The Effect of Operating in Many Realities on Memory: An Experiment on Memory Recognition in Extended Realities

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Abstract

Extended reality (XR) such as VR and AR have been increasingly adopted across domains in cognitively challenging activities such as learning, shopping, and gaming among others. There are a few concerns about the inferior cognitive affordance of XR-mediated functioning, e.g., with respect to memory retention. For better understanding how different XR technologies influence memory performance (e.g., recognition), we examine the effects of VR and AR - mediation on the ability to remember (i.e., recognize afterward) text and image-based information based on a 2 × 2 between-subject experiment (n = 155). The results indicate that VR had a negative main effect on text-based information recognition but no effect on image-based information recognition. AR had no significant main effect on the recognition of either information types. Overall, the findings as further supported by the interaction effects analysis, suggest that for memory recognition, it is always best to have a fully physical (no-AR & no-VR) or fully digital environment (AR & VR) compared to having either VR or AR alone.

1. Introduction

Memory plays an important role in different fields in our daily lives, such as healthcare [53], training [41], education [24], and business [28]. Many innovative technologies such as interactive video games, immersive technology, and human-computer interaction system have been widely used for elders' Alzheimer's treatment [10], children's memory training [31], students' learning performance [32] and advertisement effectiveness [25]. Today, extended reality (XR) technologies such as VR (virtual reality) and AR (augmented reality) have been touted in influencing memory performance, especially memory recognition, which is one of the most important areas in memory research [50].

However, in many previous studies, VR has been commonly considered as a research tool for spatial memory [34] and episodic memory [30] rather than a research variable; while AR has been mostly used to develop and test a certain memory-assisted system [43] or mobile application [17]. There are also a few concerns that users in extended realities cannot have as good performance in processing information [27] (e.g., memory recognition) as in the real-life environment due to a few limitations of XR (extended reality) technologies such as cybersickness, weak responsiveness, and difficulty of using [5]. Thus, it is still unclear that whether XR can always have (positive) impacts on memory recognition according to the limited empirical studies, which also reduces the confidences of many researchers and practitioners in the roles of XR technology.

In terms of research method, even though a few prior experiment-based studies have examined the effects of VR and AR on users' memory recognition (see, e.g. [3][9][14][39]), generalization and reliability of results have been limited due to, e.g., the lack of controlled random study design, gaps in accurately measuring memory as well as jumbled understandings of XR technologies. Moreover, in a few studies, memory recognition has been examined based on one single test, either picture [34], brand name [33], or vocabulary [38] rather than a granularly systematic

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study of comparing different types of memory recognition.

To fill the research gap, therefore, this study experimentally examines how AR and VR technology differently affect the two types of memory recognition (text-based and image-based) in the shopping context. A 2 (VR: yes vs. no) × 2 (AR: yes vs. no) between-subject experiment was conducted combining with two types of memory recognition test (N = 155). This study provides empirical evidence and practical implications on how extended reality technologies influence different types of memory recognition.

2. Background and hypotheses

2.1 XR technology

The understandings of XR technologies, such as VR technology and AR technology, have been accumulatively evolved throughout time. From being loosely referred to things such as the internet as a whole [6], virtual worlds [21], to video games [55], today VR has been considered as a kind of immersive computing technology [4] which can be used to digitally create the entire real-life setting [54] for substituting the current perceived reality. While AR has been limited to a kind of computing technology overlaying digital information only to the physical world [16][49]. However, we should notice that AR can also be used to augment other realities such as virtual reality [36], which has been called as augmented virtuality (AV). Thus, the purpose of AR technology is to digitally modify the reality, either physical or virtual.

