Rote memorization in VR environments

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Abstract. This article presents the result of an experiment on rote memorization, performed in two virtual reality (VR) learning environments, 3D virtual reality (VR 3D) and VR based on 360° images (VR 360). 201 participants took this test aiming at memorizing the capitals of unusual countries. Feedback was performed immediately after the test, by filling in an online questionnaire on a desktop. The obtained results show that the VR 3D format (29.6% of capitals recalled) is less efficient than the VR 360 (30.8%) for rote learning purposes. Moreover, the average memorization result for both formats (3D and 360) remains lower than the result obtained by another experiment which used paper format to perform the same task. Scores achieved using VR 360 (30.8%) are lower than when using paper (36.8%), that is 6.8pts less for VR 360. Therefore, the format characteristics tend to impact memorization, which for VR 360 consisted in displaying pairs of capital-country in situ, on 360° images depicting the given capital. Furthermore, the experiment tends to reveal that in immersive universes, the subject's age and involvement in an academic environment (pupils, students, professors) has no effect on the results, whereas the time spent on a task produces contrasted results.

Keywords: Virtual reality, virtual reality learning environments, rote memorization.

Introduction

VR constitutes one of the innovative training devices for educational purposes. The report « Augmented and VR survey » points out that 26% of AR/VR investments for the next 12 months will concern education in equal measure with the health sector [1]. These investments will reach 200 million dollars by 2020 and 700 million dollars by 2025, that is the 4th largest market addressed by VR. Both K-12 and higher education levels will be concerned. [2]

In various fields such as medicine, health, psychology, architecture etc.., VR appears to provide performing learning solutions, while the corresponding technologies (helmets, haptic devices, etc.) are being developed at a rapid pace, offering ever more flexibility in their use, reducing the negative effects on the vestibular system or on problems encountered when manipulating objects.

Interactions in immersive universes, close to reality, with the possibility to repeat exercises [10], without danger or threat, tend to account for superior learning possibilities compared to traditional devices.

Memorization and learning

Memorization represents a key factor in the learning process. Is this cognitive function trigerred differently in a VR learning environment? To contribute in answering this question, we have based our research on one memorization type, rote memorization.

Although less solicited at the tertiary level compared to lower levels, this type of memorization nevertheless remains fundamental in order to anchor long-term knowledge and to facilitate rapid data recall.

Memory is seen as a sophisticated process stated in three steps: encoding, storage and retrieval. Two memories come into play when information is memorized: short-term memory (STM) and long-term memory (LTM). Rote learning is mainly concerned by STM. The capacity of this memory depends on individuals. Blocks of information which can be assimilated at one time, the memory span, reaches from 2 to 9 items, but 7 on average [7]. Information present in the STM lasts around 20 to 30 sec. This memory is sensitive to interferences [3] and easily disrupted.

Textual data memorization is processed by a specific part of STM, the working memory. This type of data is apprehended via a sub-system called the phonological loop. This information is retained for a short 2 seconds. For a longer anchorage, the information must be repeated several times, or the information must be associated to clues, in order to be integrated into the semantic memory, which in non-dated, non-located, hardly emotional.

Rationale

Several studies have been conducted to question the pertinence of using VR for learning.

Yahaya (2006) showed that immersive VR environment helped increase students' understanding of decision making. The results of a study conducted in 2009 by Bowman, Sowndararajan, Ragan and Kopper suggest that, for procedure memorization tasks, increasing the level of immersion even to moderate levels, such as those found in head-mounted displays (HMDs) and display walls, can improve performance significantly compared to lower levels of immersion.

The results of these studies vary according to the learning factor(s) and the level of studies considered. Some investigations performed by the University of Copenhagen show, for example, that middle school pupils learn better when the professor is represented by gender. Girls learn better, in such environments, when the virtual professor is a young female model, whereas boys learn better if the professor is a technological item. At the tertiary level, this characteristic has no impact on learning [15]. However, a recent study by the University of Maryland showed that a VR learning environment impacts mind palace memorization. The participant's memory accuracy for recalling faces will be higher in the HMD condition compared to the desktop condition due to the increased immersion [12]. (faces memorization)

The results from a study dedicated to comparing actual and perceived learning achievements in both environments (VR and online on a desktop) were insignificant: neither of the two environments prevails. Nonetheless, the participants' perception of their learning (ease of comprehension, memorization, active learning, etc.) show that VR is assessed as superior to the other method [14]. These results indicate that VR influences the learning process by creating engaging experiences and enhances the learning motivation.

