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The Spatial Influence on Vocabulary Acquisition in an Immersive Virtual Reality-Mediated Learning Environment

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ABSTRACT

This study aims to investigate whether VR-assisted language learning facilitates EFL learners' vocabulary learning and memory retention. One hundred seventy-seven Chinese undergraduate EFL learners were divided into VRG (VR-assisted instruction group) and CIG (conventional instruction group). Participants in the VRG (n = 75) were provided with immersive VR devices, whereas the others (n = 102) learned in conventional classrooms with instructors. The results illustrate that the spatial design of virtual environments may be related to lexical memory performance. Target words that are placed in positions where they are interacted with more frequently tend to perform better in terms of being memorized. It also suggests that words corresponding to items placed between 60-180 cm of the ground are better retained. Subsequent interviews revealed that VR technology helps learners encode information based on spatial location. The VR technology's visual, aural, and textual stimulation also help learners subconsciously remember the vocabulary items.

KEYWORDS

CALL, EFL, Memory Retention, Virtual Reality, Vocabulary Learning

1. INTRODUCTION

Virtual reality (VR) technology has been extensively used in the field of education, with favorable results in terms of multimodal communication (De Freitas, 2008) and knowledge instruction (Dickey, 2010; Bignell, 2011; Low, Khoo & Chua, 2011). However, as VR technology developed, its usage in different research varies. Research has shown that the impact of immersive virtual reality (IVR) technology on English as a Foreign Language (EFL) learners is significantly higher than desktop-based virtual reality (Cho, 2018). In addition, the use of Helmet-Mounted Display (HMD) in IVR technology enables the tracking of the user's gestures and body movement and stimulating a 360-degree scene, which is close to reality. This technological advancement provides more possibilities for designing and developing language learning scenarios. Through panoramic cameras or 3D scene development platforms, users can experience the actual scenarios depicted in VR.

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Meanwhile, the influence of globalization on the economic development of developing nations like China has indirectly increased the relevance of English language skills in the professional sector (Mo & Huang, 2021). Some educational institutions in China are exploring the potential of VR technology in equipping learners with vital language skills, such as speaking (Xu, 2021) and listening (Wang, 2020). However, there is a paucity of studies on the use of VR to teach English vocabulary. Vocabulary has always been considered a critical element of English language learning. Pupils, who lack sufficient vocabulary, are unable to comprehend others or convey their own thoughts (Ahour & Dogolsara, 2015). Many empirical studies have shown the impact of vocabulary knowledge on the development of EFL learners' reading comprehension and pronunciation skills (Perfetti, 2010). Lee (2023) highlighted the significance of consistent exposure to L2 vocabulary for its retention, particularly highlighting the scarcity of opportunities for EFL learners to regularly apply acquired vocabulary. Consequently, investigating effective vocabulary learning approaches to counteract forgetting becomes pivotal for learners who are devoid of a native language environment. Moreover, recent research also emphasizes two pivotal factors influencing vocabulary retention: contextual information richness and word exposure frequency (Teng, 2019). The findings of another study demonstrated the role of spatial learning in encoding target vocabulary, thus bolstering retention (Costuchen, Vayá & Dimitrova, 2022). The findings from the study illustrated that the spatial factor affects the retention of vocabulary learnt. These collective findings underscore the potential benefits of constructing an enriched contextual space that enhances retention for learners and encourages meaningful engagement. Therefore, in light of the emergence of virtual reality technology, it enables instructors to tailor design spatial environments that provide immersive user experiences and support vocabulary retention.

This research attempts to explore the creation of a VR environment for English vocabulary acquisition based on IVR technologies, with the goal of determining its influence on vocabulary memory efficiency and retention among Chinese learners of English. Meanwhile, it is crucial to understand which VR-related aspects play a part in this process. Two research questions are presented to address this focus:

RQ1: What are the differences in vocabulary retention when using VR versus using conventional instruction?
RQ2: What are the spatial-related factors in virtual environment that affect learners' vocabulary learning?

2. IVR-ASSISTED VOCABULARY LEARNING

The concept of Immersive Virtual Reality (IVR) originates from the technology dealing with "the sensory-immersive type of virtual environment ", and it is said to be originally designed to benefit NASA's astronaut training program (Biocca & Delaney, 1995, p.57). The significance of IVR is due to its focus on the user's involvement within the virtual world, particularly the capturing of body motions. Not only does it allow users to enter the virtual environment from a first-person perspective, but also interact with the environment through physical actions. Researchers like Kaplan-Rakowski & Wojdynski (2018) stated that complete immersion in a natural communication setting is one of the most effective strategies for learning a second language. Real-life immersion is not always a viable or accessible option for EFL students in non-English-speaking countries due to a lack of resources (Freed, 1998). IVR, on the other hand, provides an alternative technique for EFL learners to immerse themselves in life-like virtual environments (Legault et al., 2019). The continuous enhancement of VR technology has directly driven research that explores the use of IVR in language learning.

