42]. For blind people, one of the greatest barriers to cultural life participation is the difficulty to access and appreciate visual art. Accessible representations, such as tactile images [10], 3D reproductions [41], or textual descriptions [7, 15] can be used to convey information about visual artworks. However, accessible representations are not available in all art venues and places of cultural interest, and even when they are available, they are present only for selected few artworks. Furthermore, it is difficult to provide accurate spatial understanding of visual artworks through non-visual channels [27]. Tactile images and 3D reproductions are also not inclusive, and cannot always be positioned in the immediate vicinity of the original works of art [37, 54].

To support blind people (who interact with mobile devices using a screen reader) in accessing visual art, we investigate artwork exploration using touch screen, with verbal descriptions provided for the touched elements. For this task, we designed two exploration modalities and implemented them as a mobile web application:

- **Attribute-based Exploration**, informed by prior literature on touch screen-based image accessibility [39], which we adapted to the problem domain of artwork accessibility.
- **Hierarchical Exploration**, designed with domain experts in art accessibility for people with visual impairments (VI).

We conducted a user study with 10 blind participants, focused on the following research questions:

Q1. To which extent the two techniques are appreciated by the blind people?
Q2. Which technique is better in terms of appreciation, preferences and artwork memorability by blind people?

To measure participants' appreciation, we define seven subjective metrics, assessing whether the examined exploration modalities are considered: **Easy to access**, **Understandable**, **Cognitively demanding**, **Useful**, **Interesting**, **Captivating** and **Exhaustive**. Furthermore we measure the amount of information and detail about the artwork that the participants remember after accessing the artwork with an exploration modality.

Both modalities obtained positive scores for all the considered metrics. In particular, all participants considered hierarchical exploration understandable, interesting, captivating and useful, assigning it a subjective score of 6 and higher out of 7. For this metric, hierarchical exploration was also higher than the attribute-based modality. Instead, the attribute-based approach was considered easier to access, with a score of 6.4 on average. Despite the fact that none of the two modalities was perceived by the participants to provide a more exhaustive understanding of the artwork, participants remembered the artwork better when accessed through hierarchical exploration.

Few participants displayed a stark preference towards one modality. Instead, most perceived that the two approaches complement each other well and should be used together. Indeed, many comments support the intuition that the information acquired while exploring an artwork in one modality form an initial knowledge that is helpful for exploration in the other modality, thus improving the overall understanding of the artwork. We believe our findings will contribute to inform the design of future touch screen-based techniques for accessible artwork appreciation by people with VI.

2 RELATED WORK

Visiting art venues, such as museums or art galleries, and being able to appreciate visual artwork is challenging for blind people [52]. Specifically, four key problems have been identified [20]:

(1) **Retrieving Information on Art Venues.** Prior works have reported that the majority of art venues' online resources have severe accessibility shortcomings [8]. For people with VI, this results in critical difficulties in retrieving information about most of the art venues [32].
(2) **Accessing Art Venues.** One of the key difficulties for people with VI is actually getting to museums and navigate inside venues [3, 43]. On the one hand, this is caused by the lack of guidance infrastructure, such as tactile paving [37]. On the other hand, museum staff and curators are often concerned with the safety of the artworks and therefore autonomous movement by visitors with VI is discouraged [21].
(3) **Obtaining Support from Art Venue Staff.** Art venue visitors with disabilities sometimes face difficulties in interacting with other visitors and museum staff who are not used to people with disabilities [43]. In particular, the scarce support by museum staff can become a critical issue for art appreciation by people with VI [20].
(4) **Accessing Artwork.** Most visual, sculpture and architecture artworks can be appreciated only visually. Only few selected works have representations that are accessible to people with VI [20] while accessing actual artworks is mostly unfeasible [9]. Indeed, the lack of possibilities to explore art is reported to be a critical issue by blind museum visitors [20].

Due to these problems, blind people seldom visit art venues [3], and some of them do not even feel that art venues should provide accessibility features for them [43]. To address these issues, a number of methodological approaches and assistive technologies have been studied. In particular, mobile and web technologies [35] have been proposed as scalable solutions to support visual art and art venue accessibility.

2.1 Art Venue Accessibility

To support blind visitors in accessing information about art venues, prior research has fostered the creation of exhaustive and accessible art venue web content [2]. Other works have explored art venue information access through virtual auditory tours [16]. In particular, researchers have focused on enabling non-visual access to detailed descriptions of museum layouts and alternative text content associated to images of artworks present in the museums [33].

A number of assistive technologies have been proposed to improve art venue accessibility for visitors with VI [20]. Common features are accessible building layouts and entrances, consistent lighting and tactile venue maps. Instead, features such as handrail guides or tactile floors are rarely present [37]. Digital supports provide location-based services for navigation assistance [17, 26, 36], and audio content in the proximity of artworks [18, 31, 44]. In particular, recent accurate navigation assistance systems [48] can be used to combine the two aspects of navigation and art appreciation [4].

In addition to the technological approaches aimed at improving information, venue and artwork accessibility, prior works also explored how to improve staff support during visit experiences for people with disabilities. For this, prior works propose to involve visually impaired stakeholders during visit planning and staff training [34]. However, intervening on staff training is seldom possible, and it is difficult to implement at scale [20].