2.2 The effects of XR on memory

Memory performance has been defined as a variety of cognitive processes involving encoding, storing, and retrieving as for different types of information [44]. The effects of XR technologies on the performance of memory have increasingly aroused academic interest (see, e.g., [9][14][22][39]). However, there seems no consensus on the effects of AR or VR on memory activities. Based on the extant studies, both VR and AR could play different roles in memory performance, varying from no impact [47][51], negative impact [23][51] to positive impact [19][35]. The inconsistent results might be related to a lack of granular analysis of memory content such as different types of information stimuli (e.g., visual information, and sound information). Given users obtain information primarily through visual perception and current XR technologies are designed mainly for simulating visual experience, it is more important to understand users' memory performance when encountering different types of visual information (such as text and picture) in extended realities. However, text-based information and image-based information have been seldom examined separately (see, e.g. [19][35]).

In most existing studies, different types of memory performances have been discussed through intentionally memorizing tasks, see, e.g. [9][14][19]. The memory performances in these studies were highly relevant to the memory capacity and memory level of the participant's brain itself. It is still unclear how much impact XR technology itself have on memory performance. We should notice that most memory activities happening in people's daily life are subconscious-related and unintentional [15][29]. In addition, VR and AR technology have been usually discussed separately (except for one study, see [51]). There is a lack of comparative studies explaining the different effects of AR and VR on memory performance. Thus, overall there is a research gap on how AR and VR technology differentially influences recognition accuracy of memorizing text-based information and image-based information.

2.3 Text and image-based memory recognition

Memory recognition refers to the identification of a stimulus as having been encountered previously or the discrimination of a stimulus as "old" from "novel" [11][46], which is related to the user's cognitive load when processing information [45]. Cognitive load refers to the used amount of working memory resources [45]. According to cognitive load theory, people have limited cognitive capacity in working memory [2], and the information on which people allocate more cognitive resources to process will be better remembered than the information people allocate less cognitive resources [45]. Generally speaking, intrinsic cognitive load is the cognitive resource required for understanding the content, which directly contributes to the memorization of the content [18][45][48], while the extraneous cognitive load is the cognitive resources required to conduct some cognitive activities related to searching and organizing information, which might generate errors in memory recognition [26].

XR technologies are more likely to influence users' memory recognition through extraneous cognitive load compared with intrinsic cognitive load. The intrinsic cognitive load is usually caused by the inherent nature of the content (e.g., the complexity of the content), while the extraneous cognitive load is more related to how the content is presented [18][48]. VR has been defined as the digital representation of the current perceived world (physical reality), while AR can overlay digital information on different surroundings, either physical or virtual. Apparently, neither AR nor VR change the amount of information and the nature of content but may change the way of information presentation.

More specifically, in the physical (non-VR) environment, the use of AR might increase cognitive load and further negatively influence memory recognition. The users in the physical reality only with AR are required to allocate more cognitive resources compared with users in the purely physical world. AR users have to mentally integrate the information from two realities at the same time: the physical environment and superimposed digital content. The mental integration of information from multiple sources leads to an increase in users' extraneous cognitive load (which is called the split-attention effect, see, e.g. [45]). On the contrary, in the reality without any technologies, users only need to process information from physical reality (the additional content was presented in printing paper, see Group 1 in this study), which leads to a lower extraneous cognitive load. Therefore, no matter text-based or image-based memory recognition, the application of AR in the physical environment might reduce memory performance. Accordingly, we propose the following hypothesis:

H1: *In the physical (non-VR) environment, AR has* ***a)*** *a negative effect on text-based memory recognition and* ***b)*** *a negative effect on image-based memory recognition.*

However, it seems that AR cannot increase or decrease the cognitive load when the physical reality is replaced by a fully digital world, e.g., the virtual reality. As has been mentioned before, the use of AR in virtual reality does not change the amount and content of information. Therefore, there is no difference in intrinsic cognitive load between virtual reality and the "augmented" virtual reality (augmented virtuality, AV). Given the overall environment and the content are both digital in virtual reality and augmented virtuality, there is such a possibility that the split-attention effect caused by processing information from multiple sources might not be significant. In a purely virtual world, the environment, the content and the form of any information have been fully digitalized. In addition, the suspension of disbelief (the intentional avoidance of critical thinking) might occur in virtual reality [8]. Therefore, the "augmented" information in virtual reality might be considered as the part of "reality" rather than easily and intentionally being distinguished as in the physical reality. The users in augmented virtuality have the same extraneous cognitive load as the users in pure virtual reality (only using VR). Therefore, there is no difference in the effect between AR and non-AR on memory performance (text-based and image-based) in virtual reality. Accordingly, we can further the following hypothesis:

H2: *In the digital (VR) environment, AR has* ***a)*** *no effect on text-based memory recognition and* ***b)*** *no effect on image-based memory recognition.*

3. Research method

3.1 Design

This study adopted a 2 (VR: yes vs. no) × 2 (AR: yes vs. no) between-subject experiment design for examining the effects of extended reality technologies on memory recognition (see table 1). Given this study aims at investigating the difference in people's memory recognition brought by technology in a natural state of life rather than the memory capacity and memory level of the brain itself, a simulated living environment setting is required for a rigorous research design. Thus, the shopping environment was selected as the experiment scenario. In the conditions without VR technology (Group 1 and 2), shop and product were presented both physically. For Group 3 and 4, the shopping environment and products were duplicated in the computer-based 3D environment. AR technology was used for the presentation of augmented information.

Table 1. The 2 × 2 experiment design

Group	Shop	AR	VR
1	Using neither VR nor AR	No	No
2	Only using AR	Yes	No
3	Only using VR	No	Yes
4	Using both AR and VR	Yes	Yes

3.2 Participants

From September to November 2019, 162 student participants were recruited to join the experiments. A total of 155 valid samples were used for memory analysis (Real = 41, AR = 42, VR = 36, AV = 36). 54.2% were male, and 76.7% were between the ages of 20-29. 57.4% of participants were bachelor students (36.8% were master students), and 59.4% were from the study area of engineering and technology. Each participant was asked to complete a 10-minute shopping in a second-hand shop (see 3.3.1 shop section). Their compensation depended upon the products they selected in the shop.

3.3 Materials

3.3.1. Shops. A physical LP record shop (4.24 × 5.09 m^2) was built into the university campus. The shop functioned as the experimental setup for each condition. In Group 1, the shop functioned as a common bricks-and-mortar shop. In Group 2 (shop only using AR), the shop functioned similarly but with the exception of product information being displayed through AR headset display (Microsoft HoloLens version 1). In Group 3 (shop only using VR), the same room was used; however, the "control" condition was fully replicated in virtual reality. For the shop using both VR and AR (Group 4), it combined the condition in Group 3 with the overlaid product information as in the condition of Group 2. The participants used the Valve Index headset and its controllers that enable the haptic interface to grab records naturally in both conditions with VR technology. 54 LP records were displayed on three different walls of the room.

3.3.2. Products. To control the influence of prior product knowledge and preference on memory, the product category was considered carefully during research design. Second-hand English LP Record was selected as the ideal product stimulus[1].

3.3.3. Product information. The AR technology was used for manipulating the display ways of extra information for each record. The extra product information (contains both image and title name of each LP record) was gathered from the website Discogs. In the non-AR conditions, all information pages were pasted either physically (Group 1) or virtually (Group 3) on the edge of the shelf in front of each record. In the conditions with AR, the correspondent information about the LP record was displayed either on the lens (Group 2) or in the popup windows (Group 4, the head position of the participant was tracked).

3.3.4. Measures. In this study, memory recognition was measured by the accuracy rate of (saw) text and image, respectively [7][42]. In each of the four groups, every participant was asked to select in total 54 records he/she just saw in the shop from a list of 144 titles and pictures of 144 LP record front covers[2]. Participants had 5 minutes for each memory recognition test (recognize title for text-based test and recognize picture for image-based test).

1 We measured previous product knowledge by seven items based on the seven-likert scale, adapted from Awasthy et al. [1]. The results indicates that participants were not familiar with the products.