Early experiments conducted with a prototype of NeverMind, an augmented reality (AR) interface designed to help people memorize effectively, suggest that the long-term memory recall accuracy of sequences of items is nearly tripled compared to paper-based memorization tasks [22].

With reference to this study conducted in 2018, we examined how memorization can be measured in a VR learning process.

Method

In 2017, a study was conducted (Salamin, & Hadorn, 2017) on rote memorization, which compared the results obtained when information to be memorized was delivered on a smartwatch or on plain paper. The results indicated that memorization via the smartwatch proved less efficient than on paper (22.6% vs 38.6% of recalled data). We wish to broaden this study to 3D VR (VR 3D) and 360° video (VR 360), two more immersive environments compared with the smartwatch.

We worked on two different hypotheses.

Our first hypothesis (H1) was that VR 3D would be more efficient for rote learning than VR 360 immersion, as the virtual environment provided was less distractive than in VR 360 and the data structure organized in such a way as to encourage memorization.

The second hypothesis (H2) postulated that the results for both VR environments would be superior to the smartwatch results. (comparison small device vs immersive devices).

Experiment

We reproduced the experiment which was performed for the smartwatch vs paper, consisting in memorizing the capitals of little or less well-known countries, followed by a quiz on a desktop to measure the rate of memorization for both items. (Salamin, & Hadorn, 2017)

So, fifteen capitals were randomly dispatched to each experiment (VR 3D and VR 360). The participants were asked to avoid mentioning whether some capitals were known beforehand. The participant could freely set the time spent on the experiment, and the number of repetitions for all the capitals proposed.

We designed two environments (Fig 1):

1. The VR 3D environment proposed a spherical map of the world floating in a plain room. The participant could make it spin with a joystick. When a pair of country/capital appeared, the sphere stopped rotating. When the participant thought he had memorized the pair, he could resume the animation using the joystick.

2. *The VR 360 environment* displayed a 360° image of a given city and a block of text mentioning the country/capital overprinting this image. The participant could move by 360° to observe the displayed details. With the joystick he could resume scrolling for the countries when he believed the pair was memorized.

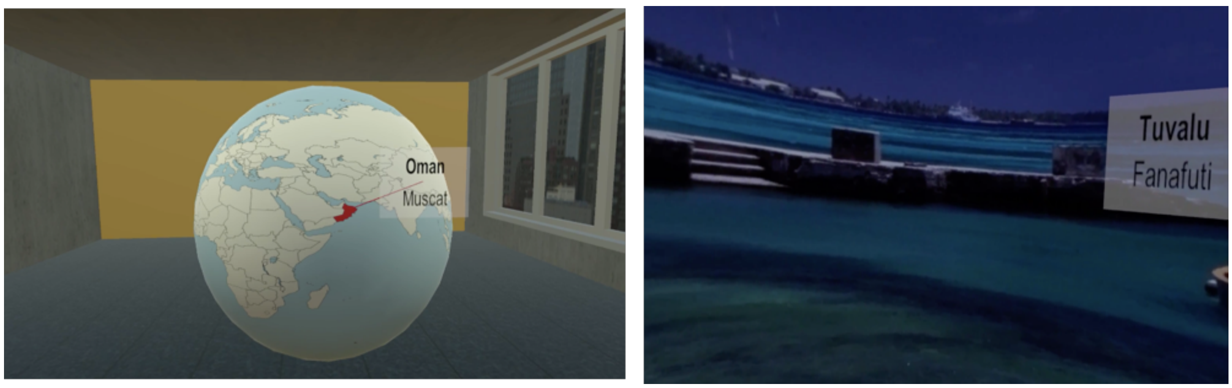

Figure 1 : the learning environments (VR 3D on the left, VR 360 on the right)

The participants were randomly attributed to each experiment, and the experiment was performed in a sitting position. Equipped with HTC Vive helmets, they interacted in the learning sequences with game joysticks. After having completed the experiment, the participants took off their helmets and moved to a desktop to fill in a quiz on the capitals present in the game. The quiz consisted of 15 items covering all the capitals shown to the participants. Each question asked participant what is the capital of <country> and the participant should enter the name of the capital. Afterwards, the questionnaires were manually processed and analyzed.

