Visualization of Cultural-Heritage Content based on Individual Cognitive Differences

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ABSTRACT

Comprehension of visual content is linked with the visitors' experience within cultural heritage contexts. Considering the diversity of visitors towards human cognition and the influence of individual cognitive differences on information comprehension, current visualization techniques could lead to unbalances regarding visitors' learning and experience gains. In this paper, we investigate whether the visualization of cultural-heritage content, tailored to the visitors' individual cognitive characteristics, would improve the comprehension of the cultural-heritage content. We followed a two-step experimental approach, and we conducted two small-scale between-subject eye-tracking studies (exploratory and comparative study), in which people with different cognitive style participated in a gallery tour. The analysis of the results of the exploratory study revealed that people with different cognitive style, differ in the way they process visual information, which influences the content comprehension. Based on these results we developed cognitive-centered visualizations and we performed a comparative study, which revealed that such visualizations could help the users towards content comprehension. In this respect, individual cognitive differences could be used as the basis for providing personalized experiences to cultural-heritage visitors, aiming to help them towards content-comprehension.

CCS CONCEPTS

• **Human-centered computing → Empirical studies in HCI**; **Visualization**; *HCI theory, concepts and models*; • **Computing methodologies → Cognitive science**;

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1 INTRODUCTION

Over the last years, cultural heritage has been a favored domain for personalization research [2]. Stakeholders from interdisciplinary fields (e.g., computer science, user modeling, heritage sciences) have collaborated to develop adaptive information systems that provide personalized cultural-heritage experiences to the end-users (e.g., museum visitors). When designing such systems, several user-specific and context-specific aspects [2] must be considered to provide the most appropriate content in the most suitable way to the end-users, aiming to assist them to have a more efficient and effective comprehension of the cultural-heritage content. With regards to the user-specific aspects, the information system designers must comply with the diversity of individuals who have different characteristics such as personality traits [1], goals [2], and visiting styles [5]. An aspect, which is not being considered as an important design factor by the current practices, is the *human cognition*, although several researchers have confirmed existing effects towards content comprehension in diverse application domains, such as usable security [9], gaming [20], and e-learning [28].

Given that cultural-heritage activities often include visual content comprehension tasks (e.g., viewing a painting in an art museum), human cognitive characteristics related to the comprehension of visual information would be of great interest as a personalization factor within a cultural-heritage context. The cognitive style *Visualizer-Verbalizer (V-V)* is such a cognitive characteristic. According to the V-V theory [16], information is processed and mentally represented in two ways: verbally and visually. Hence, the individuals are distinguished to those who think either more in pictures (visualizers) or more in words (verbalizers) [12]. Research has shown that V-V influences learning and content comprehension [10, 12] and that it is associated with visual behavior [10, 13, 28].

Despite that there is an extensive body of research which underpins that V-V affects users' comprehension of visual content, current design approaches do not leverage on these findings and do not consider V-V as an important factor when designing cultural-heritage activities. This can be accredited to the fact that there is a lack in understanding the interplay among visual behavior, cultural-heritage activities, and human cognition factor, which have not been investigated in depth. Hence, this results to an insufficient understanding on whether and how to consider such human cognitive factors practically within current state-of-the-art design approaches. Therefore, the research question that this paper discusses is whether V-V affects users' content comprehension when performing a typical cultural-heritage activity, and if so, whether there are specific visualization types, based on users' V-V cognitive style, that can be used to help users towards a deeper understanding of the visual cultural-heritage content.

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Figure 1: The paintings used in our study (from left to right): *Child with rabbits* (1879) by Polychronis Lembesis, *Café "Neon" at night* (1965) by Yiannis Tsarouchis, *The Sphinx in Cairo* (n/a) by Pericles Cirigotis, *In surgery* (n/a) by Georgios Roilos, and *The dirge in Psara* (1888) by Nikephoros Lytras.