Since 2016, researchers have been conducting studies related to vocabulary learning using VR devices that capture head movements. Researchers have also extensively explored the impact of virtual reality (VR) on vocabulary acquisition and retention. Ebert, Gupta, and Makedon (2016) conducted a study on twenty participants, who were split into experimental (VR) and control (paper cards) groups, and found VR users performed better on vocabulary exams immediately and a week after using VR. Chen (2016) further supported this phenomenon, with his study that involved 448 participants using a desktop-based VR game, with results that showed enhanced verbal cognition. Madini et al. (2017) utilized Google Cardboard in a study involving 20 females watching VR therapy videos for six weeks, and the results showed significant vocabulary improvement. Despite improved vocabulary performances, limitations like poor immersion and restricted interaction with the VR environment were also noted by these past studies.

Additionally, VR has been proven to be effective in reducing anxiety, enhancing cross-cultural learning, and aiding medical related vocabulary acquisition. Xie et al. (2019) highlighted VR's role in reducing cognitive load and anxiety while improving sense of presence and motivating learners. Legault and colleagues' (2019) study suggested text prompts in VR environments enhance vocabulary learning. Alemi's study (2020) investigated vocabulary pronunciation using VR movies, and revealed significant improvement despite a small sample size, however it also shows potential limitations in reproducibility. Whilst Lai et al. (2021), who used highly immersive VR glasses in a game-based study found that the VR group outperformed the PC group in vocabulary tests, and contributed to increased motivation and enhanced spatial memory.

According to previous studies, VR has a positive impact on vocabulary learning. Its immersive nature aids retention, comprehension, and pronunciation. However, challenges persist, such as limited immersion in certain VR setups, constraints in content accessibility in specific regions (e.g. in countries like China, the research involving immersive VR is constrained due to the inaccessibility of YouTube and Google.), and concerns regarding the validity of findings due to small sample sizes. Nonetheless, these findings highlight VR's potential to revolutionize language acquisition by creating immersive and engaging learning environments.

Several empirical studies spanning from 2016 to 2019 highlight IVR's role in enhancing vocabulary acquisition, and they involved the use of immersive technologies such as 360-degree video and Google Cardboard. Notably, research since 2019 emphasizes highly immersive head-mounted displays (HMDs), that provide more diverse and cost-effective means for vocabulary instruction. However, limitations such as restricted participant interaction and small sample sizes still persist in these studies. Aiming to address these prior shortcomings in IVR research, this study hopes to investigate how the virtual environment affects vocabulary acquisition by employing a high-immersion HMD and increasing the number of participants.

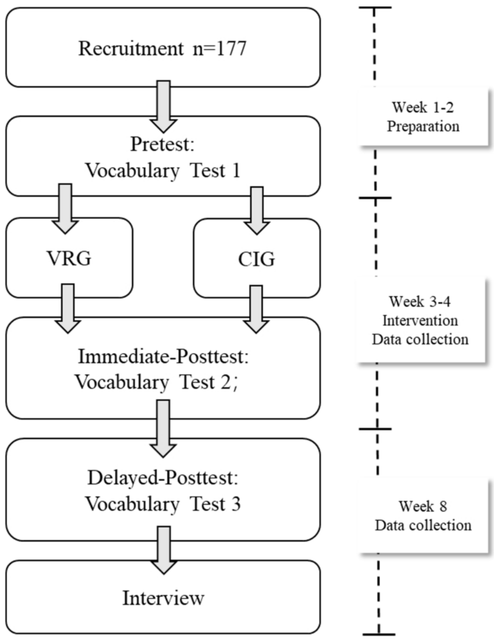
3. METHODOLOGY

3.1 Research Design

This design of this study was based on the sequential explanatory mixed method approach. This study was carried out with EFL learners at a university in China during the 2020–2021 academic session. During the recruitment, in a briefing session, the participants were told the objective and intervention procedures of the study. A total of 230 students from 8 classes from the first grade of the English major cohort in the School of Foreign Languages signed up for the experiment, accounting for 92% of the total number of students in this cohort. Consent forms were given to the participants to sign during the briefing session, and the demographic data of these participants was collected. In addition, the researcher was aided by seven senior students volunteered to join the research team as research assistants. Figure 1 shows the research design:

This study employed the repeated measure design, which involves multiple measurements of the same variable taken from the same or matched subjects either under different conditions or over two or more time periods (Salkind, 2010). Vocabulary tests were administered thrice: the Pre-test, which was conducted before the treatment (vocabulary test 1); the immediate-posttest (vocabulary test 2), conducted immediately after treatment and the delayed-posttest (vocabulary test 3), which

Figure 1. Research design



was conducted thirty days after the treatment. The RQ2 is answered by analyzing the performance of words at different positions and heights in the virtual environment, as memorized by students. In addition, insights gathered from the interviews were also used to support the findings of the quantitative analysis.

3.2 Participants

One hundred and seventy-seven Chinese undergraduates (Male = 22; Female = 155; Mage = 18.71, SD = .87) from Fuyang Normal University (FYNU) were invited to participate in the study. As shown in Table 1, these participants were all from the English Department of the University's Faculty of Foreign Languages, and they were EFL learners who had completed approximately 12 years of English language lessons in primary and secondary schools.

3.3 Instrumentation

3.3.1 Instrument for VR-Assisted Instruction Group

Researchers design a 150 m^2 virtual environment based on the Unity3D game engine, a cross-platform 2D / 3D game engine developed by Unity Technologies. The virtual environment consisted of a bedroom (A), kitchen (B), bathroom (C), living room (D), balcony (E) and courtyard (F). As shown in Figure 2, as a starting point (S), there is a circular intersection between room (A), (B), (C) and (D).