Participants

Data was collected during two pedagogical conferences and a fair open to a wide public (contrasted group method). 201 people participated in this study on a voluntary basis. The age groups represented went as follow : -16 years old (64), 16-20 (9), 21-30 (45), 31-40 (23), 41-50 (29), 51-60 (16), + 60 (15).

The most represented group was the – 16, followed by the 21-30. Women represented 40 % of the participants (79) for 60% men (122). Women were 46% to test VR 3D, while 54% tested VR 360, whereas 48% men selected the VR 3D experiment against 52% for the VR 360 experiment.

Figure 2 : participants learning capitals

Results

We used the z test to estimate if the differences between VR 3D results and VR 360 results are statistically significant or not.

The table below (Table 1) displays the score in percentage achieved for the test, by age group. On average, the VR 3D scores represented 26.9% against 30.8% for VR 360. The age group with the best correct answers was the 31-40 group, with a 42,6-average rate, with close results for each format (VR 3D :42.5% and VR 360 42.7%). On the contrary, the least performing group was the -16-age group with an average score of 15.9%, the lowest rate with VR 3D (13.8%) as well as with VR 360 (18%). All age groups, except the 41-50, score lower with VR 3D than VR 360. Only differences for age groups 16-20 and 21-30 are statistically significant.

Table 1. Percentage of recalled capitals for VR 3D vs VR 360 by age group.

Age group	VR 3D	VR 360	Average	Ranking
-16	13.8	18.0	15.90	7
16-20	14.4	37.8	26.10	6
21-30	33.1	45.6	39.35	**2**
31-40	**42.5**	**42.7**	**42.6**	**1**
41-50	31.1	24.7	27.9	5
51-60	33.3	37.8	35.55	4
+ 60	31.9	43.3	37.6	**3**
Average	**26.9**	**30.8**	**28.85**	

Factors influencing learning

A number of factors influence the memorization process [21]. Concerning rote learning, these factors can be attention, concentration, repetition, implementation of learning strategies, motivation and spaced practice (repetition of learned items after a rest period).

Age and time spent on the task constitute two elements impacting the recall rate. We consider that the more time is spent on the task, the higher the probability for the subjects to implement learning strategies in order to retain information. The other factors are either not present in the experiment (spaced practice), or not measured.

Time and age groups

The table below (Table 2) shows the average time spent memorizing capitals in each environment, by age group. The 16-20 group scored the best results with an average of (1'57). The group achieving the lowest score (21-30) for memorization, ranks 7th when considering the average time spent on memorization (4'06"). The oldest group (+60) ranks on the 6th position for time memorizing the capitals in VR 360 (3'20"), but is the fastest in VR 3D, with the 3rd ranking in terms of successful achievement.

Table 2. Time spent memorizing capitals with VR 3D vs VR 360 by age group.

Age group	VR 3D	VR 360	Average	Ranking
-16	1’49’’	2’47’’	2’18’’	4
16-20	**2’24’’**	**1’30’’**	**1’57’’**	**1**
21-30	3’32’’	4’40’’	4’06’’	7
31-40	1’38’’	2’36’’	2’08’’	**2**
41-50	1’40’’	3’07’’	2’24’’	5
51-60	1’33’’	2’52’’	2’13’’	**3**
+ 60	1’30’’	3’20’’	2’25’’	6
Average	**2’14’’**	**3’09’’**	**2‘42’’**	

Report Time-Memorization

The results presented in the table below cannot assert that the length of time spent on memorization increases the success of the task. Indeed, the slowest group (7th position) ranks second for the percentage memorized, whereas the fastest group ranks 6th for the percentage memorized. One explanation may be that some capitals were known prior to the experiment; therefore, the time spent memorizing the items was shortened, which impacted on the total memorization time spent recorded.

Time spent on the task appears to impact the result. Indeed, the 16-20 were the fastest group, but ranked last in the success-time combination, while the slowest (21-30) who spent more time on the task scored higher to rank at the 2nd position.

Age does not appear to impact on memorization, as the +60 group ranks 3rd, and with the older groups (+40) they rank among the best 3.

