Towards a Cognition-Centered Personalization Framework for Cultural-Heritage Content

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CHI'18 Extended Abstracts, April 21–26, 2018, Montréal, QC, Canada.

ACM ISBN 978-1-4503-5621-3/18/04.
https://doi.org/10.1145/3170427.3190613

Abstract

Comprehension of visual content is linked with the visitor's experience within cultural heritage contexts. Considering the diversity of visitors towards human cognition, in this paper, we aim to investigate whether cognitive characteristics are associated with the comprehension of cultural-heritage visual content. We conducted a small-scale eye-tracking study in which people with different visual working memory capacity participated in a gallery tour and then they were assessed towards exhibit comprehension. The analysis of the results revealed that people with low visual working memory faced difficulties in comprehending the content of the gallery paintings. In this respect, we propose a cognition-centered cultural heritage framework, aiming to provide personalized experiences to visitors and help them improve the content comprehension.

Author Keywords

Cultural heritage; individual cognitive differences; human cognition; visual working memory; personalization; virtual gallery exhibition.

ACM Classification Keywords

- Human-centered computing ~ User studies
- Computing methodologies ~ Cognitive science

Figure 1a: Polychronis Lembesis. (1879). *Child with rabbits*.

Figure 1b: Yiannis Tsarouchis. (1965). *Café "Neon" at night*.

Introduction

Over the last years, cultural heritage has been a favored domain for personalization research. Stakeholders from interdisciplinary fields (e.g., computer science, user modeling, heritage sciences) have collaborated to develop adaptive information systems that would provide personalized cultural-heritage experiences to the end-users (e.g., museum visitors). When designing such systems, several user-specific and context-specific aspects [1,2] 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 goals [1], personality [8], age [6], visiting style [3], etc. One such aspect, which is not being considered as an important design factor by the current design methodologies, is the *human cognition*, although several researchers have confirmed existing effects towards content comprehension in diverse application domains such as user authentication [4], e-commerce [5], and information visualization [18].

Given that cultural-heritage activities often embrace 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. *Visual working memory (VWM), which is* a measure of storage and manipulation capacity of visual and spatial information, is such a cognitive characteristic.

VWM has been shown to influence users' behavior in varying domains, such as automotive [7], evaluation of interfaces [9], and information visualization [18]. Since VWM is used to explain users' behavior when performing visual activities, eye-tracking studies have been extensively conducted to better understand users' visual behavior and investigate its association with the VWM capacity [9,18]. In the cultural-heritage domain, other cognitive characteristics (e.g., cognitive styles) have been investigated and it has been shown that they influence users' performance [10], strategy [13], behavior [14], experience [16], and that that they are reflected on users' visual behavior [11].

Despite that there is already an extensive body of research [7,9,18] which underpins that VWM affects users' comprehension of visual content, current design approaches do not leverage on these findings and do not consider VWM as an important factor when designing cultural-heritage activities. This can be accredited to the fact that there is a lack in modelling the underlying mechanics of the effects among visual behavior, cultural-heritage activities, and human cognition factors, which have not been investigated in depth, resulting to an insufficient understanding on whether and how to consider such human cognitive factors practically within current state-of-the-art design approaches.

Motivated by the aforementioned rationale, we performed a small-scale user-study aiming to investigate whether and how VWM influences the comprehension of visual cultural-heritage content, which is a step towards the consideration of VWM as a design factor in a cognition-centered personalization framework for cultural heritage content.

Figure 1c: Pericles Cirigotis. (*n/a*). *The Sphinx in Cairo*.

Figure 1d: George Roilos. (*n/a*). *In surgery*.

Figure 1e: Nikephoros Lytras. (1888). *The dirge in Psara*.

Study

Hypotheses

When the user performs a visual cultural-heritage activity:

- *H0₁*: visual working memory (VWM) is not correlated with the comprehension of visual context (VC).
- *H0₂*: visual working memory (VWM) is not correlated with the eye-gaze behavior.
- *H0₃*: eye-gaze behavior is not correlated with the visual-content comprehension (VC).

Participants

Fifteen adult individuals (8 females and 7 males) took part in our study, ranging in age between 19 and 46 years old ($m = 26.5, sd = 6.8$). The participants were undergraduate and postgraduate students.

Paintings

We selected five representative paintings (Figure 1) of the National Gallery of Greece: a) "*Child with rabbits*" by Lembesis, b) "*Café Neon at night*" by Tsarouchis, c) "*The Sphinx in Cairo*" by Cirigotis, d) "*In surgery*" by Roilos, and e) "*The dirge in Psara*" by Lytras.