2 In each group, participants were given the same 144 titles and 144 corresponding pictures.

3.4 Procedure

3.4.1. Recruitment. We used the same content in both online and offline advertisements for getting university student volunteers. In total, 265 students successfully entered our recruitment system. Then they were linked to the self-booking system on Doodle. In the end, a total of 162 university students completed the shopping tasks in the experiment, of which 155 completed the two memory tests.

3.4.2. Experiment. Once the participant arrived at the lab during a designated time slot, researchers first introduced the entire experiment process and guided participants to read the consent form and fill out the pre-survey. All participants were randomized to join one of the four groups. Once the pre-survey was completed, the participant was guided to the shop room and provided with a 5-10 minutes tutorial. For Group 2, the experimenters introduced Microsoft HoloLens and guided participants in how to wear and use the headset. For both Group 3 and 4, two shopping programs only for the tutorial purpose were developed without revealing any details of the shops and products.

Participants were asked to spend completely 10 minutes in the shop and make the purchase decision independently without knowing the memory tasks. When the shopping time was out, participants were asked to pay with the given gift card (10 euros value). When the shopping was completed, after making sure the participants without any physical problems, they were guided to return to the room and took the memory test after a period of time (participants were asked to fill out a post-survey around 30 minutes). The researcher gave the physical records that the participants bought in the shopping experiment once the whole experiment task was completed. The purchased records would be replaced with the same price records after each participant's shopping experiment.

4. Results

4.1 Descriptive results

First, table 2 presents the descriptive information of the text-based memory recognition and image-based memory recognition in the four conditions. The accuracy rate (correct selection/total selection) of text-based memory recognition in Group 1 was 73.67%, Group 2 was 58.00%, Group 3 was 53.24%, and Group 4 was 60.44%. As for image-based memory recognition, from Group 1 to Group 4, the mean value was 85.75%, 83.58%, 80.19%, and 88.32%, respectively. Generally speaking, the total selection and accuracy rate of image-based memory recognition was higher than the text-based memory recognition in any conditions.

Table 2. The descriptive results of memory recognition in the four groups

Group/shop		Total selection		Correct selection		Incorrect selection		Accuracy rate	
		Text	Image	Text	Image	Text	Image	Text	Image
Group 1 (no-XR)	M	13.00	27.76	9.46	23.39	3.54	4.37	73.67%	85.75%
(n = 41)	SD	5.86	9.93	4.56	7.95	2.78	4.49	2.78%	11.05%
Group 2 (AR)	M	17.52	28.57	9.48	23.67	8.05	4.90	58.00%	83.58%
(n = 42)	SD	9.53	9.70	4.31	8.01	6.50	4.52	2.75%	12.80%
Group 3 (VR)	M	19.08	26.72	9.78	20.44	9.31	6.28	53.24%	80.19%
(n = 36)	SD	14.36	11.50	6.85	7.83	9.37	7.59	4.01%	20.78%
Group 4 (AR & VR)	M	12.64	26.31	7.14	22.56	5.5	3.75	60.44%	88.32%
(n = 36)	SD	9.46	11.87	4.41	9.00	5.88	5.09	3.79%	11.44%
Total	M	15.55	27.40	9.00	22.59	6.55	4.81	61.61%	84.47%
	SD	10.39	10.66	5.146	8.21	6.79	5.52	21.81%	14.55%

Then, the two-way factorial ANOVA was conducted to compare the main effects of VR technology and AR technology and the interaction effect between virtual and augmented on text-based memory recognition and image-based memory recognition, respectively. AR and VR technology consisted of two levels (yes and no). We used a significance level of *0.1* for all statistical tests.

4.2 The main effects

As for text-based memory recognition, the main effect of AR on accuracy rate yielded an F ratio of F (1,151) = 1.627, p = 0.204 indicating that the effect for AR was not significant, augmented (M = 59.13%, SD = 20.14%) and non-augmented (M = 64.12%, SD = 23.23%). The main effect for VR technology yielded an F ratio of F (1, 151) = 7.340, p = 0.008, indicating that the effect of VR on the accuracy rate of text-based memory recognition was significant (p = 0.008), virtual (M = 56.84%, SD = 23.54%) and non-virtual (M = 65.74%, SD= 19.39%).