When matching the best success rate and the shortest time spent on the task, the most efficient group is the 31-40 group, followed by the 51-60. The +60 rank 3rd, while the -16 come last. However, the 31-40 group accounts for the second fastest on the task, while ranking first for the number of capitals recalled. Therefore, it is possible to perform the task rapidly and reach a good score.

Table 3. Ranking for success vs average time spent on the task by age group,

Age group	Ranking Success (+ capitals recalled)	Ranking Time (- time spent on task)	Total
-16	7	4	11
16-20	6	1	7
21-30	2	7	9
31-40	**1**	**2**	**3**
41-50	5	5	10
51-60	4	3	7
+60	3	6	9

Behavior by profession categories

We did not wish to compare scores by profession, but were interested in comparing results obtained by participants from the education field. As they were more trained to rote memorization, their results might be better than the general population. We opted for comparing the groups in the educational sector (pupils, students, professors) with the remainder of the population, represented by active professionals stemming from various sectors (construction, services, etc.) and several positions (engineers, cabinetmakers, etc.)

Group 1: Pupils, students and professors

A priori, those involved in education should be more efficient in the memorization process, as they are trained in the classrooms to memorize (or to make others memorize) items very similar to those presented in this experiment.

The table below shows that the Education (pupils + students) group slightly overtake the professors with regards to success rate but need more time to recall data.

Pupils score lower and spend less time than students (-2'07"). We can reasonably claim that, as the professors are the oldest in the Education group, they potentially know more capitals. Considering the experiment effect, or maybe the short time spent (the least in this group), they score lower of half a point compared to the students. Only differences for professors group are statistically significant.

Table 4. Results for VR 3D vs VR 360 for the Education group.

Type	Total	Sucess rate		Average	Time		Average	Ranking Success
		VR 3D	VR 360		VR 3D	VR 360		
Pupils	48	11.10%	16.00%	13.55%	1’45’’	2’29’’	2’07’’	3
Students	40	31.40%	36.50%	33.95%	4’03’’	4’25’’	4’14’’	**1**
Professors	20	44.20%	20.70%	32.45%	1’35’’	2’06’’	1’51’’	2
		25.60%	**24.70%**	**25.15%**	**2’31’’**	**3’10’’**	**2’51’’**	

Group 2: Others (professionals, retired, unemployed)

The table below shows that the group Others (not connected with education) learn more efficiently when the information is delivered with VR 360, rather than VR 3D, (+10 pts) and spend more time memorizing data in the VR 360 part compared to the other format.

Overall, this group memorizes more capitals (+2.8% success) than the Education group, while spending less time memorizing (-17"). If the pupils are withdrawn from the Education group (youthfulness, lack of experience), the results change. The group Others scores an average rate of success almost identical to the Education 2 group in less time (-1'16").

Unlike the initial assumption, this group is, therefore, more efficient in the learning process and the time spent at the task, than both groups in Education.

Only differences for other groups are statistically significant.

Table 5. Results with VR 3D vs VR 360 for the group Other.

Age group	Number	Success rate		Average	Time		Average
		VR 3D	VR 360		VR 3D	VR 360	
Others	93	28.40%	38.40%	33.40%	1’57’’	3’08’’	2’33’’
Education	108	25.60%	24.70%	25.15%	2’31’’	3’10’’	2’51’’
Education 2 *	60	37.80%	28.60%	33.30%	3’03’’	3’15’’	3’09’

*(w/out pupils)

Conclusion

Age and profession are not factors reducing rote learning when using this type of immersive environments.

The time spent on the task has no direct impact on the memorization process. However, this result must be considered with care, because the older the subject, the more likely does he already know some capitals proposed in the list.

Testing the Hypotheses

Hypothesis 1

Our first hypothesis (H1) postulated that the 3D VR (VR 3D) was more efficient for rote learning than 360° image immersion (VR 360). We assume that 3D VR was more efficient because of a previous study we conducted on perception which proved that this environment was more effective than the other one (Salamin, & Hadorn, 2018).

Indeed, for VR 3D, the structure of the data where country/capital was displayed in such way as to facilitate information filing (spherical map, rotation, positioning of the country, name and capital of the country), therefore improving recall. The graphics proposed was neutral and plain.

