In which way the use of virtual reality increases the efficiency of a learning process ?

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1 Context

Past studies showed that learning and rehabilitation are linked thanks to muscular and memory training in both fields (medical and general). Indeed, learning systems based on immitation enhance motor learning in healthy and disabled individuals [8, 2]. Memory games have proved to be efficient in rehabilitating of brain functions lost in stroke accidents. From a past exprience, we can say patients improved their memory ability unexpectedly while enjoying playing the game.

As we do not have the required medical knowledge, we will demonstrate our statements with casual exercices. These exercises train the same parts of brain and muscles as some rehabilitation trainings Thus we can admit the benefits brought up in the medical field too.

The Virtual Reality (VR) technology is an interactive computer-generated experience taking place in a simulated environment. Nowadays, the VR technology is composed of a head-mounted display and 3D audio headphones. This technology allows a fully immersive experience for the user [18].

Virtual Reality has been commercially available since the late 80's, with the first systems sold by VPL Research. This technology has always evolved through time thanks to better computer technologies and better softwares. This contributed to the "rebirth" of the VR in the late 90's [4] and later in the late 2010's.

With the development of low-cost devices, this rehabilitation can be continued at home, easing the access to these tools, in addition to their ludic and thus motivating properties. Indeed, motivation plays a major role during the learning process, as it helps to get quick and better results [9, 6, 11]. Recent technological advances have led to considerable cost reductions for VR equipments, and several companies are selling headsets that consist of 2 lenses and a place to insert a smartphone for less than \$20 [1]. A relatively lowpriced virtual-reality-based training program would be a more effective and cheaper way to exercise than attending a class in sport center [10]. The democratization of the technology also allows the telerehabilitation [4]. This means a patient can be treated by professionals from all around the world.

Within Medicine, VR has been used in teaching anatomy, training in diagnostic procedures, in rehabilitation, teaching open and minimally-invasive surgery procedures. [4]. Virtual Reality system can provide multimodal stimuli, such as visual and auditory stimuli, and can also be used to evaluate the patient's multimodal integration and to aid rehabilitation of cognitive abilities [3, 14]. VR is similar enough to reality to provide an effective training environment for rehabilitation.

In rehabilitation therapy, where repetitive feedback and motor learning are necessary, a virtual reality system can provide adequate motivation of such a mechanism [10]. In the medical field, VR has been used for the training of surgeons [12] or for the treatment of phobias [14]. The secure environment allows to control the stimuli presented to the patient so he can face his fear gradually [14]. Also, recent reports have described the use of virtual reality (VR) as a method of distraction during procedures such as administering vaccines or drawing blood [1].

In multiple articles we learn that the comparison between rehabilitation with or without VR proved that patients using this technology were more motivated and showed high levels of compliance during the process of rehabilitation [15, 5]. We can also notice that these patients showed better results and progress during these tests [7, 16, 5, 17]. For example, these studies suggests a 5 times higher growth of chances of improvement in motor strength for patients who experienced a stroke after using a VR system [17]. However, there is still work to do because, despite the number of studies about the benefits of VR in medical rehabilitation, and the number of patient who used it, and even the improvement observed, it is still not enough to prove that this method is 100% better than the usual methods [16, 17, 13].

2 Experiment

2.1 Main Goal

This study aims to evaluate the efficiency of VR (Virtual Reality) exercises which require memorization and speed.

Secondly, this study also have the intention of showing the ease of measurement of each parameter using VR technologies.
In order to demonstrate the effectiveness of VR exercises, we evaluate the results of the same exercise with and without VR. The exercise is based on the famous game "Simon". During the experiment we use a physical version of the game and a version created within a VR environment.

2.2 Secondary Goals

We evaluate the efficiency of the exercise in both the short and long term.
Indeed, it is relevant to analyze if the exercise leads to a speed improvement and an enhancement of the memorizing abilities of the test subjects.

In our experiment, the test subjects must repeat the exercise twice in a row and then repeat the exercise two days later at minimum.

We are also evaluating the impact the change in technology may cause. In order to evaluate correctly every aspect mentioned before, we made four groups of 10 test subjects :

Group 1 (named "Physical-Physical") : The test subjects do the physical exercise both times.

Group 2 (named "VR-VR") : The test subjects do the VR exercise both times.

