Virtuality or Physicality? Supporting Memorization Through Augmented Reality Gamification

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ABSTRACT

Augmented reality (AR) is evolving to become a pervasive tool for interacting with virtual objects. We conducted a comparative study to explore the impact of virtuality and physicality in supporting human memorization through gamification. A head-mounted display (HMD) AR memory matching game and a corresponding physical version game with paper boards were harnessed. The proof-of-concept version was demonstrated in an initial user study (n=12) with counterbalancing design to determine that our proposed gamified HMD AR system with virtuality could support better human memorization compared to the physical version game in reducing task time, improving usability, becoming more recommendable, and decreasing cognitive task workload. The study was then followed by quantitative analysis of the respective four metrics: game completion time (GCT), system usability scale (SUS), recommendation level, and NASA task load index (TLX). A brief qualitative analysis is presented. The results show that in our case, the virtuality outperformed the physicality in supporting human memorization in a gamified context through HMD AR in an evident range.

CCS CONCEPTS

• **Human-centered computing → Mixed / augmented reality**; **User studies**; **Usability testing**.

KEYWORDS

Augmented reality, gamification, memorization, user study

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1 INTRODUCTION

Augmented reality (AR), a similar but distinct technique from virtual reality (VR) which places people into a purely virtual environment, is becoming one of the most pervasively used human-computer interaction techniques because of its capability to enable users to interactively communicate with virtual objects in physical environment [2, 10, 31]. It is extensively employed in various fields due to the capability of generating real-time interaction and interactive interfaces of visualized digital contents [32, 34]. This technique is widely used in common devices such as mobile phones, tablets, and head-mounted displays (HMD) [19, 33]. By overlapping the virtual objects into the real environment, AR provides an immersive experience for users to have unbounded interaction between the digital and physical worlds [25, 30], and has demonstrated its applicability in domains such as industrial applications [7, 21, 35, 36], education [3, 4, 20], medication [11, 28], and gamification [12, 18, 22]. Recently, research has shown that some cognitive processes engaging AR can also improve users' cognitive functions, for instance, memorization [1, 13]. In this work, we describe a user study in which we combined AR gamification with supporting cognitive memorization to explore how virtuality and physicality affect human memory via a developed AR game in HMDs.

2 RELATED WORK

As a fundamental physiological metric, memorization is acknowledged as one of the most powerful abilities which plays a critical role in general learning processes and human brain development [16]. In particular, developing memorization capability within the spatial environment is deemed to be one of the most fundamental cognitive functions among humans [23]. Some research shows that the usage of games in AR has positively affected humans' cognitive functionality through mental reactions [5, 27]. Over the past decades, some researchers have investigated the relationships between AR-based cognitive processes and human memory [8, 15, 24]. For instance, Willemsen et al. [29] implemented an exploratory study to compare the utility of four different contexts: VR, AR, real world, and touching screen in a memory matching task, discovering that VR was superior in reducing the task completion time in their case settings. Moreover, Gargrish et al. [9] proposed an AR-based learning framework named geometry learning assistant (GLA) with regard to geometry learning with large scale user testing (n=80). They concluded that those people who were equipped with the