According to the table 3, even though the accuracy rate of image-based memory recognition had higher mean value brought by AR (M = 85.77%, SD = 12.35%) than non-AR (M = 83.15%, SD = 16.46%), there difference was insignificant, F (1, 151) = 1.656, p = 0.200. Similarly, the main effect for VR yielded an F ratio of F (1,151) = 0.031, p = 0.861, indicating that the effect of VR on the accuracy rate of image-based memory recognition was not significant, virtual (M = 84.26%, SD = 17.15%) and non-virtual (M = 84.65%, SD = 11.94%).

4.3 The interaction effects

The interaction effect between VR and AR was significant for the accuracy rate of text and image. To interpret the AR × VR interaction, the simple main effects analysis was conducted (SIDAK) using the EMMEANS syntax command within SPSS[3].

Table 3. Descriptive statistics and tests of between-subject effects

Factors			Accuracy rate	
			Text-based	Image-based
AR	Yes (n = 78)	M	59.13%	85.77%
		SD	20.14%	12.35%
	No (n = 77)	M	64.12%	83.15%
		SD	23.23%	16.46%
F (1, 151)			1.627	1.656
p			0.204	0.200
Partial η2			0.011	0.011
VR	Yes (n = 72)	M	56.84%	84.26%
		SD	23.54%	17.15%
	No (n = 83)	M	65.74%	84.65%
		SD	19.39%	11.94%
F (1, 151)			7.340	0.031
p			0.008	0.861
Partial η^2			0.046	0.000
Interaction effect: AR × VR				
F (1, 151)			11.870	4.928
p			0.001	0.028
Partial η^2			0.073	0.032

The interaction effect of VR and AR on the memory accuracy rate of text was statistically significant: F (1, 151) = 11.870, p = 0.001. According

3 The command was used for test the simple effect:
/EMMEANS=TABLES(virtual*augmented)COMPARE(virtual)ADJ (SIDAK)
/EMMEANS=TABLES(virtual*augmented)COMPARE(augmented) ADJ(SIDAK)

to the pairwise comparisons (see figure 1 and table 4), For the non-AR condition, non-VR led to a higher accuracy rate of memory recognition for text on a standardized test compared to VR technology (the difference was a whopping 20.430). The difference was statistically significant (p = 0.000). In AR condition, VR did not significantly influence text-based memory recognition (p = 0.602). For the non-VR condition, AR led to a lower accuracy rate of memory recognition for text on a standardized test compared to VR technology (the difference was a whopping 15.671). The difference was statistically significant (p = 0.001). Thus, H1a was supported. The same as our expectation, in the VR condition, AR and non-AR showed a similar level of memory accuracy of text (p = 0.140). Thus, H2a was supported

The interaction effect of VR technology and AR technology on the accuracy rate of image-based memory recognition was also statistically significant: F (1, 151) = 4.928, p = 0.028, see figure 2 and table 5. In the non-AR condition, VR led to lower accuracy of picture-based memory recognition compared with non-VR (mean difference = 5.554 p = 0.093). There was no significant interaction effect in either AR condition or non-VR condition. Thus, H1b was supported. In the VR condition, the results demonstrated that AR led to a higher accuracy rate of image-based memory recognition as compared to non-AR technology (mean difference = 8.131 p = 0.018). Thus, H2b was unsupported.