2 STUDIES AND RESULTS

To answer the research question, we followed a two-step between-subject experimental approach. In the first step, we performed an exploratory study, investigating whether and how the visual behavior of individuals who have different V-V cognitive style influenced the comprehension of the cultural-heritage content. In the second step, based on the results of the exploratory study, we created cognitive-specific visualizations, and performed a comparative study, aiming to evaluate the effects of the cognitive-specific visualizations.

2.1 Exploratory Study

2.1.1 Hypotheses. To answer the first part of the research question, we formed the following null hypotheses:

- $\mathbf{H0}_1$ There is no difference between visualizers and verbalizers regarding the content comprehension.
- $\mathbf{H0}_2$ Visual behavior of visualizers and verbalizers is not associated with the content comprehension.

2.1.2 Cultural heritage activity. Considering that browsing virtual collections and galleries is a popular way for delivering cultural-heritage content [26, 30], we developed a web-based virtual-tour application with five paintings of the National Gallery of Greece: a) *Child with rabbits* by Polychronis Lembesis, b) *Café Neon at night* by Yiannis Tsarouchis, c) *The Sphinx in Cairo* by Pericles Cirigotis, d) *In surgery* by Georgios Roilos, and e) *The dirge in Psara* by Nikephoros Lytras. The paintings are depicted in Figure 1. Each painting was accompanied with a textual description, and thus, each painting had two types of content: pictorial and textual.

2.1.3 Instruments and metrics. To classify the participants as either visualizers or verbalizers, we used a version of the Verbal-Visual Learning Style Rating questionnaire (VVLSR) [12] and the Verbalizer-Visualizer Questionnaire (VVQ) [24]. Both tests have been widely used in similar studies in varying contexts, such as e-learning [10] and comprehension of multimedia material [11]

To measure the visual-content comprehension (VCC), we designed a post-test VCC questionnaire. It consisted of ten multiple-choice questions (two questions for each painting: one about the pictorial content and one about the textual content), with high reliability (.738) according to Kuder-Richardson-20 Test. None of the participants had seen the paintings before, thus, they had no prior knowledge about their content.

Regarding the eye-tracking metrics, we focused on fixations on the areas of interest (AOIs), following common practice [21]. Given that each painting was accompanied with a textual description, two different types of AOI are identified: pictorial and textual AOIs. For each type, we measured the: number of fixations in each AOI, fixation duration in each AOI, entry time in each AOI, number of transitions among AOIs, and fixation ratio. For each metric, we considered the computed measures: sums, means, max, min. To capture the participants' eye-gaze behavior we used Tobii Pro Glasses 2 at 50Hz.

2.1.4 Participants. 23 adult individuals (10 females and 13 males), ranging in age between 18 and 33 years old ($m = 23.3, sd = 4.9$), took part in the study. According to VVLSR and VVQ, 12 participants were classified as visualizers and 11 participants were classified as verbalizers.

2.1.5 Procedure. We recruited 23 study participants, using varying methods (e.g., personal contacts, social media announcements). The participants had to meet a set of minimum requirements: have never taken VVQ and VVLSR tests before; be older than 18 years; know nothing about the paintings used in the study; have little knowledge of art history and theory. All participants were informed about the study and signed a consent form. For each participant, we scheduled a single virtual exhibition tour of the study paintings. Each virtual took took place in our lab at a mutually agreed date and time. Before entering the tour, the participant completed the VVQ and VVLSR tests (20 minutes). Next, she/he navigated through the scene (20 minutes) and viewed all the paintings (no view-order restrictions). Then, she/he distracted with a playful activity (30 minutes), which was not relevant to the virtual tour. Finally, she/he filled a form about demographics informations and answered the VCC questionnaire (15 minutes).