Instruments and metrics

To measure the visual-content comprehension (VC), we designed a post-test VC questionnaire. It consisted of ten multiple-choice questions (two questions for each painting: one about the painting concept and one about painting details), with high reliability (.862) according to Kuder–Richardson-20 Test. None of the participants had seen the paintings before, thus, they had no prior-knowledge about their content. To measure VWM we used Picture Span Test [17]. Regarding eye-tracking metrics we focused on fixations and saccades, following common practice [12]. To capture the participants' eye movements, we used Tobii Pro Glasses 2 at 50Hz.

Procedure

We recruited the 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 VWM test 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. Fifteen individuals participated in a single virtual exhibition tour of the study paintings. Before entering the tour, the participants wore the eye-tracking equipment. A few minutes were given to each participant to get comfortable with the eye-tracking glasses. Next, each participant navigated through the scene (~ 30 minutes) and viewed all the paintings (no view-order restrictions). After the tour, the participants performed the VWM test (~ 10 minutes) and they answered the VC questionnaire (~ 10 minutes). The research team collected the VWM, VC, and eye-tracking data and performed the analysis as discussed next.

Results and Discussion

To investigate *H0₁*, *H0₂*, and *H0₃*, we performed Spearman, Pearson, and Spearman correlation tests accordingly. All tests met the required assumptions. The analysis revealed: *H0₁*) a strong positive correlation between VWM and VC ($r_s = .698, p = .004$); *H0₂*) a moderate positive correlation between VWM and fixation duration ($r = .602, p = .037$); *H0₃*) a strong positive correlation between fixation duration and VC ($r_s = .901, p = .007$). No effects for other eye-tracking metrics (e.g., number of fixations, fixation rate, saccade length) were revealed. Figure 2 depicts the visual behavior of two study participants: one with high VWM, and one with low VWM.

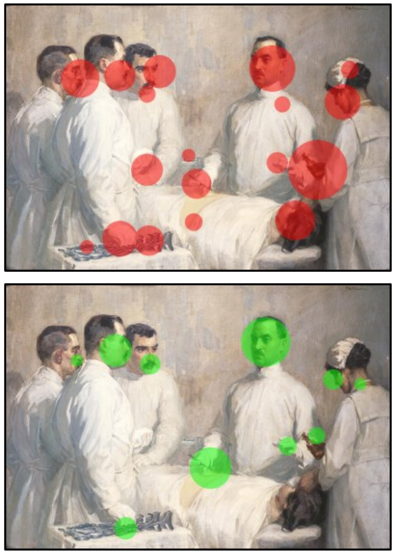

Figure 2: Visual behavior (fixations) of an individual with high visual working memory (top) and low visual working memory (bottom).

