Cultural Heritage Gaming: Effects of Human Cognitive Styles on Players' Performance and Visual Behavior

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ABSTRACT

Common design practices of current cultural heritage activities barely take into account the contextual, cultural, and cognitive characteristics of visitors. Bearing in mind that information processing is substantial in such activities, this paper investigates the interplay among human cognitive differences and cultural heritage gaming activities towards players' performance and visual behavior. Three user studies were conducted under the field dependence/independence theory, which underpin cognitive differences in visual perceptiveness and contextual information handling. Findings are expected to provide useful insights for practitioners and researchers with the aim to design playful cultural activities tailored to the users' cognitive preferences.

CCS CONCEPTS

• **Human-centered computing** → HCI theory, concepts and models

KEYWORDS

Human Cognitive Styles; Eye-Tracking; Cultural Heritage; User Study; Gaming; Field Dependence-Independence

1 INTRODUCTION

In the recent years a lot of research on video games in the cultural heritage (CH) context has been conducted [1, 2], aiming to enrich visitors' experience and improve their learning outcome. To achieve this, game designers aim to include information processing tasks through game mechanisms that guide users to seek and comprehend information, and to acquire and recall knowledge. Such tasks are related to cognitive characteristics, and therefore, it is worth investigating the impact of cognitive differences on game playing in cultural heritage contexts.

UMAP'17 Adjunct, July 09-12, 2017, Bratislava, Slovakia

ACM ISBN 978-1-4503-5067-9/17/07...$15.00
http://dx.doi.org/10.1145/3099023.3099090

The cognitive differences reflect on individuals' differences in cognitive characteristics, such as skills, abilities, and styles, which influence the strategy they follow to seek, process, and recall information [3]. Research provides evidence that differences in high-level cognitive processes, known as *cognitive styles*, affect user experience and performance in diverse application domains, such as e-learning [4], web security [5], and e-shopping [6].

Cognitive styles describe the preferred strategy an individual follow to process information. A credible cognitive style is the *Field Dependence-Independence (FD-I)*, which relies on individuals' visual perceptiveness, and it measures the ability of an individual to extract information through visually complex scenes [7]. According to FD-I, people are classified as field-dependent (FD) or field-independent (FI). FD individuals tend to have difficulties on identifying visual information and follow a holistic approach to solve visual problems. On the other hand, FI individuals tend to have no difficulties on extracting information through visually complex scenes, following an analytical approach.

Motivation and related work

Bearing in mind that people differ in the way they perceive and process information because of their cognitive styles, and that CH games are based on visual information processing tasks, it is interesting to investigate the interplay of FD-I differences on players' performance and visual behavior during CH gaming. Through such studies, designers of cultural playful activities are expected to gain valuable insights on designing adaptive games that take into consideration players' cognitive styles, so that the users benefit the most from playing CH games.

Very few studies have been conducted which raise the need of investigating the effect of cognitive differences in designing CH activities. Naudet et al. [8] proposed an approach to enhance museum visitors' experience through gaming, based on cognitive differences; but, it was not supported by a user study. Goodale et al. [9] investigated the effects of cognitive styles on the use of a system for exploring digital collections of CH. They provided evidence of links between style and search behavior, as the participants who followed a holistic approach needed less time to complete the information search task; a finding that was also revealed in our recent study [10]. Based on the findings of that study [10], we discuss three studies which emerge the need of considering cognitive styles as human design factor for CH games.

2 METHOD OF STUDY

Null Hypotheses

Based on our motivation, the following null hypotheses were formed for each game:

- H01. There is no significant effect of FD-I cognitive style on gaming performance.
- H02. There is no significant effect of FD-I cognitive style on visual behavior while playing a CH game.

The games

To investigate our null hypotheses we performed three studies using different CH games with varying game mechanics. The game of the first study was *Time Explorer,* a well–known and multiple award winning web-based game provided by the British Museum, which integrates adventure, action, and problem-solving tasks. The game of the second study was *Escape from the Mummy's Tomb,* a point-and-click hidden-object web-based game provided by Liverpool Museum. The game of the third study was *HoloTour*, an audiovisual three-dimensional virtual tourism application developed by Microsoft, which transforms users to travelers, allowing them to see and explore mixed reality environments for the purpose of experiencing physical places in space and time without physically traveling there.