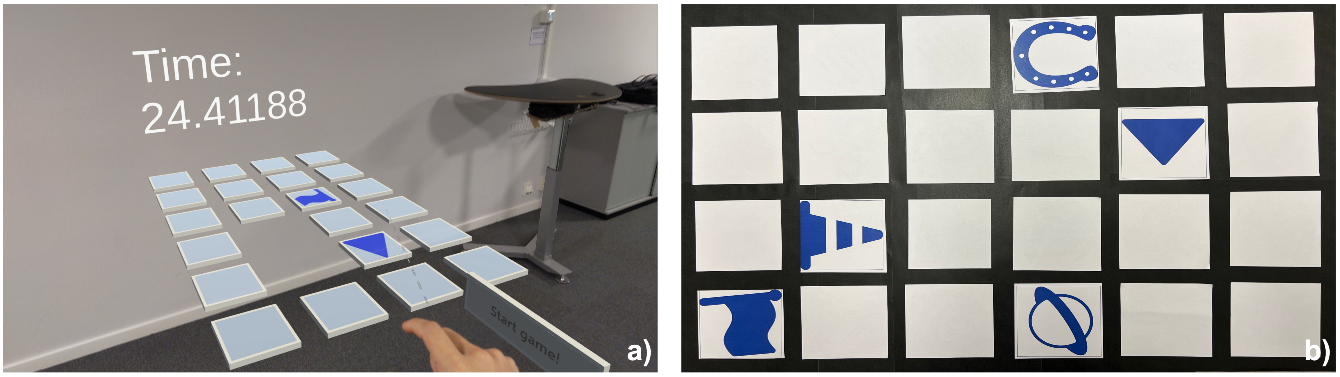

Figure 1: The example view of *a*)**: the AR version game inside an HMD,** *b*) **: the physical version game with white paper boards.**

AR intervention had better memorizing abilities than those who weren't. Hou et al. [17] investigated whether there were any gender differences in memory retention in an AR assembly task, and found that AR had a positive impact in both male and female in memorization. Recently, Rosello et al. [26] formulated an AR system called NeverMind linking a mobile phone with a headset, which demonstrated its efficacy of making memorization more enjoyable and effective. However, there is little research that explores and compares the impact of virtuality and physicality in memorization through gamified AR via HMDs. Hence, we intend to develop a gamified HMD AR system to probe the functionality of AR in supporting human memory.

3 PROPOSED SOLUTION

We designed a comparative study incorporating a memory matching game in virtual and physical form. We adapted the same principle of a common children's card game called "Memory", in which cards are uncovered in pairs and if they match they become the property of the person who draws them. If they don't match they are once again turned down and returned. The object is to remember that card's pattern for when they uncover a similar one in a subsequent turn, and the winner is the person who has the most matched pairs at the end. In our game, 24 uncovered tiles with 12 different patterns are placed in front of the user. The user can reveal two tiles at the same time. If they match, they will be removed, otherwise they are covered back for the next selection. The aim is to find all matched patterns in the shortest time. We present tiles in two different forms – as virtual or physical artifacts. All tiles have the same shape, 10cm square size, and color in both conditions. Patterns represent some simple icons in monochromatic dark blue. The tiles are organized in four rows and six columns. Figure 1 shows example views in the AR (virtual tiles) and physical (paper boards) contexts. In our case, the game will be terminated when all the tiles are matched. We intended to investigate the effect of virtual objects in AR (here are the virtual tiles) on human memorization compared to physical objects.

3.1 AR Version Game

In the virtual condition, users are requested to wear the commonly-used HMD – Microsoft HoloLens 2 to be equipped with the AR environment (a complete gaming procedure in our AR context can be referred in the supplemental video). The whole game setup is placed in front of the user, around 70 cm below the user's head. There is a simple demo game part on the left hand side and the formal game part on the right hand side. The demo game part consists of two example tiles with the same pattern, which disappear when uncovered if they match. To interact with the virtual objects, the user needs to press the virtual tiles like buttons, or just put their hand into the hologram to flip the tiles and reveal their patterns. As Figure 1.*a*) shows, there is a virtual button to start the game, and simultaneously, the timer (the button on the right hand side of the hand in the figure). In this AR setting, two tiles with the same pattern will then disappear if the user matches them. If it is not a match they will remain uncovered until the user clicks another tile with the same pattern. After all the tiles disappear, the game is terminated and the timer will stop. The entire gaming scenario is completely visible within the field of view of the HoloLens.

3.2 Physical Version Game

As Figure 1.*b*) displays, our physical version game is set to have all the tiles (made by paper boards) randomly placed on a flat and dark desk in order to mitigate the penetration effect of the blue patterns. On one side of the desk, the same game demo part is placed – two pieces of paper boards with the same patterns. When they are uncovered, they will be removed from the desk by the authors. On the other side of the desk, the formal setup of the game is arranged – 24 paper boards representing the tiles with the patterns contained are put in random positions. When two identical patterns are uncovered at the same time, the authors will swiftly remove the two paper boards from the desk, otherwise they will be flipped back for another selection. The removal of the matched paper boards and flipping of the unmatched ones were executed as a quick and automatic process by the authors. This measure was taken to ensure the time consumed is similar to the tile disappearing time in the AR version game. When all patterns are found, the game will end and the author responsible for time measurement will stop the timer.