Table 1. Descriptive statistics of the participants

Sampling	Gender		Gender Ratio (M/F)	Mean Age	SD	Groups	
N=177	Male	N=22	0.14	18.71	0.87	VRG	N=75
	Female	N=155				CIG	N=102

This is the initial position of the learner upon entering the virtual environment. Learners must access the balcony (E) through the living room, and then enter the courtyard (F) from the balcony. After the virtual environment has been built, the 3D objects corresponding to the 90 target words were placed in each room. These items found in the virtual rooms could be activated by the rays emitted by the handle to obtain word information.

The researchers exported the project as an app for the Android mobile operating system and named it Franklass 1.0. Whilst Pico Neo 3 (https://www.pico-interactive.com) was chosen as the VR display device for this study. This is an HMD that captures the movements of the user's body and arms and has two handles. The learners can control their movement using the right-controller and interact with the objects in the scene through the rays emitted by the left-controller. While the item being interacted with becomes highlighted, the learner can obtain the spelling and pronunciation of the word corresponding to the item. Figure 3 shows the participant's perspective through the device tracking record:

3.3.2 Instrument for Online Instruction Group

The instruction of the conventional group was conducted through a Learning Management System (LMS) called DingTalk (https://www.dingtalk.com). The functions of DingTalk are similar to Microsoft Teams, it allows teachers to interact with learners through cameras and microphones and to present their slides and handwritten materials.

3.4 Material

Ninety vocabulary items that include words such as "blender," "mop", "broom" etc. that related to household and furniture items were selected to form the list of targeted vocabularies. The selection criteria are: Firstly, the learners have not been exposed to these words as they do not form part of the wordlist prescribed by the first-year university syllabi, nor are they part of the vocabularies listed in NCEE (the national college entrance examination). Secondly, to aid in visually illustrating meanings

Figure 2. The planform of the VR classroom

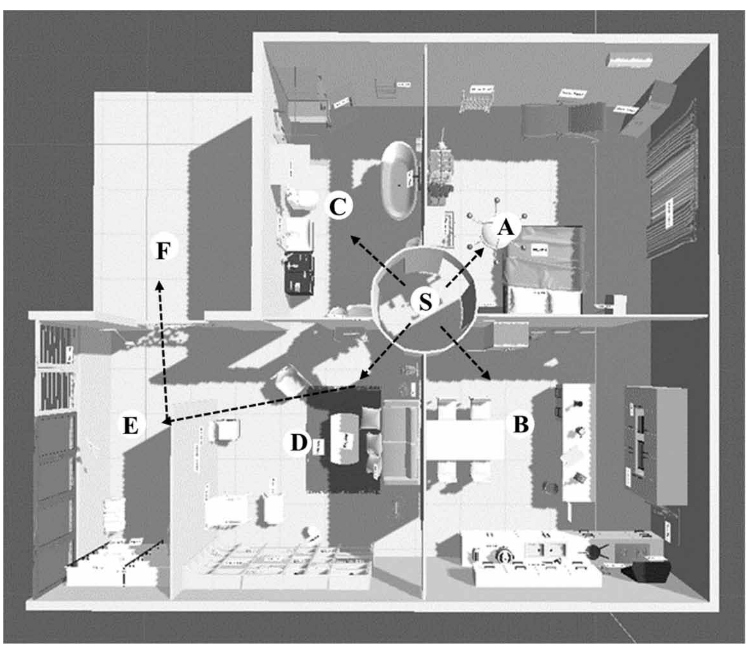
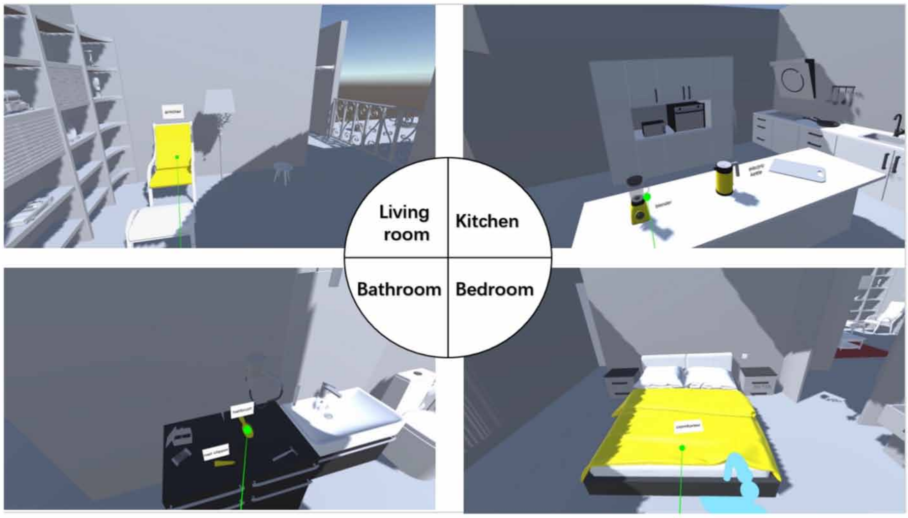


Figure 3. Screenshots from the participants' tracking video



in virtual environment setting, it has been decided that only concrete nouns related to household and furniture items will be chosen. A 50-item test (with each item carrying 2 points and totaling 100 points) has been set up as the pre-, post-, and delayed tests. The test was designed to test the learners' comprehension of these 90-targeted words, whereby learners were required to fill in the blanks found in sentences using the words they have learned. The sentences would provide the cues that would assist the learners in deciding the appropriate words to be filled in. For the pre-, post-, and delayed tests, each set of test entailed 50 questions that were randomly drawn from a pool of 90 test items. This is to ensure every participant was assigned with a unique set of test questions. This method helped to preserve test integrity, prevent repetition of questions, as well as uphold reliability and validity of the tests.