2.2 Artwork Accessibility

Blind people commonly use tactile images [23] or verbal descriptions to access artworks [37]. Verbal descriptions [14], in the form of audio guides, are available in most museums. However, audio guides are most often designed for sighted users. They might require to insert numerical codes or scan tags provided in the vicinity of artworks, which is difficult for blind people. Furthermore audio guides often prioritize a captivating narrative and assume that the visitor can see the artwork, instead of providing accurate visual information for the benefit of blind visitors [37]. While descriptions specifically designed for people with VI exist [7, 15], they are rarely available and included within audio guides.

Tactile images (**i.e.**, reproduced as reliefs) are also common, but usually available for few selected artworks only, as they need to be specifically designed and crafted [20]. Existing tactile images are also often unmaintained and thus prone to decay [37]. 3D printing can facilitate the creation of 3D artwork replicas [41], for example sculptures, as well as the creation of tactile images for 2D artworks [13]. However, 2D artworks need to be first designed as tactile images [13]. Automated image processing can expedite tactile image creation [10], but it is unclear how the quality compares to professionally made tactile images. Furthermore, tactile images use braille labels, which can accommodate only short descriptions [22], and many people with VI are not proficient in braille [55].

A combined approach, associating auditory feedback to tactile images, improves artwork understanding by people with VI [14, 25]. In contrast to purely tactile representations, braille proficiency is not required since textual content can be provided verbally [1]. 3D printed models can also be augmented with multimodal audio-haptic exploration [13]. However this approach requires custom adaptation of 3D printed models with additional hardware.

Web technologies can also be used to develop solutions for artwork accessibility. For example, home-printed tactile representations of artworks can be combined with online audio guides to augment the auditory artwork access with concurrent haptic exploration [6, 24]. Still, this exploration modality depends on the user's capability to explore the tactile representations while listening to the audio guide. Furthermore, tactile representations need to be designed by experts, and then printed at home by the user. Screen readers have been used to support the presentation of alternative text content associated to artwork images [33], but without the ability to explore the visuo-spatial structure of the artworks.

On mobile devices, touch screen exploration associated to screen reader interaction can support visuo-spatial exploration of alternative text content associated to different parts of an image [39]. A similar approach is implemented in Microsoft SeeingAI [38] for describing objects captured in photos when the user interacts with them. However, this interaction paradigm has not been previously applied to artwork accessibility.

We advance the state-of-the-art in visual artwork accessibility, introducing two novel interaction techniques for audio-haptic artwork exploration, and their implementation as a mobile web app. The two techniques leverage touch screen as the interface for scanning the artwork image area, while additional information on the explored elements is provided through verbal feedback. Using a commodity mobile device, the user can access this data on the move, for example when visiting a museum with friends or family. The first technique adapts *spatial* screen reader interaction [39] to artwork accessibility, proposing artwork segmentation based on specifically designed descriptions. The second one, designed with domain experts, presents a hierarchical segmentation of the artwork elements and more verbose descriptions. Both techniques provide verbal content based on *DescriVedendo* artwork descriptions, which is described in the following.

2.3 *DescriVedendo*

DescriVedendo [15] is a method for crowdsourced creation of figurative art descriptions, designed to be accessible to people with VI. Unlike prior efforts [7], in which the guidelines for accessible artwork descriptions were designed and are implemented by domain experts, in *DescriVedendo* the guidelines were created and are implemented following an iterative crowdsourced design, involving end-users and volunteer crowdworkers, in addition to domain experts. The guidelines were defined starting from a dataset of free-form artwork descriptions created by volunteer sighted crowdworkers, identifying commonalities among descriptions considered more accessible by end-users and domain experts.

Current *DescriVedendo* guidelines consist of 10 key points[1], addressing, for example, the artwork complexity (guideline 1) and level of realism (guideline 2). Following *DescriVedendo* guidelines, crowdworkers can produce descriptions that detail key visual elements of an artwork, thus supporting a better understanding of its structure and visual characteristics. Through specifically designed questionnaires, the produced descriptions are iteratively validated and improved by other crowdworkers, end-users and domain experts, until satisfactory results are reached.

[1]English version of *DescriVedendo* guidelines: http://bit.ly/desc-en

3 ARTWORK EXPLORATION

The two proposed techniques extend *spatial* screen reader interaction [39]: different regions are identified in the image, each associated to an alternative text that is read by the screen reader when the region is accessed. In our approach, as in the standard screen reader interaction, to access the regions the users can freely explore the image by scanning the touch screen with a finger. While sliding the finger, each time a new region is touched its alternative text description is read. Through proprioceptive sensing (*i.e.*, understanding spatial disposition of the explored elements by perceiving own body movements [51]) it is possible to comprehend the structure of the explored image [19]. Alternatively, the users can use left/right swipe gestures to sequentially access each region and read its alternative text.