Group 3 (named "Physical-VR) : The test subjects do the physical exercise the first time and then do the VR exercise two days later.

Group 4 (named "VR-Physical) : The test subjects do the VR exercise the first time and then do the physical exercise two days later.

2.3 Simon Game

In the physical version, as can you see in the figure 1 above, we have four different colors, which light one after another, producing a different sound for each color.

The goal for the user is to memorize the order in which the button is lighted, and reproduce it by moving his hand in front of each color (a sensor will detect the hand of the user). After succeeding it, the same sequence will restart, but there will be more buttons's lightning than before. The longer the sequence will grow, the harder the game will be. If the user fails to reproduce the sequence exactly, the game is over.

We developed the same game but in a virtual reality environment, in which the concept is the same and the player uses the controller of the VR-system to select a color.

Figure 1: The Simon game

2.4 Test Subjects

The experiment is conducted on a sample of 40 people. The age of the subjects varies between fifteen years and thirty years.

We don't make any difference between men and women because we treat symptoms and not a disease that could have different effects regarding the sex of the test subject. All of the test subjects don't have neither physical nor mental disability.

2.5 Protocol

2.5.1 Margin of error

Goal
Calculate the margin of error of human measurements using stopwatches.
Initial conditions

- Requires 4 people, 1 to perform the exercise and 3 to measure its speed of execution.

- Needs 3 stopwatches.

Protocol

- A person will repeat a series of 3 colors under the Simon's rules of the game.

- Three people measure the reproduction speed of the player's series.

- The stopwatches are started when the game displays the first color of the sequence and are stopped when the first color of the next sequence is displayed.

- Thanks to an editing software (Adobe Premiere), we measure the time taken by the game to present the sequence to be reproduced and the time taken by the game to restart a sequence of colors after activation of the last color by the player.

- These two values are added together and subtracted from the total measured time to obtain the player's time only. Their standard deviations are then calculated to identify the margin of error of the measurements.

2.5.2 Virtual Reality

Goal
Measure the time taken by a user to complete a game and save the related data.
Initial conditions

- The test subject has not played the game in the last 48 hours.

- A researcher sets up the exercise for the player.

Protocol

- The rules of the game are explained to the player: a sequence of colours will appear; the player will have to reproduce this same sequence without error. If it succeeds, the sequence will be one color longer. The player must go as far as possible in the game without making mistakes.

- A session is composed of a game done by the player and his results saved in a log file.

- The player tests the game once before starting the timed session.

- The player does 2 sessions.

2.5.3 Physics

Goal
Measure the time taken by a user to complete a game and save the related data.
Initial conditions

- The test subject has not played the game in the last 48 hours.

- We need 3 researchers with one stopwatch each. 2 researchers measure the duration of each level, while the other will measure the player's response speed during level 4.

Protocol
Exercice :

- The rules of the game are explained to the player : A sequence of colours will appear; the player will have to reproduce this same sequence without error. If it succeeds, the sequence will be one color longer. The player must go as far as possible in the game without making mistakes.

- A session is composed of a game done by the player and his results saved into a spreadsheet.

- The player tests the game once before starting the timed session.

- The player does 2 sessions.

Total duration of each level :

- The researchers start the stopwatch when the first color appears in the example sequence.

- A "step" is made each time the first color of the example sequence of a level appears.

- When the player loses, the measured data is saved into a spreadsheet.

Player response speed :

- Once the player has reached level 4, the stopwatch is started when the last color disappears in the example sequence.

- A "step" is made each time a color is validated by a player.

- The data is then saved into a spreadsheet.

2.6 Data Analysis

We now analyze the data from all of the tests we run during this experiment, displayed in different kinds of graphics
The box plot graphics, althought based on all of the test subjects, only highlight 50% of them. Those 50% were chosen because they are close to the median value.
Indeed,the two colored boxes represent the interquartile range (or middle 50%), which is a robust statistical dispersion measure, which helps to avoid having too much dispersion when analysing data. Thus, it allows us to get a more representative point of view of the results obtained during our tests.