3.5 Procedure

3.5.1 VR-Assisted Instruction Session

Participants from VRG first received a 1.5-hour training course on the use of equipment and software. They were allowed to withdraw from the experiment at any time if they felt any discomfort. Upon entering the virtual room, learners were free to move around and interact with objects in the room via the use of the handles. With the help of an assigned research assistant, learners were asked to put on the VR headset together with headphones. The moment the students entered the virtual environment; they were initially placed at a starting point (as shown in Figure 2). There are four doors leading to different rooms at the starting point, and learners can randomly choose a room to enter. In the rooms, they can interact with the items placed in these rooms via the VR handheld controller. When these items are clicked, it will initiate an interactive process, whereby a panel containing the spelling of the corresponding word pops up while the pronunciation of the word is played (as shown in Figure 3). Learners can decide for themselves the chronology of rooms and items to be explored in the virtual environment, including the order in which they learn the vocabulary items and the number of times they interact with any item. As the session was ending, the research assistants would alert the participants and assist them in removing the devices. In this study, none of the participants withdrew from the intervention due to physical discomfort, and only 3 participants requested to sit in a rotating chair to complete their session due to mild dizziness. Based on the screen recording function of VR glasses, 15 participants were randomly chosen, and their learning process recorded. The recordings consisted of sessions which lasted 40 minutes each, and over 5 consecutive days, which resulted in a total of 200 minutes.

3.5.2 Conventional Instruction Session

In instructing the CIG, the instructor would carry out the lesson using the conventional teaching approach involving the use of visual aids, explanations, and DingTalk. Among the virtual aids used for instruction purposes, they include slides featuring phonetic symbols corresponding to the targeted vocabulary, which are supplemented with photos, translated into Mandarin words and accompanied by sample sentences. The instructor would also demonstrate the pronunciation of the words and memorization strategies that the students could use. This method ensured that similar to the learners from the VR group, the learners in the CIG had opportunities to be exposed to visual and auditory input related to the targeted vocabulary items.

3.5.3 Interview

This study enlisted 15 VRG participants as interviewees in order to better understand how VR environment affects the students' learning. The students were divided into three groups based on their scores in the immediate-post test, i.e. high score (rank 1-5, n = 5), medium score (rank 36-40, n = 5), and low score (rank 70-75, n = 5). The aim of this sampling strategy is to obtain the perspectives from students with varying levels of vocabulary performance. The interview data were subsequently coded based on the ideas that emerged.

4. RESULT

4.1 Performance on Vocabulary Retention

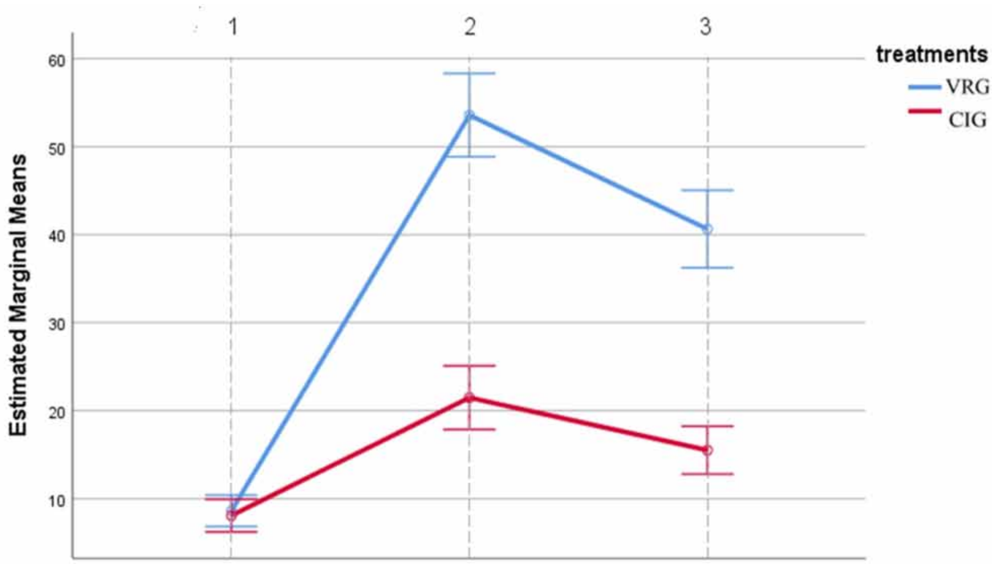
The performance of the two groups of learners in vocabulary tests is depicted in Figure 4. These scores provide insights into the changes in the participants' vocabulary performance after the intervention, and after a considerable period of time. Specifically, Figure 4 depicts the vocabulary test scores of participants belonging to the Virtual Reality Group (VRG) and the Conventional Instruction Group (CIG) across the Pretest, Immediate-Posttest, and Delayed-Posttest phases.