On top of this interaction paradigm, we designed two novel artwork exploration modalities: *Attribute-based Exploration*, and *Hierarchical Exploration*, which were afterwards implemented in the form of a web application, accessible using mobile devices. The process of identifying the image regions and the corresponding alternative text is based on the *DescriVedendo* descriptions [15], but it is specific for each techniques, as described in the following. For this study, the segmentation is performed manually, using a web-based tool [47]. However, image segmentation and annotation could also be crowdsourced by non-expert crowd workers [12], or generated automatically, as in previous works which used automated segmentation of artworks for the creation of tactile images [49].

3.1 Attribute-based Exploration

Attribute-based exploration was designed to enable quick spatial scanning of the artwork image, with verbal descriptions provided for each item in the image [30]. For each item (*e.g.* character, object) mentioned in the description, a polygonal region is created. Each region is identified by a label (*i.e.*, item's name) and it is associated with a list of attributes: short words or sentences derived from the description, which are used to define the item's characteristics, such as its color, shape, motion and position. The label and the attributes are read as alternative text when the region is touched.

For example, consider the following *DescriVedendo* passage[2], referring to the 5 disciples depicted in the painting "Cristo e la Samaritana al pozzo", shown in Figure 1:

> *"In the background, we see five disciples, who seem to come from the village where Jesus had asked them to look for something to eat. Indeed, in the lap of the young disciple on the left, we see a basket of red cloth with some loaves of bread. This is the only disciple walking alone: he is shown in full figure, dressed in a green tunic up to the calves; his gaze is turned towards the scene of the encounter between Jesus and the woman, whom he observes respectfully and with curiosity. In the center, behind the well and the Samaritan, and therefore more distant from us, we see four other elderly disciples, who gesticulate pointing to the well, while talking in pairs. They too are probably trying to intuit the dialogue taking place between Jesus and the woman."*

[2]The full certified *DescriVedendo* description is available in Italian: http://bit.ly/art-ita and English: http://bit.ly/art-engl.

(a) Attribute-based segmentation

(b) Hierarchical segmentation

Figure 1: Segmentation of "Cristo e la Samaritana al pozzo" (Jesus Christ and the Samaritan women at the well)

Attribute segmentation maps every item mentioned in the description to its characteristics, as shown in Figure 1(a):

- **five disciples** - seem to come from the village where Jesus had asked them to look for something to eat.
- **four elderly disciples** - gesticulate pointing to the well, talk in pairs, probably trying to intuit the dialogue between Jesus and the woman.
- **young disciple** - walks alone, shown in full figure.
- **gaze** - turned to Jesus and the woman, observes respectfully and with curiosity.
- **basket of red cloth** - with some loaves of bread.
- **green tunic** - up to the calves.

When a region is accessed through touch screen, the system reads its label and the associated attributes. Note that the regions can overlap. In this case, when the user touches a point contained in two regions, the smaller one is activated. This is useful, for example, in the case of the well depicted in Figure 1(a), which is partially covered by the Samaritan woman. In this case, the Samaritan woman is the smaller region, and therefore it is read on overlapping areas.

3.2 Hierarchical Exploration

As a part of our design process, we involved two *DescriVedendo* members as domain experts, a typhlologist and an educator for blind students, with years of experience in art curation and accessibility for people with VI. As an informal test, we asked the domain experts to try the attribute-based modality implementation and provide their opinions about the exploration of artworks using this technique. They tested the system for about 5 minutes each, and afterwards they provided a number of insights stemming from this experience. The discussion lasted about 1 hour in total. The domain experts reported that they were positively impressed by the interaction and compared it to the exploration with tactile images.

> *"You move the finger on the surface of the touch screen and perceive different parts like in tactile images."*

However, they also highlighted three possible problems, which were considered for the design of a new exploration modality:

- **P1** - **Overview** Similar to tactile images, attribute-based exploration does not provide immediate global understanding of the artwork structure. Instead, it needs to be derived from the regions exploration, which could be cognitively demanding.
- **P2** - **Interactive Area** Attribute-based approach could be exhausting to listen, since it triggers many short utterances, typically read at high frequency due to the fact that there are many small areas and even a small finger movement on the screen can traverse many of them.
- **P3** - **Relationship** In tactile images, it is hard to identify what different explored parts are and how they are related to each other. In attribute-based exploration, audio descriptions help to realize what the elements are, but since descriptions are unrelated one to another, a clear understanding of relationships between elements is still hard to grasp.

The resulting exploration modality provides hierarchical access to artwork content, organized in three levels. **Level zero** refers to the entire image: a general description is provided before the user starts exploring. The description is extracted from *DescriVedendo* and includes information about the artwork (*e.g.*, artist, size, orientation) and a description of the spatial disposition of the key artwork areas (**P1 - Overview**). Based on *DescriVedendo* guidelines, the *key areas* are usually: main subject, second plane, and background.

After listening to the general artwork description, users access **level one** of the hierarchy, in which they can explore the key areas. Since key areas are fewer and larger than attribute-based regions, the user can slide their finger on the touch screen without triggering many different verbal descriptions. This approach is intended to be less exhausting than exploring attribute-based regions (**P2 - Interactive Area**). The alternative text associated with key areas is the full description used in *DescriVedendo* for the same part and therefore it is more verbose than that of the attribute-based regions.