Figure 2: The example scene of the participant in the user study with a): the AR version game with an HMD and b) : the physical version game with paper boards.

4 EXPERIMENT DESIGN

An initial user study was carried out to benchmark the exploration of how virtuality could affect human memory through an AR game compared to a physical one. Twelve participants (n=12, 7 self-identified males and 5 self-identified females, M = 26.71, SD = 5.03) were recruited through email in the author's university. Each participant was told to complete both the AR memory matching game and the physical game using paper boards. A counterbalancing design was employed to mitigate any order effect, with half of the participants starting with the AR game and the other half with the physical one. This process was entirely randomized to determine the order of the two types of game. There was a short demo session presented to each participant before they formally commenced the game so as to get them adapted to the two environmental configurations (Figure 2). When a participant was confident with the usage system by playing with the demo and confirmed readiness by the introduction given from the authors, the study started. The built-in timer in the HMD measurement recorded the game completion time (GCT) for each AR game finished, while the duration of the physical game was recorded and noted by the authors. After completing the two games, everyone was asked to fill in a system usability scale (SUS) [6] questionnaire to evaluate the usability, and the NASA task load index (TLX) [14] to measure the cognitive workload. Moreover, they were also requested to rate the recommendation level of these two game genres, by filling another 7-point Likert scale. These four metrics were employed to evaluate and compare the performance, the cognitive workload of participants, and the usability of both versions of the game. Nobody reported any discomfort in any kind and all of them accomplished the study smoothly. The approximate duration of each study session for each participant was 10 minutes. The whole study was experimented in a bright and spacious function room in authors' local university where the lighting conditions were appropriate for observing the virtual objects. Here, we pose four hypotheses:

- **H1:** Our gamified HMD AR system with virtuality can reduce GCT to support better human memorization compared to the physical game version.
- **H2:** Our gamified HMD AR system has better usability compared to the physical game version.
- **H3:** Our gamified HMD AR system is better recommended by people compared to the physical game version.
- **H4:** Our gamified HMD AR system can reduce cognitive task workload for facilitating human memorization compared to the physical game version.

5 RESULTS AND ANALYSES

In this section we present the results we collected from the user study. The data of the four metrics evaluated – GCT, SUS, recommendation level, and NASA TLX – and their corresponding quantitative analyses are illustrated and visualized. Finally, we also present a brief qualitative summary extracted during the experimental processes.

5.1 GCT

The measured GCT was utilized to verify **H1**. The user study showed the GCT (Figure 3.a)) used by the physical memory matching game version with paper boards was 166.61(s) (SD = 35.59) on

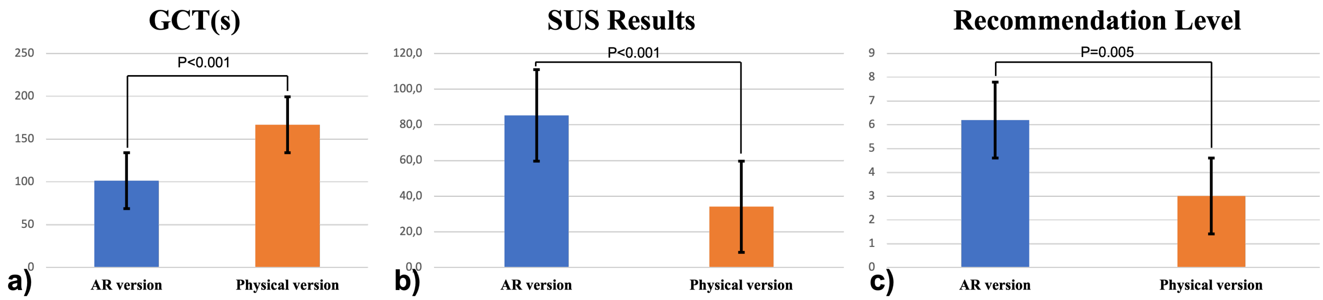

Figure 3: Results of *a*): GCT(in seconds), *b*) : SUS score, and *c*): recommendation level on the AR version game and the physical version game.