The data presented in Figure 4 indicate that in the Pretest phase, both groups of participants demonstrated comparable proficiency in the target vocabulary, as evidenced by their average scores which differed by a mere 0.27 points. Following the implementation of distinct intervention method, a substantial disparity emerged between the average scores of the two groups. Specifically, the Virtual Reality Group (VRG) exhibited an average score that was 32.98 points higher than that of the Conventional Instruction Group (CIG), and with the highest score reaching 93 points. After a 30-day interval, the vocabulary performance of participants in both groups experienced some degree of decline. Nevertheless, the average score of the VRG remained higher to that of the CIG by 25.33 points. In comparison to their performance in the Immediate-Posttest, the VRG demonstrated a decline of 24.16%, while the CIG experienced a decline of 25.72%. Furthermore, the average score of the VRG in the Delayed-Posttest (M = 40.64, Max = 88, Min = 8) was found to be 12.95 points lower than that of its Immediate-Posttest. The retention rate for the VRG was determined to be at 75.84%. Simultaneously, the average score of the CIG in the Delayed-Posttest (M = 15.31, Max = 64, Min = 0) was 5.3 points lower than that of the VRG Immediate-Posttest. The retention rate for the CIG was at 74.28%. These findings suggest that after a 30-day period, the retention rates of both groups in relation to their Immediate-Posttest vocabulary mastery were deemed comparable.

4.2 Spatial-Related Factors in Virtual Environment

The number of correct answers, based on words placed in different rooms, was counted in order to understand the effect of word distribution on memory performance. As shown in Figure 5, vocabulary

Figure 4. VRG and CIG vocabulary test scores in pretest, immediate-posttest, and delayed-posttest



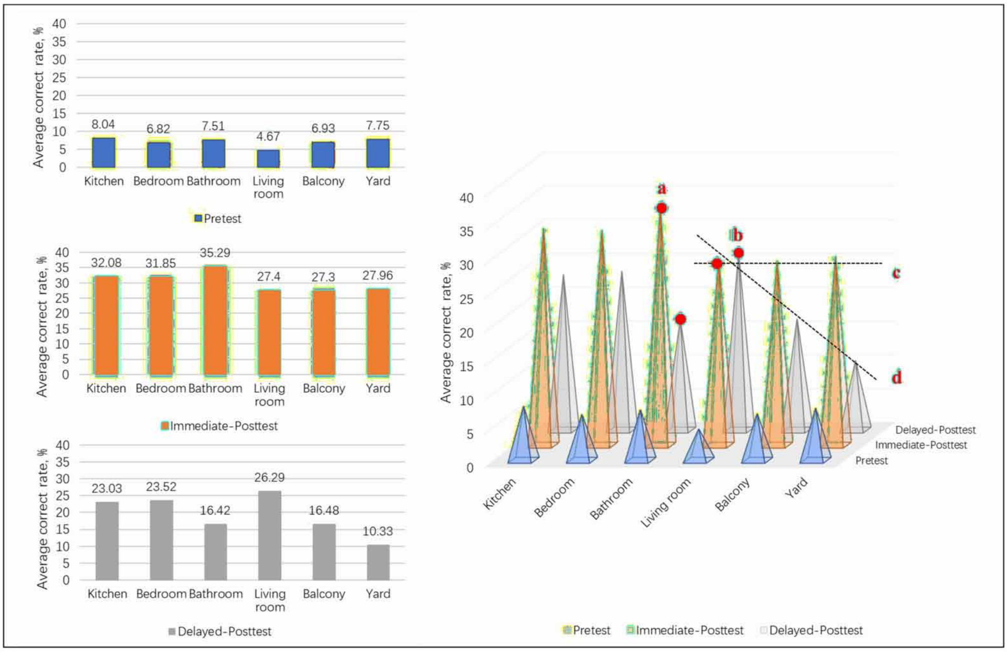
Group	Pretest				Immediate-Posttest				Delayed-Posttest			
	$\bar{X}$	Max	Min	SD	$\bar{X}$	Max	Min	SD	$\bar{X}$	Max	Min	SD
VRG	8.61	35	0	7.74	53.59	93	12	20.56	40.64	88	8	19.12
CIG	8.88	31	0	8.53	20.61	59	0	14.51	15.31	64	0	11.43

mastery in the Pre-test is low in all rooms, with a maximum value of 8.04% (kitchen) and a minimum value of 4.67% (living room). After the treatment, the level of vocabulary mastery improved. The correct rate of words placed in the bathroom went through a steep increment, jumping from 7.51% to 35.29% and then dropping significantly to 16.42% in the Delayed-Posttest (as marked in **point a**). In contrast, the rate in the living room only dropped from 27.4% to 26.29% (as marked in **point b**). Another set of data reflects the rate of words in three other rooms (living room, balcony, and yard) with increasing distance from the starting point. According to the **auxiliary line c**, the average correctness in Immediate-Posttest between the rooms is quite similar (about 27%); but in Delayed-Posttest, there is a gradual decline (as shown in **line d**).