2.1.6 Results. To investigate $\mathbf{H0}_1$, we performed a Mann-Whitney U Test. The test met the required assumptions, as the distributions of the correct answers (i.e., VCC score) for both visualizers and verbalizers were similar, as assessed by visual inspection. Median score for visualizers and verbalizers was not statistically significantly different (Table 1). However, the analysis regarding the comprehension on each type of content (i.e., VCC_{pic} for pictorial-content comprehension and VCC_{text} for textual-content comprehension) revealed significant differences. In particular, visualizers had a significantly better VCC_{pic} ($U = 32.000, z = -2.217, p = .027$), while visualizers had a significantly better VCC_{text} ($U = 33.500, z = -2.287, p = .022$).

Table 1: Statistical analysis on content comprehension

				$\mathbf{VCC}_{total}$
Cognitive dimension	**N**	**Median**	**Mean**	**Std.**
Visualizer	12	6.000	6.082	.900
Verbalizer	11	6.000	6.093	1.578
Mann-Whitney U Test	$U = 60.500, z = -.358, p = .721$			

				$\mathbf{VCC}_{pic}$
Cognitive dimension	**N**	**Median**	**Mean**	**Std.**
Visualizer	12	3.500	3.582	.669
Verbalizer	11	3.000	2.820	.982
Mann-Whitney U Test	$U = 32.000, z = -2.217, p = .027$			

				$\mathbf{VCC}_{text}$
Cognitive dimension	**N**	**Median**	**Mean**	**Std.**
Visualizer	12	3.000	2.521	.674
Verbalizer	11	3.000	3.272	.786
Mann-Whitney U Test	$U = 33.500, z = -2.287, p = .022$			

To investigate $\mathbf{H0}_2$ we performed a series of Spearman's correlation test between the visual behavior metrics and VCC. The results revealed several low and moderate correlations, and a strong positive correlation ($r_s = .883, p < .001$) between VCC and the ratio of fixation duration on pictorial and textual AOIs (Equation 1).

$$VB_{dur-ratio} = \frac{Fixation.duration_{pictorial.aois}}{Fixation.duration_{textual.aois}} \quad (1)$$

To further investigate the effect of V-V cognitive style on the visual behavior of the users, we performed an independent-samples t-test to determine whether there are differences in $\text{VB}_{dur-ratio}$ between visualizers and verbalizers. The test met all the required assumptions. The $\text{VB}_{dur-ratio}$ was higher for visualizers ($m = 1.890, sd = .775$) than verbalizers ($m = 1.238, sd = .299$), statistically significant difference of ($p = .017, t(21) = 2.619, d = 1.110, 95\%CI : [.135, .172]$). The results underpin that visualizers tend to perform longer fixations on the pictorial AOIs, while the verbalizers tend to perform longer fixations on the textual AOIs.

2.2 Visualization

The results underpin the necessity of providing customized visualizations for both visualizers and verbalizers, in order to help them comprehend better the content of the paintings. Considering that visualizers have an inherent preference for pictorial content, while verbalizers have an inherent preference for textual content, we propose a *cognition-based visualization* that aims to trigger the visualizers' attention to textual AOIs and the verbalizers' attention to pictorial AOIs. Through the *cognition-based visualization* we expect visualizers to comprehend better the textual content and verbalizers to comprehend better the pictorial content of the paintings.

A common approach to make an individual with specific cognitive characteristics to focus on specific AOIs is to exclude the other AOIs [9]. However, this cannot be applied in a virtual gallery-tour, where both pictorial and textual AOIs are important to the visitor. Therefore, we cannot exclude one type or another, but we need to direct users' attention to the AOI type that they do not inherently prefer. In particular, we need to direct the visualizers' attention to textual AOIs and the verbalizers' attention to pictorial AOIs.