Apparatus

The study participants played the games on different technology devices. In particular, *Time Explorer* was played on a desktop computer with LG Monitor 22'' 22MP48D at a screen resolution of 1920x1080 pixels; *Escape from the Mummy's Tomb* on Samsung Galaxy Tab 3.8 8'' tablet at a screen resolution of 1280x800 pixels; and *HoloTour* on Microsoft HoloLens. To record the participants' eye movements, we used Tobii Pro Glasses 2.

Instruments

Cognitive style elicitation

To classify study participants as field-dependent (FD) or field-independent (FI), we used the original *Group Embedded Figures Test (GEFT)* instrument. The test consisted of three sections, in which the participants had to identify simple forms within complex patterns in a given time. For each participant, a raw score was calculated by adding the number of the simple forms correctly identified in the second and the third section; thus, the score range is between 0 and 18. The cut-off score was 12, as it has been used in several studies [4, 10], meaning that the participants who scored 12 or lower were classified as FD, and those who scored from 13 to 18 were classified as FI.

Performance metrics

Each game had its own performance metrics, which constitute the total score. The performance metric we used for the *Time Explorer* and *Escape from the Mummy's Tomb* games was the time the players needed to finish the game. The performance of *HoloTour* was measured on the number of items visually discovered.

Eye-tracking metrics

All games were based on visual exploration tasks. According to our recent literature review [11], *fixation count* is one of the eye-tracking metrics than can be used to investigate the effect of FD-I on visual exploration tasks. Fixation count is the number of fixations of an individual within an area of interest (AOI), considering visits and re-visits to the AOI. In our studies, each game item which the player could interact with and obtain CH information, was an AOI.

Participants

For each study, different sets of participants were recruited. All participants were experienced game players (*i.e.*, more than 12 hours per week of single-player gaming), and they had never played any of the games before. For the first study, 32 (8 females, 24 males) participants, aged between 18 and 27, were recruited. For the second study, 34 (14 females, 20 males) participants, aged between 18 and 34, were recruited. For the third study, 25 (11 females, 14 males), aged between 20 and 41, were recruited. After playing the game, the participants undertook GEFT and they were classified as FD or FI. For the first study, we had 15 FDs and 17 FIs, for the second study we had 16 FDs and 18 FIs, and for the third study we had 12 FDs and 13 FIs. In all studies the individuals participated voluntarily and signed a consent form.

3 RESULTS

3.1 Study A – Time Explorer

To examine whether the hypothesis H01 is rejected or not, the independent–samples t–test was used. All assumptions were met. FDs completed the game in less time (206.20 ± 57.49) than the FIs (277.29 ± 64.63), a statistically significant difference (71.094, $t(30) = 3.268$ and $p = 0.003$). To examine whether the hypothesis H02 is rejected or not, the independent–samples t–test was performed, with fixation count as the dependent variable. All assumptions were met. The analysis of the results revealed that FIs fixated on more items than FDs (47.167 ± 17.291 vs. 24.625 ± 9.303; $t(12) = 3.155$, $p < 0.003$). Therefore, field-independent individuals viewed more items than field-dependent individuals, and they needed more time to finish the game.

3.2 Study B – Escape from the Mummy's Tomb

To examine whether the hypothesis H01 is rejected or not, the independent–samples t–test was used. All assumptions were met. FDs completed the game in less time (321.13 ± 32.56) than FIs (418.02 ± 59.21), a statistically significant difference ($p = 0.016$). To examine whether the hypothesis H02 is rejected or not, an independent–samples t–test was performed, with fixation count as the dependent variable. All assumptions were met. The analysis of the results revealed that FIs fixated on more items than FDs (10.27 ± 1.03 vs. 8.23 ± 1.81). Therefore, field-independent individuals spent more time on displayed information for each museum object, while field-dependent individuals were more interested in finishing the game.

3.3 Study C – HoloTour

To examine whether the hypothesis H01 is rejected or not, an independent–samples t–test was used. All assumptions were met. FIs interacted with more items than FDs (37.31 ± 2.65 vs. 30.14 ± 2.41). Regarding, visual behavior, FIs fixated on more items than FDs (43.09 ± 3.87 vs.38.27 ± 2.21), having a more intense and focused visual interaction. FIs scanned thoroughly the scene, trying to find visual cues to get more information about the civilization, while FDs were interested for only a few and very important assets, and then they were more interested in finding a way to finish the game.