These results indicate differences in terms of the correct rate of words placed in different rooms, and the amplification of these differences with the passing of time. One possible explanation for this may be due to learner's learning effect which makes between-room differences recessive at the beginning. However, after 30 days, some learners would experience difficulty in retrieving these words. This phenomenon indicated that the influence of spatial factors would only be apparent after a period of time. The distance of the room from the starting point is another factor that should be taken into consideration. The design of the virtual room is designed in such a way that learners have to go through the living room and balcony to access the yard. This design makes the living room the most frequented area, as one has to pass through the living room to get to the other two areas. This shows that the retention of vocabulary could be related to the frequency of learners' visits. On the other hand, in terms of the locale of these items, the data in Figure 6 suggested that it could be a probable factor that affect the learners' vocabulary performance:

As shown in the Figure 6, the correct rate of words located at different height intervals is measured. The virtual room is divided into 5 height intervals. (For example, the virtual object corresponding to the word "bench" is located in the range of 0-60 cm; the "drop light" is located in the range of

Figure 5. Average correctness of words distributed in living room, kitchen, bedroom, bathroom, balcony, and yard in pre-test, immediate-posttest, and delayed-posttest



240-300 cm.) According to the **region α**, in Immediate-Posttest, words located in the height range of 60-180 cm have a higher memory performance than other intervals, which is also observed in the **region β**, showing a similar memory performance in Delayed-Posttest. Considering that adult learners are generally between 160-175 cm in height, objects in the 60-180 cm height range are within their line of sight and perhaps are therefore easier for these adult learners to spot. This means they can spot and interact with these objects without looking up or down. This phenomenon is speculated to be related to the frequency that the objects are visited.

4.3 Perspectives From Learners Upon Using VR

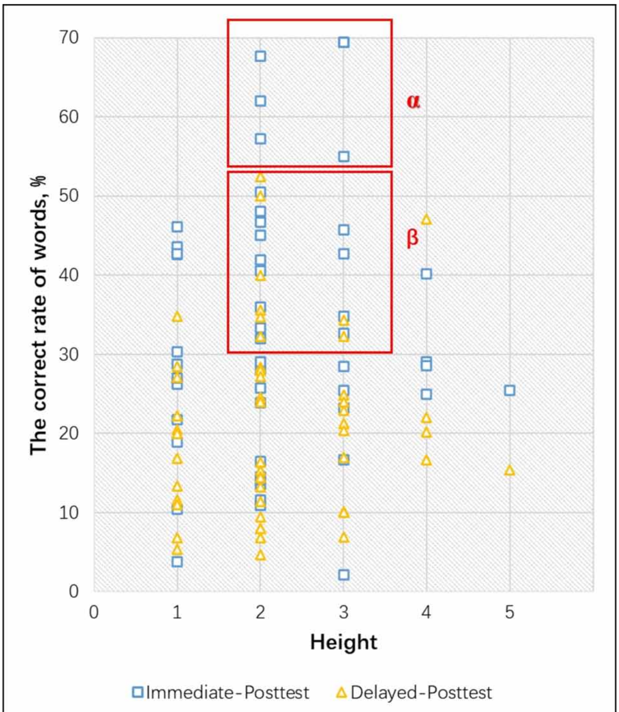
To a certain extent, the above results illustrated that in the virtual environment, the horizontal and vertical distribution of target vocabulary items may affect the learner's memory retention. The following interview data further reveals how spatial factors affect VR-assisted vocabulary learning. Using the keyword analysis approach, 9 of the 15 interviewees mentioned that they retrieved words by recalling the location of the object corresponding to the word in the virtual room. Some interviewees pointed out the relevance of spatial factors in their vocabulary memorization.

For example, Student VR-HA, who made drastic progress in her VR-assisted learning, has mentioned that:

当我在测试中看到"空调"的时候,我会想到当时在那个(虚拟)房间里空调的位置,然后我就能拼写出这个单词了。
When I saw the 'air conditioner' in the test, I would think of the location of the air conditioner in that (virtual) room at that time, and then I could spell out the word.

Student VR-HA described how she was assisted in recalling the spelling of words by retrieving the location of items based on her memory of the location and height of the items. Another respondent,

Figure 6. Correct rate of words distributed between 0-300 centimeter from the ground in immediate-posttest and delayed-posttest



Height /cm	1	2	3	4	5
	Very low	Low	Mediate	High	Very high
	0-60	60-120	120-180	180-240	240-300

Student VR-HB, also from the high vocabulary performance subgroup, mentioned a similar retrieval process and provided more details:

我能回忆起单词所处的整个环境,包括物品的形状和单词面板。
I can recall the entire environment that the word is in, including the shape of the object and the word panel.

From Student VR-HB ‘s viewpoints, it shows that she has captured the whole VR environment in her mind and can recall the corresponding locations of objects, shapes, and even the spelling of words shown on the panel. The above interviews demonstrated that the virtual environment aided in creating an imagery space for learners to mark the objects for better retrieval process.

In addition, exploring an unfamiliar environment may give learners greater motivation than the texts printed in textbooks. The 3D space and the target vocabulary items placed at different locations provide learners the opportunity of exploring compared to the 2D presentation of knowledge.

For instance, Student VR-HC from the high score group said:

通过课本学习单词有一种被动接受的感觉……但是*VR*给我带来了主动学习的动力。因为它不会即刻展示给我,我需要自己去点击它……我变得更主动了。

Learning vocabulary through textbooks has a feeling of passive acceptance... But what VR gives me is the motivation to learn actively. Because it is not shown to me immediately, I need to click on it myself... I'm more proactive.