We begin by looking into the memory performances at different times of the experiment. Indeed, if the training is successful, we should see an improvement in the amount of color the test subject is able to memorize before finishing the

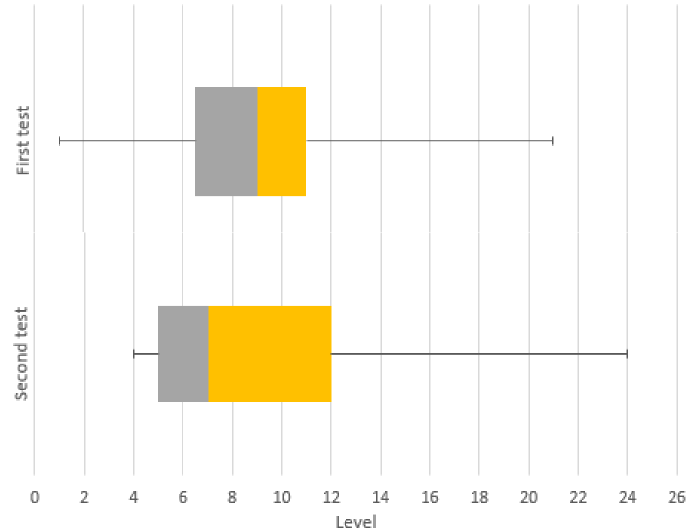

Figure 2: Box plots of the first and second test of the first VR session

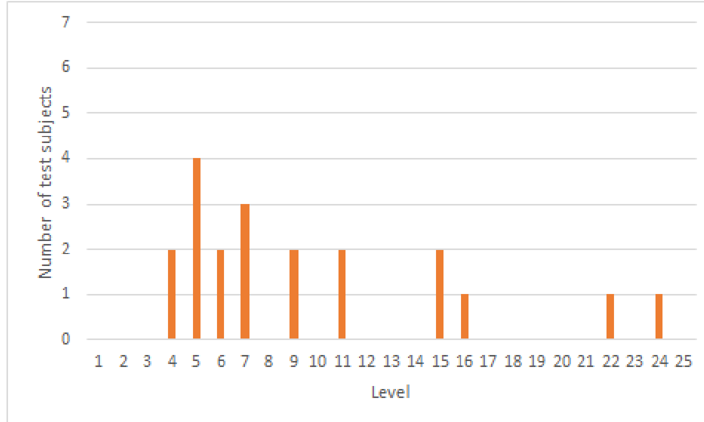

Figure 3: Number of test subjects by levels reached for the first VR session

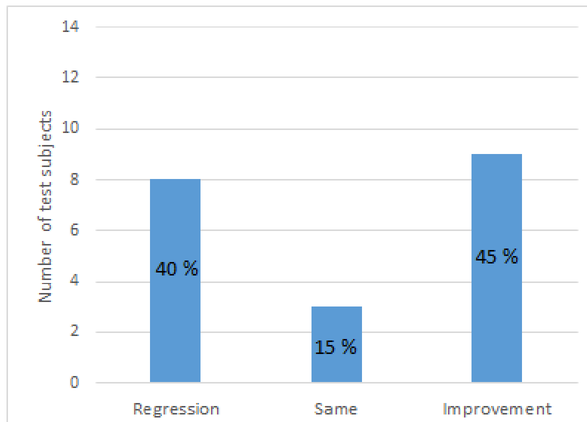

Figure 4: Progession of the test subjects between the two tests for the first VR session

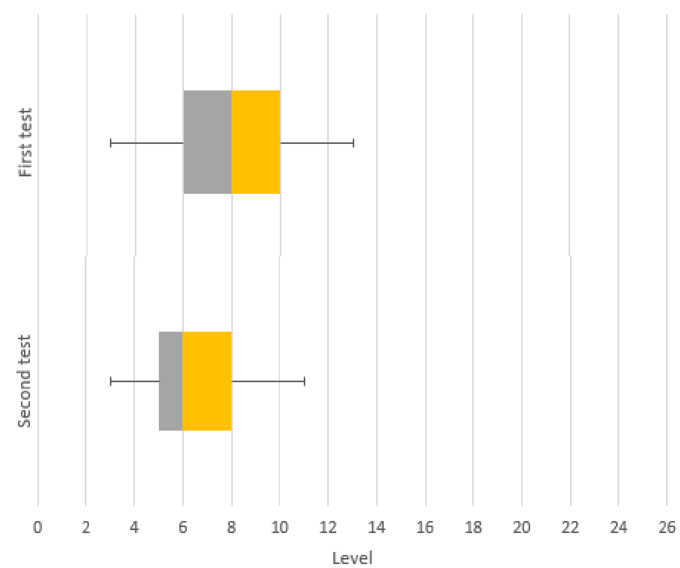

Figure 5: Box plots of the first and second test of the first physical session

game.
First, we analyze the number of colors memorized on the short term, which means during the first session of the experiment (for both VR and Physical game).