average, whereas the AR version game with HMDs had a mean GCT of 101.35 (SD = 22.26). After the normality of the data was affirmed, a dependent sample t-test (p = 0.05) was performed and revealed that all participants had statistically significantly shorter GCT in the AR game compared to the physical one, with $t(9) = 4.628$, $p < 0.001$. As the results revealed, the time consumed by participants who played the game using our AR version has experienced a noticeable reduction compared to that with the physical one. In a word, the AR game has facilitated better memorization for participants in our context.

5.2 SUS Score

After collecting the answers provided by participants regarding all the questions listed in the SUS questionnaires, we calculated the SUS scores based on the basic calculating principles to address **H2**. Then, a pre-requisite normality testing was implemented and the SUS scores showed normal distribution. Here, a dependent t-test (p = 0.05) determined that the mean usability in the AR version (M = 85.23, SD = 4.36) differed statistically from the usability in the physical version (M=34.00; SD=1.77), ($t(9) = 19.798$, $p < 0.001$). As shown in Figure 3.*b*), an evident difference is enclosed between the two versions of the game, which implied the much higher usability was revealed in the AR version game with HMDs compared to the physical one.

5.3 Recommendation Level

This metric was harnessed to demonstrate **H3**. During the study, each participant was asked to rate how likely they would recommend the two different approaches. As the normality of the collected data did not appear, we used a Wilcoxon signed-rank test (p = 0.05) to identify the statistical significance of the recommendation level. The result indicated that the reported recommendation level from the AR version game with HMDs (M = 6.20; SD = 3.92) elicited a statistically significant superiority to the physical version game with paper boards (M = 3.00, SD = 1.05) in contextual human memorization (Z = -2.814, p = 0.005). As Figure 3.*c*) shows, the mean value of the recommendation level was closely approaching the highest one for AR version while the physical version was obviously much less favoured. This shows that most of the participants were willing to recommend the memory matching game with HMD AR in contrast to the physical version.

5.4 NASA TLX

For cognitive workload measurement, NASA TLX was exploited to test our **H4**. The collective results are visualized and can be found in Figure 4. As it shows, differences in Mental Demand, Physical Demand, Effort, especially Performance and Frustration are considerably substantial. Since the normality of the data was not satisfied, a Wilcoxon Signed-Rank Test (p = 0.05) was performed to examine the two groups regarding Total Demand and each index. The study showed that all participants had statistically a significantly greater cognitive workload (in terms of Total Demand) with the AR game version (M = 36.67, SD = 12.20) compared to the physical one (M = 61.75, SD = 17.52), Z = -2.803, p = 0.005. The results also revealed a statistically significant decrease of the AR version upon: Mental demand (Z = -2.302, $p < 0.05$), Physical Demand (Z = -1.841, $p < 0.05$), Performance (Z = -2.703, p = 0.007), Effort (Z = -2.298, $p < 0.05$), and Frustration (Z = -2.705, p = 0.007). There was no statistically significant decrease in Temporal Demand.

5.5 Qualitative Summary

Most participants gave compliments for the AR memory matching game with the aid of HMDs. The participants mostly stated that they had much fun from playing the game with virtuality. One participant said: *"The touching is sensitive, the tiles are clearly presented and the patterns look very evident in AR."* Another participant explained: *"It was great to see the visual tiles disappear after I matched them because it was an incentive for me to proceed with the rest of the tiles, but with more empty space. Also, when I played with the paper boards, I felt like it was more difficult for me to remember the patterns and the locations."* The AR game was mostly praised mainly due to its clarity and touching sensibility, as well as the straightforward demo part. One participant reported additionally: *"The demo was an excellent directive in leading me to the game context that I understood quickly. The tiles were very well visualized, and the touching was very sensitive which made me play the game more smoothly."* Another participant complimented the floating timer: *"The timer worked like a hint and reminder that drove me to finish the game more quickly. I like it since it feels like an extra motivation for me."*