To help visualizers pay more attention on the textual AOIs and increase textual-content comprehension, we adopted a popular technique found in the literature: emphasize specific key-words, that are critical for a better comprehension [4]. Hence, the textual AOIs can be visualized in two ways: the *default* way, which is recommended for verbalizers, and the *emphasizing* way, which is recommended for visualizers. To help verbalizers pay more attention on the pictorial AOIs and increase pictorial-content comprehension, we applied a saliency filter to the pictorial AOIs, which is a typical technique to attract attention to specific areas of pictures [9]. Hence, the pictorial AOIs can be visualized in two ways: the *default* way, which is recommended for visualizers, and the *salient* way, which is recommended for verbalizers. The simple dichotomous algorithm (in pseudo-code) to define the visualization of each painting is:

Algorithm 1 Simple dichotomous algorithm to set the visualization of an AOI based on the user's V-V cognitive dimension

```
procedure SetCognitionBasedVisualization
    if user is visualizer then
        Set AOI → text → vis to "emphasis"
        Set AOI → pic → vis to "default"
    else
        Set AOI → text → vis to "default"
        Set AOI → pic → vis to "salient"
```

2.3 Comparative study

To investigate whether the cognition-based visualization would assist visualizers and verbalizers to comprehend better the paintings' content, we conducted a between-subject comparative study.

2.3.1 Hypotheses. To answer the second part of the research question, we formed the following null hypotheses:

- $\mathbf{H0}_3$ Cognition-based visualization does not affect significantly the visual behavior of visualizers and verbalizers.
- $\mathbf{H0}_4$ Cognition-based visualization does not affect significantly the comprehension of visualizers and verbalizers regarding paintings' content.

2.3.2 Cultural heritage activity. The activity was the same with the one discussed in the exploratory study. However, the cognition-based visualization was applied for each painting, depending on the V-V cognitive dimension of the user.

2.3.3 Instrument and metrics. They were identical with the instruments and metrics that were used in the exploratory study.

2.3.4 Participants. We recruited 20 adult individuals (8 females, 12 males) ranging in age between 20 and 31 years old ($m = 25.3, sd = 3.8$). According to VVLSR and VVQ, 10 participants were classified as visualizers and 10 participants were classified as verbalizers.

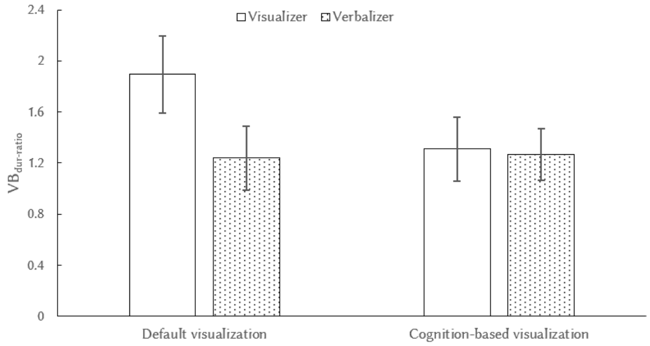

Figure 2: The cognition-based visualization type helped the visualizers increase their fixation duration on the textual AOIs.

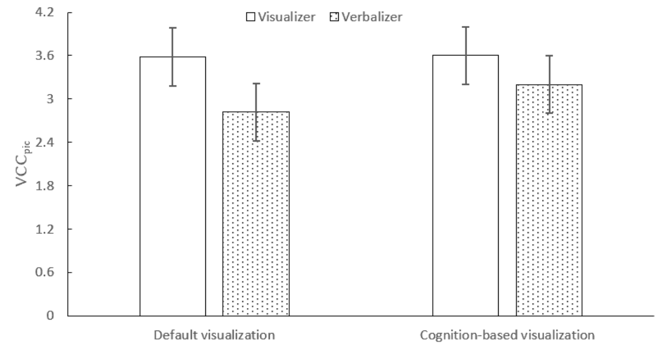

Figure 3: The cognition-based visualization type helped mainly verbalizers to perform better in pictorial-content questions.