This respondent mentioned how the process of exploring the environment made her feel more proactive in her learning. She also mentioned that this was not due to the target vocabularies, rather it is due to the manner in which the vocabularies were showed and acquired, which made a significant difference for her.

The interviews also revealed that spatial factors had an impact on learners' vocabulary learning through the style in which they are decorated. Here is one exemplary response:

就像这个虚拟房间,我想可能是美式的设计风格......有点类似......感觉我直接走进了一个美国家庭。
Just like this virtual room, I think it might be American design style... it's a bit similar...it feels like I walked directly into an American family.

4.3.1 Student VR-HD

Student VR-HD's response reflects the fact that the style of design in the space made her imagining herself as a visitor to an American home. This mindset may affect her learning behaviour, as she will perhaps spend the rest of her time exploring the rooms and learning about the words as a visitor. Interestingly, some irrationalities in the design of the virtual space adversely affected the vocabulary learning. As Student VR-MA said:

我有时候很爱吐槽:"拖把怎么能放在冰箱旁边呢?""小便池怎么可以里浴缸这么近?"这种不合理的地方让我对这些单词记得很深。
I sometimes grumble: 'How can the mop be placed next to the refrigerator? How can the urinal be so close to the bathtub?' This kind of unreasonableness makes me remember these words well.

Student VR-MA 's response seems to reflect the concerns of many virtual space designers, who often worry about design perfection. However, just as many designs in the real world, there exists imperfection in design. These imperfections ended up as points of memorization for learners to memorize words. In short, the content of these interviews demonstrates how learning in 3D spaces is different from learning from textbook or slides. The interview date demonstrated that the spatial location in the virtual environment provides learners with a memory aid. Not only does it help in recalling information about the words; the design of the space provided learners with a scene which allows them to focus on exploring the environment and memorizing relevant vocabularies. The VR-assisted language learning mode enables vocabulary learning to occur spontaneously and unconsciously.

5. DISCUSSION

IVR is projected to have a significant influence on education (Radianti et al., 2020). This pre-supposition is further verified in this research. Based on quantitative analysis, the inter-group analysis revealed that learners utilizing VR technology demonstrated notably higher vocabulary retention (30 days post-learning) compared to those engaged in conventional instruction. Both cohorts received visual and auditory input; however, the differences are found in the dimensionality, with VR offering a 3D visual experience as opposed to the conventional 2D format. This discrepancy in retention, as shown in this study, concurs with the findings from Costuchen et al.'s (2022) study. This suggests that VR's immersive nature creates a sense of presence among learners, which contributes to the learners' vocabulary learning. Notably, this aligns with the notion of "more informative context" articulated by Teng (2019), wherein the spatial depth of 3D visuals provides learners with a richer array of spatial cues compared to the 2D formats. Similarly, the positive correlation between learners' attention and vocabulary retention is also shown in another study by Mohamed (2018). In this study, it shows that the context of VR-supported learning and learners' attention can operate autonomously and within confined parameters. The findings from these previous studies elucidated that strategically situating targeted vocabulary items within specific spatial locations in VR environment does facilitate the learners to focus on these words, which help them to learn and remember due the different inputs that accompanied these words. The results of this study are consistent with previous studies in other contexts: EFL learners using VR technology have achieved higher vocabulary memory efficiency (Legault et al., 2019; Alemi, 2020; Lai et al., 2021). It has to be pointed out that in this study the interval between Immediate-Posttest and Delayed-Posttest was 30 days, which was longer than the other empirical studies.

Moreover, in previous studies, most of the control group's intervention materials were single inputs, such as vocabulary cards (Madini et al., 2017; Yossatorn, 2019), audio (Legault et al., 2019) and slides (Xie et al., 2019). Participants in the control group were asked to learn the contents of these materials on their own. However, the discrepancy that exists in the form of information input between groups has been improved in the design of this study. In this study, just like learners from the VRG, learners from CIG can get the pronunciation, pictures and sample sentences for the target vocabulary during class hours. The results showed that VR technology enhances vocabulary acquisition performance not just based on the fact that it provides rich visual and audio input forms, but also from the fact that it manages to effectively integrate various inputs: Learners no longer need to link target vocabulary to visual information, audio information, or word meaning in a linear manner; instead, they can gain many pieces of information about a vocabulary item simultaneously and realistically. As mentioned by student VR-HD in the interview, the whole learning process felt like visiting an American family. From the perspective of second language acquisition, this is a more efficient subconscious acquisition (Kasper, 1999). When the learner explores the virtual environment and interacts with the objects in the room, this process of acquiring vocabulary knowledge is subconscious. At the same time, due to the lack of a teacher's influence, the manner VRG learners explored the environment also showed behavioral changes that positively affect their learning. It is believed that this may prompt a change in the learners' vocabulary learning approach.