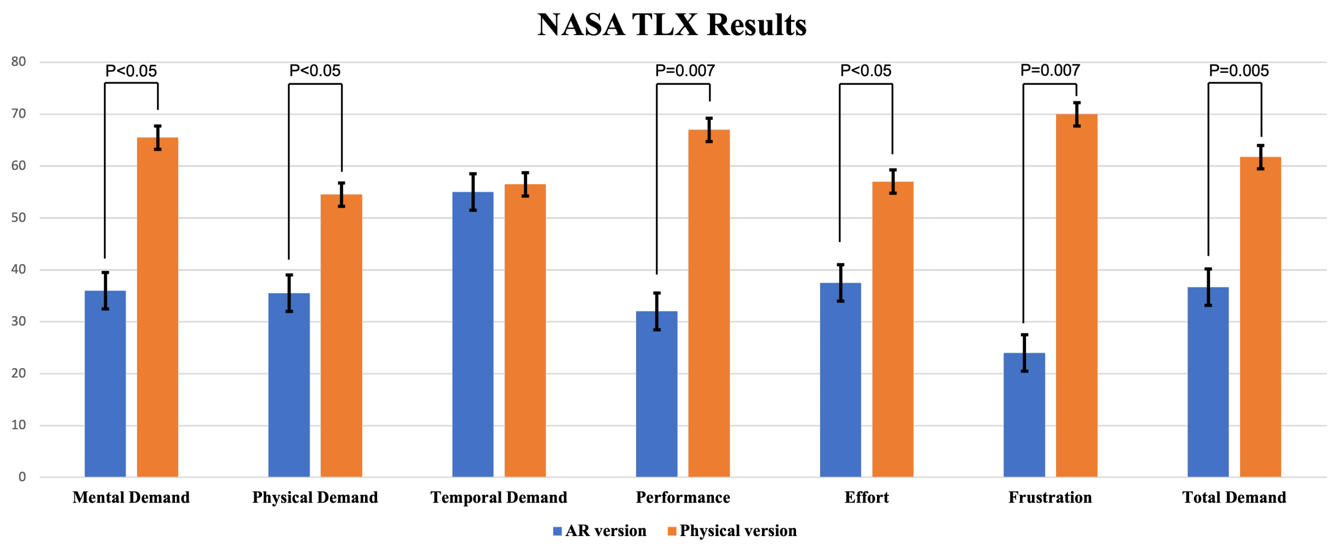

Figure 4: Results of NASA TLX. Significant differences were found among all the indexes including Total Demand except Temporal Demand.

6 DISCUSSION

In our study, we implemented a comparative study to explore the impact of virtuality and physicality supporting human memorization. We utilized the gamified environment as the study context, which was manifested as a memory matching game. For the virtual version we developed an HMD AR memory matching game, while paper boards were used for the physical version game. We harnessed a moderate sized user study (n=12) with counterbalancing design to verify our hypotheses posed at the beginning of the experiment. Our study indicates the evident advantageousness for facilitating human memorization by using virtuality. There was a noticeable difference in GCT, SUS, recommendation level, and NASA TLX that showed that virtuality did provide superiority in gamified memorization.

However, we are aware that our study still has some limitations. First, our AR app design could be enhanced, for example by adding more tiles and more patterns that could be more easily memorized. Second, as an initial user study, the limited number of participants might not show the full spectrum of the outcomes. Last but not least, there can be some inaccuracies in time measuring. For instance, the response time after users start the game in the AR version and the tile removal time in the physical version might also be included in the recorded time, which will affect the final results. Also, the removal and flipping of the paper boards in the physical game can be slightly different from the AR version game, as human response can be slower than the programmed setup in HoloLens.

7 CONCLUSION AND FUTURE WORK

In this paper, we have demonstrated that virtuality is superior to physicality in supporting human memorization in the context of gamification. Our proposed solution includes an HMD AR memory matching game together with a physical version using paper boards for comparison. The initial user study with the collected metrics – GCT, SUS, recommendation level, and NASA TLX show the result consistency and verify our hypotheses successfully. For future work, we envision to refine the game app and to implement a larger scale and more complete study. Also, more types of gamification modalities not only the memory matching game will be involved and the time measurement will be made more precise.

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