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procedure CCP(U, A):
 c_t = getCognCertaintyThreshold()
 d_t = getFixationDurationThreshold()
 while U.performs(A):
  U.cogn.refineModel(U.eye, A.time)
  foreach (AOIs as AOI):
    if ((U.cogn == "l-VWM") &&
        (U.cogn.c >= c_t) &&
        (AOI is active)):
        v_t = U.cogn.getMinViewTime()
        while (U.eye[AOI].dur < d_t):
          A.AOIs[AOI].setViewTime(v_t)
        A.AOIs[AOI].releaseViewTime()
end
```

Algorithm 1: An example of a rule of the cognition-centered framework in pseudo-code. If the user has low VWM, the system assists him/her to produce longer fixations on critical areas of interest.

The study results revealed that the individuals who were less efficient in storing and managing visual information (i.e., low VWM) produced shorter fixations, meaning that they were less focused and attentive during the activity. Hence, they could not comprehend the visual information and perceive the painting context as deeply as individuals with high VWM. This was reflected on the VC performance, as the lower VWM an individual had, the fewer questions he/she answered correctly.

The results necessitate assisting users with specific cognitive characteristics (low VWM in our study) to better comprehend visual-content. The information system should provide alternative interaction means to such individuals. Therefore, there is a need for designers to consider cognitive characteristics as a personalization factor for visual activities in the cultural-heritage domain. Otherwise, following a "one-size-fits-all" design approach, regarding human cognition, would result in a comprehension unbalance, which could eventually lead to differences in learning gains between individuals with different cognitive profiles, and have an impact on their engagement and experience.

Cognition-Centered Framework

To avoid the discussed unbalance, the designers of interactive cultural-heritage systems should consider human cognition as a design factor. Therefore, we propose the design of a *cognition-centered personalization framework for cultural heritage content* (Figure 3). The framework provides the means to adjust the visual cultural activities to the unique cognitive characteristics of the users, aiming to improve their visual-content comprehension through personalized interactions. The framework leverages on the findings of studies like the reported one, by transforming the interdependencies among eye-gaze data, human cognition, and cultural heritage design factors into formal representations of personalization rules. It consists of two main layers: the *user modeling* layer and the *personalization* layer.

The *user-modelling* layer is responsible to elicit, store, and maintain cognition-centered user profiles. It is based on an eye-gaze driven elicitation mechanism that aims to infer human cognitive characteristics through transparent and in-run-time classifiers [15]. Along with eye-gaze data, other types of interaction data (e.g., social behavior data [3]) could be used complementarily to improve classification efficiency. To increase the accuracy and the robustness of the user-modelling layer, the classification is based on run-time (i.e., while user performs an activity) refinement processes based on machine learning and computer vision techniques.

The *personalization layer* aims to tailor the cultural-heritage activity to provide unique personalized configurations for users with specific cognitive characteristics. It is based on the personalization engine, which takes as an input the cognitive profile of the user (e.g., low VWM, holistic [13], field-dependent [10]), which derived from the user-modelling layer. The rules of the personalization derive from studies like the reported one (e.g., low-VWM must fixate on specific points of the painting for a certain amount of time, field-dependent users must collect a certain number of game-items [16]). Algorithm 1 presents an example of implementing such a rule. Based on the cognitive profile and the rules, the personalization engine adapts the content presentation mechanics to the cognitive needs and preferences of the end-users. Hence, the end-users receive cognition-centered personalized cultural activities (e.g., personalized virtual art-museum tours).

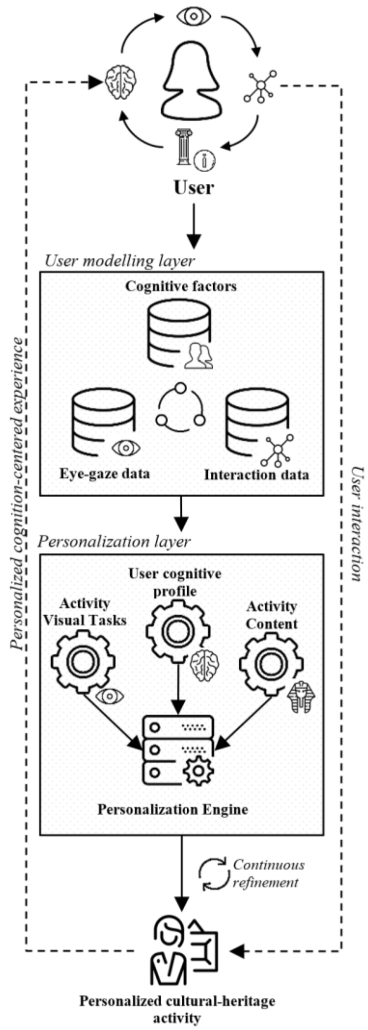

Figure 3: Cognition-centered personalization framework for cultural-heritage content

As an example: a virtual gallery aims to help low-VWM users to comprehend the content of the exhibited paintings. When a user enters the tour, our framework assigns him/her with a VWM cognitive profile, through eye-gaze driven classification (user-modelling layer). The cognitive profile is used as an input to the personalization engine (personalization layer), which adapts the content presentation and provides a personalized tour guide. For a low-VWM user, who tends to produce short and few fixations, the personalized guide assists him/her to produce more and longer fixations on critical areas-of-interest of the painting scene by indicating these and pursuing users' visual attention. Thus, the low-VWM user is expected to better comprehend the cultural heritage content, and eventually have an increased learning gain and an enhanced experience.

Limitations and Future Work

Our study has limitations, which are related primarily to the small and non-diverse study sample. However, we performed the appropriate statistical tests, which met all the required assumptions. Regarding the external validity, we expect our findings to be replicated in other cultural-heritage contexts, or contexts that embrace visual exploration tasks. Our immediate future work consists of a) increasing the size and the diversity of the sample to provide more robust results, b) adding more factors to the framework to build more inclusive user cognitive profiles, and c) developing and evaluating the cognition-centered personalization framework for cultural-heritage content towards users' experience, content comprehension, and knowledge acquisition.

Conclusion

This paper reported a small-scale empirical study which investigated the interplay among visual working memory, users' visual behavior, and visual-content comprehension within a cultural-heritage activity. The results underpin the added value of supporting individuals with low visual working memory in cultural-heritage interaction realms by scaffolding visual information exploration and comprehension tasks. To assist such user types, we proposed an initial conceptual design of a cognition-centered personalization framework for cultural-heritage content. We envisage that building personalized mechanisms would have many positive implications from the users' point of view, as such mechanisms would support the users' efficiency of processing visual information cognitively and eventually improve users' engagement and comprehension.

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