5 DISCUSSION

The quantitative analysis in all three studies revealed observable differences between field-dependent and field-independent players in the way they approach a cultural heritage game. In particular, field-dependent players followed a holistic strategy and they were motivated intrinsically by the goal of each game (*e.g.*, perform a high total score). Therefore, they finished the games in less time than field-independent players, but they collected less items. This could reflect on the fact that field-dependent individuals are generally less inclined to find hidden in-game objects, as they have difficulty in detecting details. On the other hand, field-independent players developed a more analytical approach and they explored more game scenes and interacted with more game assets. Hence, field-independent individuals tended to develop self-defined goals and found more in-game objects than field-dependent players. However, this had an impact on the time needed to finish the game, as they spent more time than field-dependent players trying to interact with game assets.

The aforementioned findings were reflected on the visual behavior of both field-dependent and field-independent players. They followed different visual strategies while scanning the game scenes and searching for objects to accomplish game objectives. In particular, field-dependent players produced generally less fixations than field-independent players. Thus, field-independent players had increased visual attention, and they could more easily detect in-game hidden objects, as they followed a more focused and analytical visual strategy, while field-dependent players had a disoriented visual behavior. Hence, field-independent could interact with more objects to get information, as they visually explored more items than field-dependent players.

Therefore, field-independent users had access to more cultural heritage information (*e.g.*, information about the Incas warriors, mummies in Ancient Egypt, gladiators' battles in Roman Empire). Therefore, it is more likely that field-independent players would enhance their learning experience, as they visually scanned, and eventually, had access to more knowledge assets than field-dependent players. Measuring the learning outcome is not the goal of this paper, but it is a future step of our research endeavor. However, since the cultural heritage game designers followed a "one-size-fits-all" approach, and they did not consider cognitive characteristics as a personalization factor, we argue that this could have an impact on the learning outcome, assisting field-dependent individuals less, and developing a learning imbalance.

Contribution and design implications

The contribution of the paper entails two important aspects; theory and application. Regarding theory, the studies provide evidence that socio-cognitive theories, such as Field Dependence-Independence, can be considered as applicable frameworks in understanding player interactions in the cultural heritage domain, as it was also revealed in our previous works [10, 12]. Regarding the application aspect, the study results suggest that cognitive styles should be considered as human-design factor when designing playful cultural experiences. Therefore, the players would not be unintentionally favored because of their individual cognitive characteristics, such as cognitive styles. They should be engaged in playful cultural activities that would help them perform best and have increased access to in-game assets that provide them with information about cultural heritage.

Such experiences are not based on a "one-size-fits-all" approach, and they should be supported by adaptive mechanisms. These adaptive mechanisms should provide the players with personalized games, aiming to have individuals engaged in both playful and learning cultural activities. To do so, the cognitive characteristics (*e.g.*, cognitive style) of each player should be automatically identified in real-time. Therefore, an automatic user modeling process is required. Taking into consideration the technological advances on the eye-tracking industry, the integration of eye-tracking tools to new technological frameworks (*e.g.*, augmented/virtual reality), and that the differences among field-dependent and field-independent individuals were reflected quantitatively on their visual behavior, the user modelling process could rely on an implicit and eye-tracking based method, as we proposed in our recent paper [13].

Through such a mechanism, a user profile would be built for each individual engaged in a cultural activity, and along with other characteristics, such as behavioral patterns [14, 15], would provide the designers with a framework for creating adaptive and personalized cultural experiences, tailored to the individuals' characteristics, goals, needs, and preferences.

In this paper we presented three case studies of individuals playing cultural heritage video-games in varying interaction devices. However, it would be interesting to include location-based games (e.g., in-museum games), and investigate more user characteristics, game mechanics, and metrics (*e.g.*, different age groups; players of different experience; players' immersion).

6 CONCLUSION

This paper revealed that individual differences in cognitive styles are quantitatively reflected on individuals' performance and eye gaze data, while engaged in varying cultural heritage playful activities, using varying interaction devices. In our studies, field-independent individuals were favored the most, because of their cognitive style. Therefore, there is a need of creating adaptive information systems and cultural activities, which would provide personalized immersive experiences, tailored to the individuals' cognitive preferences, ensuring high performance and reflecting on increased knowledge acquisition during a game, thus, it would be more likely to enhance the learning outcome.

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