When a key area is accessed, a double-tap gesture initiates the exploration of the contained regions at hierarchy **level two**. Key area descriptions provided at level one inform the user about the structure of the contained level two regions (**P3 - Relationship**). From level two exploration, the user can return to level one exploration with a double-tap gesture. Level two regions are also fewer and larger than attribute-based regions, and each corresponds to an element described in *DescriVedendo*, without subdividing it further in its parts. For example, in the attribute-based approach there is one region for the leftmost disciple and other three describing its details mentioned in the description: the gaze, the green tunic and the red cloth basket (see Figure 1(a)). Instead, at hierarchy level two, there is only one region for the disciple (see Figure 1(b)).

As for the key areas, alternative text associated with level two regions is the corresponding description used in *DescriVedendo*. In our example, the part describing the "five disciples" is the second plane key area, colored in blue in Figure 1(b). The key area contains two regions at level two, the "young disciple" and "four elderly disciples". The associated descriptions are:

- **five disciples** (key area) - seem to come from the village where Jesus had asked them to look for something to eat. In the lap of the young disciple portrayed on the left, we see a basket of red cloth depicted with some loaves of bread.
  - **young disciple** (region) - This is the only disciple walking alone: he is shown in full figure, dressed in a green tunic up to the calves; his gaze is turned to the scene of the encounter between Jesus and the woman, whom he observes respectfully and at the same time with curiosity.
  - **four elderly disciples** (region) - gesticulate pointing to the well, while talking in pairs. They are probably trying to intuit the dialog taking place between Jesus and the woman.

As we see, the text content in the two approaches is similar, but in attribute segmentation, it is partitioned in smaller elements that can be accessed directly, while hierarchical segmentation has key areas that need to be entered to access detailed regions.

4 USER STUDY

To investigate whether the proposed exploration modalities are appreciated by blind people, we conducted a study with 10 blind participants. Originally we aimed to conduct the study at a museum, comparing the exploration modalities with a tactile image baseline. However, due to COVID-19 epidemic, we could not run the study at the museum. Hence, the tactile image baseline could not be tested. Instead, we conducted the study telephonically, using a mobile web app implementation of the two exploration modalities.

4.1 Apparatus

The web app is implemented using *D3.js*[3] JavaScript library for dynamic visualizations, on top of which we developed functionalities for touch screen exploration of images and verbal text-to-speech using system screen reader. The app and its source code are available online[4] and accessible on both Android and iOS, with Safari, Firefox and Chrome browsers.

[3]https://d3js.org/

[4]https://m-hearing-masterpiece.web.app/index_home_2.0_it.html

Only one painting, "Cristo e la Samaritana al pozzo" (see Figure 1), was used for the study, because it is the only artwork that has both a *DescriVedendo* description and a tactile image [11] available. However, the configuration and the complexity of the painting are consistent with other paintings (mostly figurative art) of which *DescriVedendo* descriptions are available[5].

4.2 Participants

We recruited 10 blind participants through our network of contacts and through a local association of people with VI. Of them, 3 participants are legally blind and others are totally blind[6]. Most were blind since birth, while 4 are late-onset blind, defined as those who became blind after 12 years of age [53]. Participants' age ranged between 25 and 62 years of age (37.3 ± 11.1)[7]. Only *P*3 had prior experience with the *DescriVedendo* description of the painting, while *P*10 had prior knowledge of the subject of the painting but not of the painting itself.

All participants use iOS devices except for *P*5 who is an Android user. For the study, each participant used the device they habitually use. Self-reported expertise with mobile devices was generally high, with all participants reporting a score of 4 or 5 out of 5, besides *P*9 who reported 3. Participants visited art venues mostly between 2 to 5 times per year. Outliers were *P*5, who visited museums and art galleries about once per month, while *P*8 and *P*9 visited museums very rarely. Detailed demographic information is presented in Table 1.

Table 1: Participants' demographic data

ID	Sex	Age	Visual Impairment		Expertise with mobile (1-5)	Art venue visit freq.
			Type	Onset		
*P*1	M	48	Totally blind	Birth	5	3 / y.
*P*2	F	25	Legally blind	Birth	5	3 / y.
*P*3	M	62	Legally blind	45 y.	4	4 / y.
*P*4	F	41	Totally blind	Birth	5	3 / y.
*P*5	M	32	Totally blind	22 y.	4	1 / m.
*P*6	M	32	Totally blind	14 y.	5	4 / y.
*P*7	M	37	Totally blind	Birth	4	2 / y.
*P*8	M	37	Totally blind	13 y.	4	rarely
*P*9	F	25	Legally blind	Birth	3	rarely
*P*10	M	34	Legally blind	Birth	5	5 / y.

4.3 Study Design and Protocol

We first collected the participants' demographic information and gave them an overall description of the study and its goals. Then we introduced one of the two interaction modalities, which were counterbalanced to mitigate effects of order. Even participants started with the attribute-based modality and odd participants with the hierarchical one. Since the painting is a landscape, we reminded the participants to set the device in landscape mode. We described the considered modality, and asked participants to explore the artwork with it as much as desired.