2.3.5 Procedure. We followed the same study procedure with the exploratory study.

2.3.6 Results. To investigate $\mathbf{H0}_3$, we performed a two-way ANOVA with V-V cognitive dimension and the type of the visualization as the independent variables, and the $\text{VB}_{dur-ratio}$ as the dependent variable. The test met all the required assumptions. The results revealed a significant interaction effect ($F(1, 39) = 4.835, p = .034, eta = .110$). Focusing on each independent variable, a significant effect was revealed both for cognitive dimension ($F(1, 39) = 6.272, p = .019, eta = .129$) and the visualization type ($F(1, 39) = 4.039, p = .047, eta = 1.104$). Regarding the main effects, the visualization type helped most the visualizers as they increased the fixation duration on the textual AOIs, and thus, their $\text{VB}_{dur-ratio}$ was decreased ($F(1, 39) = 9.039, p = .005, eta = .188$). No main effects were revealed for the verbalizers regarding the visualization type. Regarding the cognitive dimension, no effects were revealed for the subjects who used the cognition-based visualization type, while there were significant effects for the subjects who used the default visualization type, as discussed in the exploratory study. The results are depicted in Figure 2.

To investigate $\mathbf{H0}_4$, we performed a two-way ANOVA with V-V cognitive dimension and the type of the visualization as the independent variables, and VCC as the dependent variable. The test met all the required assumptions. The results revealed no interaction effect. Focusing on each content-type, the analysis revealed no effects for VCC_{pic} (Figure 3). Regarding, VCC_{txt}, the analysis revealed an effect both for the V-V cognition dimension ($F(1, 39) = 7.013, p = .012, eta = .152$) and the visualization type ($F(1, 39) = 8.940, p = .005, eta = .186$). Focusing on main effects, visualizers who used the cognition-based visualization provided significantly more correct answers regarding the textual AOIs ($F(1, 39) = 5.520, p = .024, eta = .124$), as depicted in Figure 4.

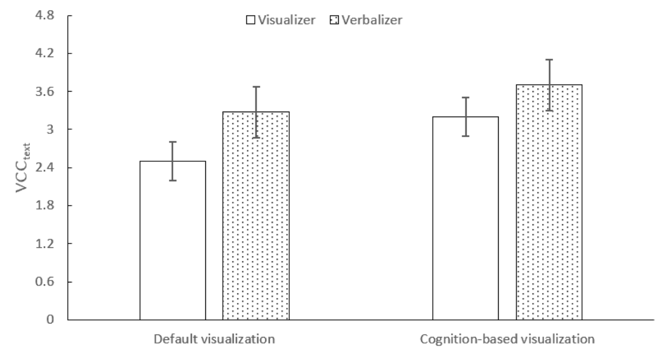

Figure 4: The cognition-based visualization type helped both visualizers and verbalizers to provide more correct answers to textual-content questions.

3 DISCUSSION

The results of the exploratory study underpin that individual cognitive differences have an impact on the users' visual behavior and content comprehension when performing a cultural activity. As expected, visualizers focused on the pictorial content and the verbalizers focused on the textual content in the visual exploratory activity (i.e., virtual gallery tour), verifying the results of other studies [10, 28] in other domains. Considering that each painting provided information both in pictorial and textual format, the overall content comprehension of both visualizers and verbalizers was not different, but it was average. The inherent preference of visualizers for pictorial content influenced the content-related comprehension, as they comprehended the content of the pictorial areas of interest, but not the content of the textual areas of interest, as they produced shorter fixations on them, which implies difficulties in memorability [29]. Likewise, the inherent preference of verbalizers in processing textual information, resulted in shorter fixations on the pictorial areas of interest. Hence, verbalizers had low performance regarding pictorial-context comprehension, but they performed well regarding textual-context comprehension.