This box plot graphic shows us, for each session, the range of levels reached. We see two boxes on each side of the median value of this range.
For the first session the subjects complete between 3 and 13 levels during the game. The median has a value of 8, and 25% of the chosen subjects reach between the 6th and the 8th level while the other 25% reach between the 8th and the 10th level.
During the second session, we see that the range of levels completed is from 3 to 11. The median value is now 6, and while 25% of the subjects complete between the 6th and the 8th level, the other 25% only reached either the 5th or the 6th level.

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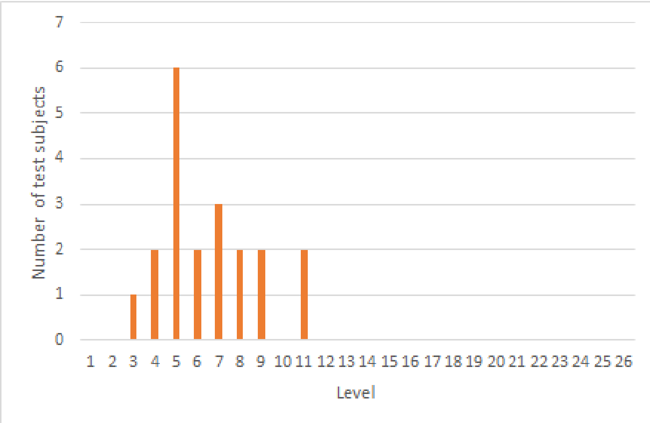

Figure 6: Number of test subjects by levels reached for the first physical session

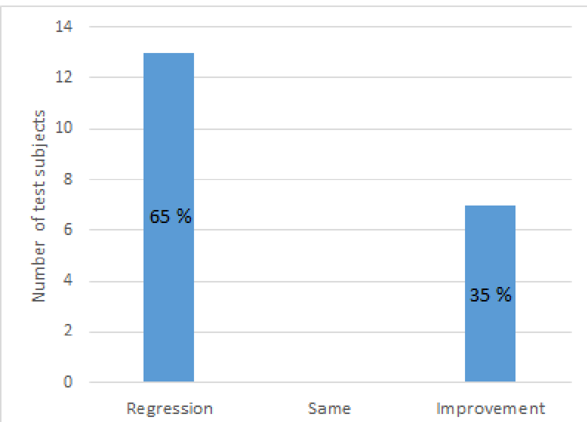

Figure 7: Progession of the test subjects between the two tests for the first physical session

between the 6th and the 8th level, the other 25% only reached either the 5th or the 6th level.

Then, we look into the same data but on the long term : For both session.
Finally, we compare the data for the two different technologies used in order to see which is the best learning technology.

The second part of this analysis will be about the speed of execution.
If the training is successful, we should see an improvement in the test subject's speed of execution of the different exercises.

The training, supposed to be done at home by anyone, should be easy, from the setup of the environment to the actual beggining of the game. We can measure here the time spent on the different interface pannels and how much time the user spends to setup the machine, with the help of our instructions.

2.7 Tools

The Simon game
The Simon game is a memory board game in which the player has to reproduce the order of lights displayed by the game by, in our version, putting his hand over the required color.

Virtual Reality Headset/Controllers (HTC Vive/Oculus Rift)
With these systems, we are able to create a simulated environment we can control and in which the user can interact.

Unity3D
A real-time engine developed by Unity Technologies we used to develop (using the C# language) the 3D environment, allowing user interactions and data analysis.

Blender
A free open-source 3D computer graphics software toolset we used to create 3D model. For example here, we reacreated the shape of the Simon board game.

Timer
Used by the operator to evaluate the time data of the current player.

Paper/Pen
Used by the operator to write down the observed data of the current player.

Statistics Analysis
Used to compile and compare our data.

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