Cho (2018) explains how VR technology stimulates learners' sense of presence and the resulting concept of "Spatial Presence". He emphasizes on the correlation between spatial memory and spatial presence, which makes VR an "essential tool" for vocabulary memory. Moffat (2009) believes that, by developing schemes or encoding information into patterns, learners can overcome forgetfulness. To promote the learner's ability to encode information, the "Method of Loci" is one potentially effective strategy for learning and memorizing (Murthy, 2014). Loci refer to "places" in Latin, and the method involves the processing of both spatial locations and imaginal associations (Lea, 1975). Bass and Oswald (2014) summarized this approach into three steps. First, individuals memorize a few locations, such as a building with a gate, entrance, garage, lounge, stairs, kitchen, and bedroom, each of which are called cues. Second, individuals form an image of incoming information or relate new information to existing items visualized in the room. Third, they generate a sequence of information, which can later be retrieved. Cho (2018) believes that the 'Method of Loci' is related to spatiality, and learners need to use spatial location to encode the content that needs to be remembered. The interactive 3D environment supported by VR technology provides convenience for learners to use the "Method of Loci", so it is considered a suitable memory tool (Pantelidis & Veronica, 2010). During the interview, student VR-HD from the high score group mentioned that she retrieved word information by recalling the location of the "air conditioner" in the Immediate-Posttest. In addition, student VR-HB also mentioned the important role of "location" in her vocabulary memorization process. The interview also revealed that the use of "Method of Loci" mostly appeared in the high-performance group, while it was not mentioned by the learners with lower scores. This reflects the impact of individualized differences on learning effectiveness. Vindenes (2017) believes that informants with higher spatial ability obtain more benefit from using the VR environment, due to 'Method of Loci'. This helps explain the difference in vocabulary memory performance of learners using VR technology. Based on the interview data, it is believed that these individualized differences mainly concern spatial ability, autonomous learning ability, and environmental adaptation ability. Learners who are not equipped with these abilities may have difficulty adapting to IVR assisted language learning.

Another feature of VRG that relates to spatial factor, which has been proven by this study, relates to the sequences of vocabulary learning. In conventional instruction, the order of learning vocabulary is often determined by the teacher, or according to the word list in the textbook. In conventional language learning, the target wordlist is usually determined by the teacher. Experienced teachers usually design the lessons following specific order when they teach vocabulary items. Learners in CIG typically spend a specific amount of time on one word before learning the next one, and usually the wordlist will not be repeated in subsequent lessons. In contrast, learners in VRG can decide their access route in the virtual room, whereby repetition does happen, and they are also free to decide how long or how frequent to interact with each word. Unlike lessons in conventional classroom, in the virtual environment, some words are positioned above and some are below, which forms a three-dimensional positional relationship. Whereas this phenomenon does not take place in CIG group. By analyzing the screen recording video, it is found that some words are learned in less than 20 seconds by some learners. The videos also show that, after a while, these learners will come back and review them again. It seems that these learners did not follow any specific order when they explore the vocabulary items in virtual environment and behave more like explorers. They would pay more attention to getting know the environment, and the time allocated to explore and learn each word differs. Without the teacher participation, these students exhibited different learning behaviours from those in the conventional classrooms: they did not follow any specific order. Instead, individual learners exhibited different manner of exploration which resulted in learning the words in different order. VRG learners interact with each word using shorter period of time, but they visited the words more frequently compare to CIG learners. It seems to suggest that VRG learners tend to learn about these words in an incidental manner. This difference is thought to have an impact on the memory performance of the two groups. According to Ellis (2015, p.25), "acquisition is the incidental process by which learners 'pick up' a language without making any conscious effort to master it." These data reflect the unique attribute of virtual environment which facilities incidental learning, and indirectly it contributes to vocabulary retention. Under the influence of spatial factors, the learners' vocabulary learning behaviour undergoes changes, whereby their vocabulary scores improved, which evidently prove that VR can be an effective vocabulary learning tool.

6. CONCLUSION

The findings of the present study revealed the associations between spatial locations of objects in a virtual environment and the retention rate of learners. These findings provide insights that may benefit the designers and developers of virtual environments for language teaching and learning. Firstly, since learning in virtual environments is devoid of teacher guidance, learners' attention and exploration directly influence their learning performance. The findings of the present study suggest that vocabulary items that the learners visit more frequently resulted in better retention performance. This suggests that designers of virtual environments that catered to language learning may want to consider placing important instructional objects at localities that are more likely to be visited by learners. From a spatial design perspective, designers may want to pay closer attention to factors that motivate learners to visit specific locales more frequently. These factors may include ease of access, relative distance, and noticeable aspect.

Secondly, as an option that encourage self-directed learning, language instructors may want to consider including VR-related learning packages that allow learners to explore and acquire new vocabulary knowledge. Thirdly, the design of virtual learning environments should take into account the average height of learners in order to place the target vocabulary items within the learner's field of view. Heights that are not within the range of optimal views of learners may result in less attention from the learners, thus affecting their memory retention. Finally, teachers and developers need to recognize that learner attention is one of the significant factors that impact learning behaviour in virtual environments. Due to the lack of the teacher's role, the locale of objects and the directing of students' attention are pertinent aspects in VR-assisted learning during the acquisition of vocabulary. Future studies need to take these aspects into account.

Lastly, the limitations of the present research are as follows: Firstly, the 90 target words selected in this research are all concrete nouns, and it does not include words such as verbs, adverbs, adjectives etc.; Secondly, the relatively small number of interviewees may not provide a comprehensive picture of the experiences and perceptions of learners using VR. Finally, the vocabulary learning performance explored in this research only involves vocabulary memory performance but does not include vocabulary usage performance. Future researchers may want to address these limitations when they conduct studies related to the use of VR for language learning purposes.

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CONFLICT OF INTEREST

The authors of this publication declare there is no conflict of interest.

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