[5]http://bit.ly/art-brera

[6]www.ada.gov/lodblind.htm

[7]In the following, we use the notation average±standard deviation

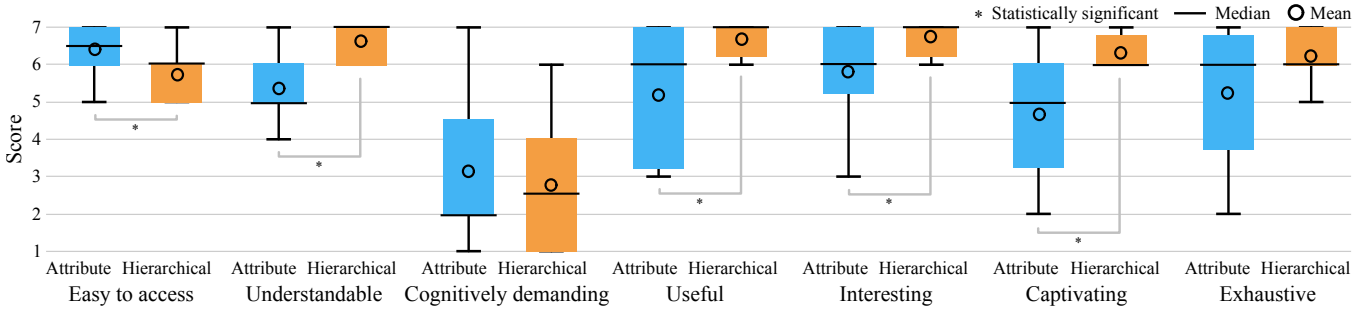

Figure 2: Questionnaire scores

After the exploration, we asked the participants to describe the artwork, and collected their answers to a series of questions on the tested modality. We repeated this procedure with the same artwork for the other exploration modality. We did not ask the participants to describe the artwork again because we were interested only in what they learned after the first exploration. Finally, we asked additional comparison questions and comments about the two modalities. The study lasted 30 minutes on average. Full study data, including questions, participants' comments and notes is available online[8].

4.4 Evaluation Metrics

After each exploration modality, a questionnaire was used to assess whether the participants perceived the considered modality:

- **Easy to access** - if the interaction with the exploration modality was perceived to be easy to access
- **Understandable** - whether the information provided was perceived to be easy to understand
- **Cognitively demanding** - if the interaction with the exploration modality was perceived to be cognitively demanding
- **Useful** - if the information provided was deemed useful
- **Interesting** - whether the information provided was considered interesting
- **Captivating** - if accessing the information with the exploration modality provided was considered captivating
- **Exhaustive** - whether the information about the artwork structure and its elements was perceived to be complete

The scores for each metric were collected on a 7-point Likert scale (1-completely disagree to 7-completely agree). After testing both exploration modalities, the participants were also asked to compare them considering each metrics (*e.g.*, which modality was more accessible, understandable), to verify whether the provided absolute scores corresponded to the relative perception of the two.

We also measured the exploration duration and, for the first exploration modality, we asked the participants to describe the painting, in order to assess which modality provided a clearer understanding of the artwork. To each description we associated a score based on what the participants were able to recall about the artwork: 1 if they remembered nothing or almost nothing; 2 if they recalled some of the key elements (Jesus, Samaritan, Disciples); 3 if they grasped all key elements; 4 if they additionally remembered some details; and 5 if they remembered all or almost all elements.

[8]http://bit.ly/art-res

We performed the statistical analysis of the collected metrics. For description scores, we used Mann-Whitney U-test, a nonparametric test appropriate for ordinal, unpaired data [46]. Other metrics were compared using Sign test, which is also a nonparametric test, shown to be appropriate for the analysis of paired Likert-like data [45].

5 RESULTS

We detail the results of the statistical analysis performed on the collected metrics. Then, we discuss participants' preferences along with the results of the comparisons between the two modalities. Finally, we report and examine the participants' comments.

5.1 Quantitative Analysis Results

Figure 2 reports the quantitative scores for the 7 collected metrics. For both exploration modalities, all scores were positive on average, indicating that **both modalities were appreciated by the participants (Q1)**. In particular, **attribute-based exploration was considered easy to access**, with a score of 6.40 ± 0.70. With average scores over 5, it was also considered understandable (5.4 ± 0.84), useful (5.3 ± 1.83), interesting (5.8 ± 1.4) and exhaustive (5.2 ± 2.04). Attribute-based exploration was also perceived to be captivating, with a score of 4.7 ± 1.64. Hierarchical exploration achieved scores over 6 for most metrics. It was considered **understandable** (6.6 ± 0.52), **useful** (6.7 ± 0.48), **interesting** (6.7 ± 0.48), **captivating** (6.3 ± 0.48) and **exhaustive** (6.2 ± 0.79). With a score of 5.70 ± 0.67, it was also perceived to be easy to access.