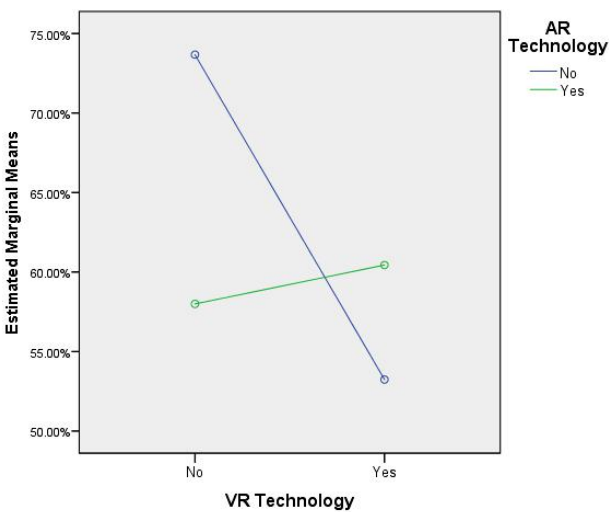

Figure 1. The interaction effect of VR and AR on text-based memory recognition

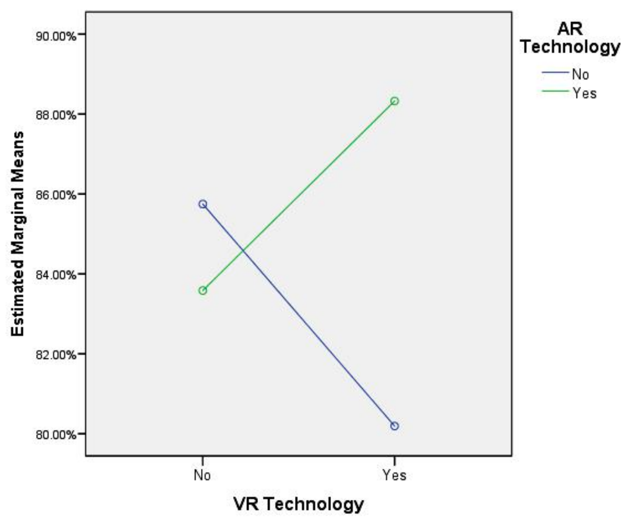

Figure 2. The interaction effect of VR and AR on image-based memory recognition

Table 4. Pairwise comparisons on text-based memory recognition

Dependent Variable: Accuracy rate of text							
	(I)	**(J)**	**Mean Difference (I-J)**	**Std. Error**	**Sig**	**95% Confidence Interval**	
						Lower	**Upper**
Non-AR	non-VR	VR	20.430	4.708	**0.000*****	12.639	28.221
AR	non-VR	VR	-2.444	4.681	0.602	-10.191	5.304
Non-VR	non-AR	AR	15.671	4.525	**0.001*****	8.182	23.160
VR	non-AR	AR	-7.203	4.858	0.140	-15.243	0.837

Based on estimated marginal means
*. The mean difference is significant at the 0.1 level.
Adjustment for multiple comparisons: Sidak.

Table 5. Pairwise comparisons on image-based memory recognition

Dependent Variable: Accuracy rate of image							
	(I)	**(J)**	**Mean Difference (I-J)**	**Std. Error**	**Sig**	**95% Confidence Interval**	
						Lower	**Upper**
Non-AR	non-VR	VR	5.554	3.288	**0.093***	0.111	10.996
AR	non-VR	VR	-4.741	3.270	0.149	-10.153	0.670
Non-VR	non-AR	AR	2.164	3.161	0.495	-3.067	7.395
VR	non-AR	AR	-8.131	3.393	**0.018****	-13.747	-2.515

Based on estimated marginal means
*. The mean difference is significant at the 0.1 level.
Adjustment for multiple comparisons: Sidak.

5. Discussion and conclusions

Based on the 2 (VR: yes vs. no) × 2 (AR: yes vs. no) between-subject experiment with 155 participants, this study investigated the difference of text-based memory recognition and image-based memory recognition in the four different realities that were designed for shopping. The results indicate that in general, VR had a negative main effect on text-based information recognition but no effect on image-based information recognition, while AR neither could influence text-based nor image-based memory recognition. However, the interaction effect of VR and AR on both text-based and image-based memory recognition were statistically significant. The findings, as further supported by the interaction effects analyses, suggest that for memory recognition (both for text and image-based information), it is always best to have a fully physical (no-AR & no-VR) or fully digital environment (AR & VR) compared to having either VR or AR alone.