3.1 Cognition-based visualizations

The aforementioned results underpin the necessity of adopting cognition-based visualizations to help both visualizers and verbalizers to comprehend better the visual information presented in cultural-heritage contexts. We proposed a simple dichotomous rule (Algorithm 1) which provides a customized visualization of each art-exhibit based on the cognitive profile of the user. In the case of a visualizer, the visualization type aims to direct her/his attention to textual areas of interest, while in the case of a verbalizer, the visualization type aims to direct her/his attention to pictorial areas of interest. To evaluate the proposed visualization mechanism, we performed a small-scale between-subject eye-tracking study. The results revealed that the cognition-based visualization helped both user types to perform better regarding the comprehension of the paintings' content. The visualizers who used the cognition-based visualization mechanism provided more correct answers to the textual-content questions than the visualizers who used the default mechanism. Likewise, the verbalizers who used the cognition-based visualization mechanism provided more correct answers to the pictorial-content questions than the verbalizers who used the default mechanism. At the same time, there were no differences between visualizers and verbalizers regarding either the pictorial or the textual content comprehension. Therefore, they both increased the overall score of the content comprehension (including questions related to both pictorial and textual content).

3.2 Towards a cognition-centered approach for presenting cultural-heritage content

The results of the comparative study underpin the necessity of adopting a cognition-centered approach, such as a framework, to deliver personalized cultural-heritage activities, tailored to the users' individual cognitive preferences and needs. Such framework is expected to benefit both cultural-heritage stakeholders and end-users. Stakeholders from interdisciplinary fields (e.g., curators, educators, guides, designers) are expected to use such framework to create personalized cultural-heritage activities, tailored to the cognitive characteristics of the end-users (e.g., museum visitors). End-users are expected to be benefited towards achieving their goals (e.g., improve content comprehension) through cognition-effortless personalized interventions, as they adapt to the end-users' individual cognitive characteristics.

As discussed in [22], the cognition-centered framework consists of two main modules: the *user-modeling* module and the *personalization* module. The *user-modeling* module is responsible to elicit, store, and maintain cognition-centered user profiles. It can based on elicitation mechanisms which exploit data from various sources, such as eye-gaze interaction [23] and social-behavior data [5]. Refinement processes based on machine learning and computer vision techniques can be used to ensure the accuracy and the robustness of the user-modeling module.

The *personalization* module aims to adapt the cultural-heritage activity to the unique personalized configurations for users with specific cognitive characteristics. The personalization engine takes as an input the cognitive profile of the user, provided by the user-modeling module, and exports the personalized cognition-based visualizations, following a rule-based approach. Studies like the reported one provide the personalization rules. Following an inclusive and open approach, the cognition-centered framework should support various cognitive styles and skills that have been found to affect users' experience and/or behavior in cultural-heritage contexts, such as field dependence-independence [19], visual working memory [22], and personality traits [15].

3.3 Implicit elicitation of Visualizer-Verbalizer cognitive style

The study results revealed that there is a strong correlation between users' visual behavior and content-comprehension, when considering the Visualizer-Verbalizer cognitive dimension as the control factor. Given that eye-trackers become cheaper, smaller, more robust, and they are integrated in varying technological frameworks, such as mobile devices [6] and head-mounted displays [3], and they have already been used and evaluated within cultural-heritage contexts [14, 17], eye-gaze data could be the building factors of the cognition-centered framework, aiming to a) implicitly elicit user cognitive profile and b) provide personalized visualizations.

Considering the recent works on eye-gaze based elicitation of users' cognitive characteristics [8, 23, 27] and the technological advances in the eye-tracking industry, the development of transparent and in-run time elicitation modules that would model the users according to their cognitive characteristics is feasible in the near future and in immersive contexts that are based on visual interaction, such as mixed-reality [19]. Our recent works have revealed that the elicitation of the users' cognitive style can be performed with high accuracy and in the early stages of a visual search activity when considering task complexity [23], task segments [23], and time [8] as the elicitation parameters along with the eye-gaze data.