Comparing the two modalities (**Q2**), **attribute-based exploration was considered easier to access**. The difference was statistically significant ($Z = 2.3$, $p < .05$). Instead, **hierarchical modality was found to be easier to understand**. Also in this case, the difference was statistically significant ($Z = 2.65$, $p < .01$). **None of the two modalities was perceived to be significantly more cognitively demanding** than the other. For this metric, attribute-based exploration scored 3.1 ± 1.91, while hierarchical exploration had 2.8 ± 1.87. **Hierarchical exploration also reached a higher usefulness score, and it was considered more interesting and captivating than attribute-based exploration**. For all three metrics, the difference was statistically significant ($Z = 2.2$, $p < .05$). **None of the modalities was perceived to provide a more exhaustive understanding of the artwork**, despite a higher score for hierarchical exploration than for attribute-based exploration.

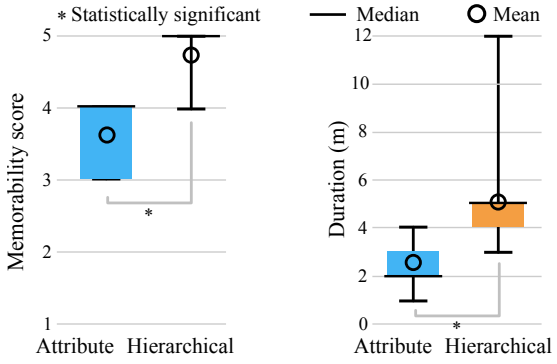

Figure 3: Memorability and Duration

In contrast with the user subjective evaluation, as shown in Figure 3, **hierarchical exploration actually provided a better understanding of the elements contained in the painting** (significant difference with $U = -2.19$, $p < .05$), reaching a memorability score of 4.8 ± 0.45, compared to 3.6 ± 0.55 of the attribute-based exploration (**Q2**). At the same time, Figure 3 shows that the **hierarchical approach required more time for the exploration** (5.2 ± 2.49) than attribute-based approach (2.4 ± 0.84min), which was also significantly different ($Z = 3.16$, $p < .005$).

5.2 User Preferences and Comparisons

Attribute-based modality was preferred by 2 participants, and 2 were undecided, but leaning towards the hierarchical modality (**Q2**). Instead, 6 **participants expressed preference for hierarchical exploration** (see Table 2). However, 4 of these also stressed that selecting one or the other modality was a hard choice, and that **both modalities are useful for the exploration**, jointly or for different use cases (**Q1**).

Table 2: Subjective feedback and preferences (a = attribute-based, h = hierarchical, / = undecided)

ID	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	a	h	/
Easy to access	a	a	a	a	a	a	a	h	a	/	8	1	1
Understandable	h	/	h	h	h	h	h	h	h	h	0	9	1
Cognitively demanding	h	/	h	a	h	a	a	a	h	a	5	4	1
Useful	h	h	h	a	h	a	h	h	h	/	2	7	1
Interesting	h	h	h	h	h	h	h	h	h	a	1	9	0
Captivating	a	h	h	h	h	h	h	h	h	h	2	8	0
Exhaustive	a	a	h	h	a	a	h	h	h	a	5	5	0
Preference	a	a	h	h	h	/	h	h	h	/	6	2	2

The results to the comparative questions in general correspond to the quantitative scores for the collected metrics. Indeed, 8 **out of** 10 **participants considered attribute-based exploration easier to use, while the majority found hierarchical exploration to be more understandable, useful, interesting and captivating**. As before, none of the two modalities was perceived to be more cognitively demanding or exhaustive.

5.3 Comments and Quotes

The quantitative and comparison results were strongly reflected in the participants' spontaneous feedback (Translated from Italian).

5.3.1 ***Attribute-based Exploration.*** Most participants considered attribute-based exploration to be simple to access but providing basic descriptions. For example, *P*9 and *P*8 report respectively:

> *"The description is quite essential. You grasp a general idea on what is there, but it is hard to understand where the elements are and more details about them."*
>
> *"Previous modality [hierarchical] was more descriptive, this one is more detailed, I do not have a global understanding as in the other modality. This is more fragmented."*

Some of the participants who accessed attribute-based exploration first actually commented that having more detailed descriptions would be useful, confirming the hypothesis outlined by *DescriVedendo* experts. For example, *P*5 commented:

> *"It could be useful to be able to select an object and have a more specific description."*

Similar to the domain experts, *P*1 and *P*3 also noticed the similarity to tactile images. In particular *P*3 stated:

> *"It is similar to tactile images. If this approach was associated to a description it would be better."*

Nonetheless, some participants found that attribute-based exploration provided more details and that exploring without long description would help them to understand the structure of the work better. For example, *P*1 and *P*10 reported:

> *"[with attribute-based exploration] I immediately grasp the spatial disposition of the elements."*
>
> *"This is more what I had in mind, I also found some elements I missed before: well, vase, rope."*

5.3.2 ***Hierarchical Exploration.*** Most participants reported that hierarchical exploration was more captivating and the scene was easy to imagine. *P*8 and *P*9 commented respectively:

> *"I can vividly imagine while exploring. It is especially useful for those who had sight before as in my case."*
>
> *"For sure more exhaustive than the other one. It gives more details and presents them more emotionally. It is easier to imagine the painting this way."*

However, *P*5 noted that there were less details than before:

> *"better, but I would like more objects and details."*

5.3.3 ***Interaction between Exploration Modalities.*** Most participants note that the modalities work well together and that information provided by one modality helps the exploration in the other. For example, *P*2, who first tried hierarchical exploration, states:

> *"Given that I have prior information, now exploring everything, even without the hierarchy I remember well the structure of what is being described."*

Similarly, *P*7, who first performed attribute-based exploration, notes:

> *"There are some elements I have explored before which I removed. But now I remembered them while exploring, because the exploration is more vivid."*

However, the order of the two modalities suggested by the participants is most often the same they performed. Indeed, *P*7 concludes:

> *"Having it [hierarchical] as the second exploration is very useful."*

At the same time, *P*8 and *P*10, who performed hierarchical exploration as the first modality, report:

> *"Hierarchical gives me a vision of overall work. Attribute-based is more detail-oriented."*

> *"They are complementary. Hierarchical is needed, otherwise you do not get the details in the attribute-based."*

5.3.4 ***Exploration for People with Low Vision.*** Legally blind participants had some residual vision but did not seem to perceive useful information from their iPhone screens. Only *P*10, who used a large iPad device, noted that the selected elements are highlighted on the screen:

> *"Wow, it also contours elements! Now I want to zoom and try to see better."*

The same participant also suggested:

> *"It would be nice that the segmentation [hierarchical] is more accurate and specific, not only conceptual because I see color variations and I would like that there is an interpretation to all blobs of color I see."*

5.3.5 ***Comments and Suggestions.*** Some participants suggested improvements or modifications. For example, *P*1 commented that perspective information is generally hard to grasp when trying to understand paintings. Thus, a sonification approach that conveys the distance of the explored elements was suggested:

> *"It is hard to understand the perspective distance with such bi-dimensional exploration and associated descriptions. Continuous background sound could be useful for perspective information."*

*P*6 reported that the image should be centered on the screen because it is very close to the navigation bar on iPhone and therefore it sometimes interferes with the exploration:

> *"Image should be moved down a bit, otherwise I end up on the iPhone navigation bar."*

Instead, *P*4 suggested to add optional background music and different voices for a more stimulating experience:

> *"I would use hierarchical exploration, with some different voices and music which would increase interest - they should however be optional so not to increase time and cognitive load."*

6 DISCUSSION AND LIMITATIONS

We discuss key study results and the limitations of our approach.

6.1 Limitations of the User Study

The study design presents an inherent limitation in the fact that a single artwork was used for the evaluation. Furthermore, another limitation is introduced by the requirement to conduct the study remotely, due to COVID-19 epidemic lockdown. We discuss the effects of these two limitations in the following.

6.1.1 ***Evaluation with a Single Artwork.*** Originally, we wanted to evaluate the proposed exploration modalities in comparison to tactile image exploration. Since a *DescriVedendo* description and a tactile image are available for only one artwork to which we have access, namely "Cristo e la Samaritana al Pozzo", we used solely this painting for the user study. Clearly the evaluation on a single painting poses a limit to the generalizability claims for the proposed exploration modalities. However, we note that the selected artwork is a typical example of figurative art, as other *DescriVedendo* artworks. Indeed, it presents a realistic and objective scene, depicted in perspective, with a main subject, a second plane and a background. Thus, while we cannot guarantee that our approach would fit every artwork, we are confident that the evaluation with other figurative artworks present among *DescriVedendo* descriptions would yield similar results as the selected one.

Nonetheless, an important next step for our work will be to assess the effectiveness of the proposed exploration modalities with other artworks. In the first place we will consider other pictorial figurative artworks, but also abstract art, as well as architectural and sculptural art. *DescriVedendo* descriptions will be needed for those artworks that still do not have them. This might require also to extend *DescriVedendo* guidelines for including also non-figurative artwork descriptions.

6.1.2 ***Remote Study During COVID-19 Lockdown.*** Our aim was to run the study in a controlled scenario, on a same mobile platform for all participants, with the supervision of an experimenter to observe and intervene if needed. Due to COVID-19 lockdown, that was not possible. Instead, we conducted the study telephonically, using the web app implementation to test the proposed touch screen exploration modalities. Participants were at home, using their own devices, with an experimenter providing support remotely.

The key limitation of not being able to conduct tests at the museum is that we were not able to assess the tactile image baseline. Since the domain experts suggested that the attribute-based exploration is similar to tactile images, we wanted to explore this intuition by adding tactile image as an additional experimental condition. While we were not able to perform this evaluation, comments from the participants (*P*1, *P*3) confirm that there is a similarity between attribute-based exploration and tactile images. After the reopening of the museum, we will validate this claim by performing additional comparative studies including tactile image as a condition.

Furthermore, the use of different devices influenced the exploration for some participants. For example, *P*6 used an iPhone model with a thin bezel on which it is easy to end up on the navigation bar, which would disturb the exploration. Instead, *P*10 used a large iPad device which made the exploration easier and provided more information visually as the participant had some residual vision.

Another limitation is that we also were not able to visually observe the participants' interaction with the system. While often we were able to understand if a participant needed additional explanations or assistance by asking questions, sometimes we realized that there were difficulties only later on or during the test. For example *P*3 started the exploration with the device in portrait mode, and only after a while we noticed this and reminded the participant to rotate the device.