The VR 360 experiment proposed a photo of the capital or an outstanding part of this capital (street, ocean, building) and placed both data in an information block displayed as an overprint of the image. The graphics proposed was plain, but the photos, however, comprised more complex elements.

In both cases, the country was displayed in bold, placed above the capital.

For this experiment, concerning the population involved, the facts invalidate hypothesis H1. For all age groups, VR 360 produces results superior to VR 3D with regards to recall, that is 30.8% for VR 360 against 26.9% for VR 3D.

The display aiming at facilitating structured filing of the information to be learned (VR 3D) had no positive influence on the number of capitals recalled.

Immersion in a "realistic" universe, wider in VR 360 than in VR 3D may partly explain this difference. Moreover, the photos proposed in VR 360 were such as to provoke epistemic (knowledge) emotions: interest, surprise, confusion, amazement/admiration [24]. Thus, the photo of the ocean and the various blue tones of the sky used to depict the Tuvalu-Fanafuti pair, may have encourage retention and recalling.

Hypothesis 2

The second hypothesis (H2) postulated that the results obtained in both VR environments would be superior those collected for the experiment with the smartwatch. (comparison small device vs immersive devices). In the survey conducted by our team in 2017, the memorization rate for the capitals presented on paper reached 36.8%, against only 22.6% for the smartwatch [23]. The watch functions (managing sports, health, time) compared to paper (traditional format for learning), as well as the narrow size of the screen, may partly account for this result. We assumed that VR experimentation, more immersive than a smartwatch, will therefore better sustain memorization.

The results obtained by the 2018 research on immersive devices (an average of 28.8% of correct answers) are higher than with the smartwatch (+ 6,2pts), which tend to prove that the immersive experiment may impact this type of learning. Displaying information without a visual referent and the simple see-wipe used on a smartwatch offer insufficient characteristics to encourage memorization.

The VR 3D and VR 360e result is lower than the one obtained when using paper (- 8pts). So far, paper remains the best vector for this type of learning, possibly because of the long-lasting learning habit provided by this format.

Discussion

Voluntary recall of information relies on active mechanisms re-using the initial encoding clues. The more elaborated, organized, structured is the information, the easiest it will become to recall it [6]. Our research unfolds as if the VR experiment (complete immersion, novelty effect, spherical map movement, more abstract evidence than in the other environment) interfered with data memorization.

During informal discussions subsequent to the experiment, some participants mentioned that in the VR 3D, they lacked the mnemotechnical means they usually called upon to integrate this type of information (association of sounds, initials, hidden meanings helping with the memory task: example: Bolivia-Sugar: sugar is common in Bolivia, etc.). They attempted various anchorage means, without success, even when trying to express them explicitly: Bolivia-Sugar: I will memorize this by saying that much sugar can be found in the capital of Bolivia, when the pair country/capital appears on the screen. Some participants even claimed they had the impression that the mnemotechnical-data clue interaction used for memorization vanished when they took off their helmet. The same effect would apply when repeating information in their head (articulatory repetition). They felt as though the data was fading when coming back to physical reality.

Limitation, perspective and conclusion

The main limitation of our study lies in the non-measurement of data persistence. Indeed, if the memorization rate is good at the very moment of the experiment, and not as good three months later, the pedagogical value of the means used, is influenced. In a few weeks we intend to contact again the panel of participants to submit them to the same knowledge test as the one performed in situ. We can then cross these results with the recall rates to complete the already carried out observations and interpretations.

Another limitation concerns the informal discussions with the participants which lacked an accurate protocol and can, therefore, only serve as clues. Lastly, if the data volume (201 participants) offers some interesting information, it is insufficient to generalize obtained results.

The main results hereby presented (better recall rate with VR 360 than VR 3D and the smartwatch, but lower scores than with paper), as well as some suggested reasons (epistemic emotion) lead to interesting research options. As rote memorization depends on a variety of experimental factors (type of device, interest in the task, need to achieve the task, emotions connected with the task, etc.), it is pertinent to refine future experiments to encourage the interaction between emotion-memorization for all four devices considered.

Time spent on the task produces contrasted results and has limited impact on results.

Lastly, this experiment suggested that, different to a persisting assumption, age and belonging to an academic group has little or no impact on the results obtained in virtual environments, ostensibly more familiar and favorable to younger generations.

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