Therefore, our study findings could contribute to building a user-modeling module which extends the current range of cognitive characteristics and increases the validity of other studies (and eventually the elicitation accuracy and performance). Based on the transparent and run-time elicitation of users' cognitive characteristics, adaptation interventions can be applied in order for the cognition-centered framework to provide personalized visualizations, tailored to the users' individual characteristics. For example, when a user is classified as visualizer in a virtual gallery tour, the framework would provide her/him with default pictorial areas of interest along with emphasizing textual AOIs, based on the appropriate adaptation rules, aiming to disperse her/his attention on both types of areas of interest.

4 STUDY VALIDITY AND LIMITATIONS

This research work entails several limitations inherent to the multidimensional character and complexity of the factors investigated. Regarding internal validity the study environment and the study procedure remained the same for all participants. The methodology and statistical tests used to answer the research objectives met all the required assumptions, despite the rather limited size of the sample, providing internally valid results.

Regarding the ecological validity of our study, the study sessions performed in times and days convenient for each participant. The desktop computer was powerful enough to support the virtual guide tour and did not affect participants' experience in the shade of poor performance. The use of an eye-tracking technology was a limitation, as the individuals do not use such equipment when performing computer-mediated activities. However, the fact that the eye-tracking technology used were wearable glasses, made the participants feel more comfortable after a while, as they could interact with the system as they would normally do. At this point is worth-mentioning that we used an expensive and accurate eye-tracking apparatus which could sabotage the application of such schemes in typical real-life cultural-heritage scenarios. Therefore, there is a need to investigate whether we would have the same results when using more conventional and cheaper eye-tracking tools (e.g., based on web-camera feed) or whether simple eye-gaze data that are easily detected, such as number of blinks, could provide similar results.

For the scope of the study, we focused only on visual interactions. However, cultural-heritage activities also include audio-based and spatial interactions, such as storytelling applications [7] and location-based games [25]. Hence, there is a need of investigating whether individual cognitive characteristics influence visitors' behavior and experience in such contexts. In the same line, recent studies in the cultural-heritage domain have raised the importance of the visitors' emotional engagement [18]; an aspect that needs to be investigated in relation to visitors' cognitive characteristics.

We expect that our results will be replicated for activities that are based visual search tasks which can be found in varying domains, besides cultural-heritage, such as e-shopping, e-learning, and engineering. Regarding the technological context, we expect our results to be applicable for contexts which exploit the technologies across the virtuality continuum (AR/MR/VR), especially contexts that create environments rich in visual information, such as head-mounted displays (HMDs) and cave automatic virtual environments (CAVEs). Finally, our study increases the external validity of studies which investigate the effects of Visualizer-Verbalizer cognitive style on visual-search tasks [10, 28].

5 CONCLUSION

In this paper, we first reported the results of an eye-tracking study aiming to investigate the effects of V-V cognitive style on the comprehension of the content of five paintings during a virtual gallery tour and explain the results considering the users' visual behavior. Significant differences were revealed between visualizers and verbalizers regarding the comprehension of pictorial and textual content. Their performance was also strongly related to their visual behavior, which was different for visualizers and verbalizers. Hence, this paper provides evidence that users with different V-V cognitive style follow different strategies when performing a visual exploratory cultural-heritage activity (e.g., virtual gallery tour). These strategies are reflected on their visual behavior and they lead to unbalances regarding content comprehension. Triggered by the study results, we designed an assistive mechanism based on the visual behavior of the visualizers and verbalizers, which provided customized cognition-based visualizations of the paintings. To evaluate its efficiency, we conducted a comparative eye-tracking study. The results revealed that the cognition-based visualizations helped both visualizers and verbalizers to comprehend better textual and pictorial content respectively. Therefore, this work provides evidence that the cognitive styles (e.g., Visualizer-Verbalizer) can be used to provide personalized cultural-heritage experiences, aiming to improve content comprehension and eliminate learning unbalances between users with different cognitive characteristics.

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