6.2 Attribute vs. Hierarchical Exploration

While designing the two exploration modalities, we formed hypotheses about their possible strengths and weaknesses. For example, after discussing with the domain experts, we expected the attribute-based modality to be perceived as more cognitively demanding, which, however, was not confirmed by the results. However, confirming our expectations, attribute-based exploration was found to be quicker and easier to access since it did not have multiple exploration levels present in hierarchical exploration. Conversely, hierarchical exploration was found to be more interesting and captivating because it uses verbose descriptions instead of attributes.

We did not expect the two modalities to provide different levels of artwork understanding since they essentially contain the same descriptions, summarized for attribute-based exploration and verbose for hierarchical modality. The participants as well did not perceive that one modality provided better understanding of the artwork than the other. However, the descriptions provided by the participants after the hierarchical exploration were more complete and detailed than those provided after the attribute-based modality. A possible motivation is that hierarchical exploration, perceived more interesting and captivating, helps the users to focus better to the description, hence contributing to memorize artwork elements. Furthermore, hierarchical exploration presents a general description of the artwork, and contains a smaller number of elements compared to the attribute-based modality, which may help the user to form a better understanding of the spatial relationships between the artwork's elements, as suggested by the *DescriVedendo* team.

As a key takeaway, we argue that involving domain experts during the design of the hierarchical exploration contributed to make this modality better suited for recollecting artwork information. Suggestions provided by domain experts, which informed the hierarchical exploration design, are ultimately responsible for the higher appreciation and improved understanding of the artwork. Due to this, we believe that considering the specific problem domain and involving the domain experts is invaluable when designing solutions for accessible touch screen interactions with visual data.

6.3 Personalization and Combined Exploration

Many participants ($P1$, $P3$, $P5$, $P10$) argued that personal preferences and characteristics may deeply affect the exploration modality preference and performance. On this $P1$ clarified:

> *"There are many cognitive styles: more spatially oriented ones and verbally oriented ones. I always used tactile images, since grade school, and I developed a spatial cognitive style. Others may be different. For example in this case I immediately grasp the spatial disposition of the elements, but verbal details, not as much."*

$P3$ and $P5$ commented that residual vision might also impact exploration preferences. $P3$, who had some residual vision, argued that, in absence of an initial description to contextualize the exploration, attribute-based exploration would be difficult for people without residual vision. Similarly, $P5$, who is totally blind, commented that attribute-based exploration would probably work better for someone with residual vision. However, he also claimed that this might depend on the artwork complexity and element density.

Most participants argued that both modalities were useful and had a role in the artwork exploration. Some ($P2$, $P5$, $P6$, $P7$, $P8$, $P10$) suggested that the two modalities complement each other and should be used together. Interestingly, participants had diverging opinions on what should be the initial exploration modality. Some believed that hierarchical exploration is suitable for an initial overview of the the artwork and that attribute-based exploration is useful, afterwards, to grasp more details ($P5$, $P6$, $P8$, $P10$). Others ($P2$, $P7$) were instead convinced that attribute-based exploration provides a good initial understanding of the spatial disposition of the key artwork elements, which can then be described in details through hierarchical exploration.

These results suggest that, as often happens with assistive technologies, there is not a single solution that best suites all users and situations. Thus, solutions for artwork exploration should allow in-depth personalization of the interaction, and fine tuning of both touch screen exploration and verbal descriptions, either through manual or automated settings, based on the analysis of user characteristics and usage data [28]. Solutions for accessible artwork access should also provide the ability to perform the exploration in multiple different modalities. These should be easy to adapt quickly and frequently, and it should be possible to create a number of different exploration presets adaptable to the specific user needs.

7 CONCLUSION

We investigated the design space of touch screen exploration of visual artworks, through touch screen interface coupled with verbal descriptions, aimed at supporting blind people in appreciating art. For this task we designed two exploration modalities. Attribute-based exploration, based on prior literature, provides direct access to all the elements in the artwork, which are described through a series of short keywords and phrases when accessed through touch screen. Hierarchical exploration, designed together with domain experts, provides an initial description of the artwork as a whole. Afterwards the user can explore key artwork elements to obtain their detailed descriptions. Finally, fine details can be accessed for each key element, providing additional information about them.

User studies with blind participants show that attribute-based exploration is faster and easier to perform, while hierarchical approach is more interesting and provides a better understanding of the artwork. Nonetheless, both modalities were appreciated by the participants, who were particularly interested in their combined use. We discuss our findings, providing design considerations to support future research in touch screen-based audio-tactile artwork exploration for blind people. We also believe that the exploration modalities presented here, as well as their evaluation, could be applicable in the broader field of image exploration by people with VI. However, we stress the importance of involving domain experts during the design of accessible image exploration modalities, which was shown to be successful in the case of hierarchical exploration.

As a future work, we will explore crowdsourcing and automated techniques for the segmentation task. We will perform additional studies, investigating how single design choice dimensions impact the results achieved by the proposed exploration modalities, and how the proposed modalities compare to tactile image exploration. Finally, we will extend our investigation to people with low vision.

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