The results of the main effects of this study indicate that VR has the possibility of significantly decreasing the accuracy of text-based memory recognition. One reasonable explanation might be that the current VR technology still has limitations in terms of, e.g., field of view, fidelity, and resolution, which cannot provide users with a good visual experience of reading text-based information. Thus, VR might require more effort in processing text-based information [13][37]; users might have less motivation and desire to discover, read and memorize text-based information in a VR environment compared with a non-VR environment. AR seems cannot influence text-based memory recognition.

According to the interaction effect of AR and VR, it can also be seen that there is the best performance on text-based memory recognition when both content and environment are entirely physical (Group 1, no XR). The reality without any involvement of technology is beneficial for the processing, recognition, and memorization of text information. This may be related to the traditional way of reading; as for text information, most users still prefer and get used to physically paper-based online reading rather than digitally electronic reading [12][52].

In addition, neither AR nor VR can alone significantly influence image-based memory recognition. However, the use of AR (vs. non-AR) in virtual reality leads to higher accuracy of image-based memory recognition. In the virtual reality environment, the augmenting digital information may be easier to attract the user's instantaneous attention than non-augmenting digital information, which may be beneficial for image-based memory. The use of VR (vs. non-VR) in the non-AR environment has the possibility of reducing lower memory recognition of the image. Thus, when only VR is used to duplicate the environment digitally, picture-based memory recognition is not as good as in the circumstance where content and environment are entirely physical. While if AR is added into VR, picture-based memory recognition can be increased significantly and almost the same as in physical reality[4].

6. Contribution and limitations

The empirically experiment-based study makes a great theoretical contribution by filling the research gap on the effect of different extended reality technology on memory as well as practical implications by providing references on how to influence memory recognition. Based on the 2×2 experiment design in the shopping context, this study conducted a comparative study of AR and VR, which contributes to the human-computer interaction and information system research. More importantly, there is a lack of discussion on the user's memory from the perspective of XR technology in the extant literature. This study conducted a more granular analysis of two types of memory recognition, which enrich technology-led psychology research. The results of this study can be widely used in different scenarios (the

4 According to the interdependent sample t test between, there was no significant difference between Group 1 (no XR) with Group 4 (AR&VR)

shopping context was created for experimental design). The memory recognition of users, students, consumers, and employees can be influenced by different forms of XR technologies. Practitioners and XR system designers should pay attention to the decreased memory recognition of text when the VR technology is used alone in activities. Because it is always best to have a fully physical (no-AR & no-VR) or fully digital environment (AR & VR) compared to having either VR or AR alone, practitioners and designers should consider how to combine VR and AR for matching the specific goals in the fields such as business, education, training, and entertainment.

Although this study has adopted a rigorous experimental design and conducted the scientific analysis, it still has limitations. Even though we have used advanced XR devices to minimize the influence caused by the difficulty of operating system on memory recognition (in Group 2, 3 & 4), there might still be some uncontrollable variables (e.g., unfamiliarity and discomfort towards using XR devices) that had affected the results. Additionally, the results were mainly related to the shopping context. Future studies can consider investigating memory performance in some other real-life settings such as learning and entertainment environments. Further, memory performance can be compared and studied with other cognitive performance and behavioral activities in future studies. As for the sample, only student participants were recruited to participate in the experiments. The results of memory recognition might only be limited to explain the effect of XR technology on young user's memory performance. Future studies should expand the diversity of samples and investigate the differential impact of age on memory in different extended realities. Also, other sensory cues such as auditory, tactile, olfactory senses can effectively change the level and quality of memory [20][40]. Future studies could also investigate the influences of multisensory experiences brought by XR technologies on memory performance.

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