# Normative data for a cognitive VR rehab serious games-based approach

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## ABSTRACT
Acquired brain impairments are responsible for cognitive dysfunctions that affect daily life activities. Promoting cognitive exercise through ecologically-based interactive media such as virtual reality is an emerging option. Although the first step towards ecological ways to stimulate cognitive functions has been given, assessment still relies on non-ecological measures such as pencil-and-paper protocols. We propose that an effective alternative to these traditional evaluation methods is to assess patients while they execute exercises that mimic real-life tasks, such as shopping, dressing, or preparing breakfast. For this, normative data is required. This paper reports a study designed to gather normative data on several daily-life exercises run by a non-clinical sample. The descriptive data on task performance and effects of prior experience with video-games are discussed.

## Keywords
Virtual reality, cognitive rehabilitation, normative data.


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## 1. INTRODUCTION
Acquired brain impairments may result from a myriad of episodes, ranging from infectious diseases (for example, herpetic encephalitis) to traumatic brain injuries (from, e.g., motor vehicle accidents) or even substance abuse (for example, alcohol or heroin). These episodes often impact on cognitive functioning, including on attention, memory, and decision making, compromising the regular performance of daily life activities [1-5]

The most common way to assess such deficits, as well as the impact of training, stimulation and rehabilitation programs, is through paper-and-pencil evaluation measures such as memory and attention tests. However, these tests do not reproduce people’s actual daily tasks. It is quite possible that the validity of their results may be somewhat limited to performance on those specific exercises that appear on the questionnaire, and that the translation of these results to daily life functioning may suffer some level of uncertainty.

Evaluation measures that diagnose and assess the impact of intervention programs in daily life contexts are thus mandatory. A virtual reality (VR) platform where patients could fulfill daily-life activities compromised by cognitive impairments and where, at the same time, data from the performance of such activities could be drawn from would be a viable solution [6].

VR, due to its ability to reproduce several aspects of reality through such characteristics as interactivity and immersion, has been long used as a surrogate of reality to treat anxiety disorders through exposure in a controlled and non-threatening environment, as well as to engage patients with diverse cognitive impairments in pleasing rehab games (for a review of the pros and cons of the use of VR application within the mental and rehab realm see [7,8]). VR seems also to be a viable option to conduct cognitive stimulation exercises on impaired populations [9-13].

Although VR-based solutions are a novel approach, the assessment techniques used in VR-based interventions are still based on "old" traditional pencil-and-paper tests. This is somehow awkward in our view. The ecological and immersive valence of the VR applications finds no correspondence in the paper-and-pencil evaluation context. The common evaluation methods are focused on specific cognitive domains, which do not necessary produce an insight on the ability of participants to maintain a functional daily life. This inability of traditional assessment methods to produce data from which daily life behavior could be inferred has been well described elsewhere [see 14,15].

We argue here that traditional assessment methods should be complemented by approaches able to measure patients' ability to perform real life tasks rather than only improvements in pencil-and-paper exercises, in particular if the choice of cognitive rehabilitation program is a surrogate of a real-life approach, such are VR based programmes. In other words, the assessment strategy should follow the same principles of the rehabilitation programme based on real life activities.

The digital nature of VR applications make it relatively easy to assess what is going on in the virtual world. The system can be programmed to record everything that happens: trajectories, execution times, errors, and indecisions, among many other indicators. The VR environment can be assumed to reflect in a more truthful way the actual obstacles that an impaired individual has to overcome on a daily routine. Improvements on indicators of overcoming these obstacles (e.g. less errors, lower execution times, less indecisions and shorter trajectories) may indicate that the cognitive functions required to perform the required tasks were improved. Although it is not possible to assure the direct translation to a real world situation, improvements on VR tasks that mimic real life are probably more reliable than non-ecologically-based pencil-and-paper test results.

If we assume the above, it becomes necessary, in order to develop reliable measures for VR-based cognitive rehabilitation, to establish standard values from a non-clinical population so that deviations to normal functioning can be assessed. This means that such a platform should compare the performance indicators of cognitively impaired individuals with normative values established with a cognitively normal population (i.e. not impaired by trauma or substance abuse).

Accordingly, this paper reports on a study that represents a first step in this direction, and was designed to produce normative data from several daily life tasks displayed on a VR platform aimed at stimulating cognitively patients with cognitive impairments. This data is automatically recorded on a *.txt file for further analysis and comparisons with clinical samples.

# 2. METHOD

## 2.1 Participants

59 (28 males) participants were recruited from the general population. They were asked to participate in a study designed to evaluate cognitive abilities. The mean age was of 27yrs (*SD* = 10.69) and 69.5% had previous experience in using a PC for gaming purposes. Education levels ranged from 9 years of formal education to post-graduate education, with an average of 13 years of education (*SD* = 2.05).

## 2.2 Measures

The VR application scenario consisted of several daily life activities designed to train cognitive functions. In this study, our intention was to collect normative data concerning the execution in each of the tasks. The dependent variables were based on hit rates and execution time during each of the tasks. A total execution time was also estimated as a global indicator of task performance. These data were automatically saved on a *.txt file for further analysis.

## 2.3 Procedure

The VR platform consisted of a small town populated with digital robots (bots). The town comprised several buildings arranged in eight square blocks, along with a 2-room apartment and a mini-market in its vicinity, where participants were able to move freely around and to grab objects, if they wanted (Figure 1). The platform was developed using Unity 2.5.

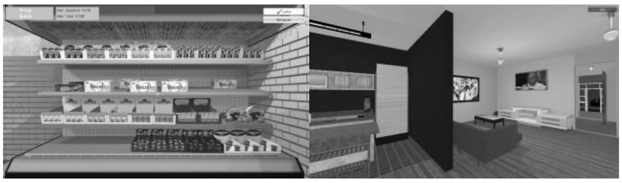

**Figure 1. Two examples of the VR platform. On the left side the market, and on the right side, the apartment.**

Each participant underwent a short training in a 3D scenario in order to ensure a minimum ability to move around and to interact with 3D objects. After this training session, the participant's avatar was spawned in the apartment where it had to complete the following tasks in a sequential order: (1) Wardrobe; (2) Memory game; (3) Virtual Kitchen Test (4) Recall task; (5) Shopping. In the Wardrobe task the participants were instructed to choose 3 pieces of clothing according to male/female gender (shirt, pants and shoes). In the next task, a matching game in which the participants had to complete an 8 fruits matching trial was used to assess memory. The next task consisted of a pre-existing 3D kitchen scenario. The Virtual Kitchen Test involves planning and sequencing different steps in breakfast preparation and the baking of a cake. This task requires that the participant drag sequentially, from a kitchen cabinet, the cake ingredients that are displayed on a list. Following this test, the participants were exposed to an LCD screen in the virtual apartment with 15 video clips of TV news. After a 60-seconds period, they were asked to recall each of the video clips. Once outside the apartment, the avatar had to find its way to the mini-market store where it had to complete a shopping task with a predefined amount of money. In the final task the participants were instructed to buy 7 products (i.e., 1 milk bottle, 1 pack of sugar, 1 bottle of olive oil, 1 package of crackers, 1 bottle of soda, 1 bottle of beer, and 1 can of tuna) with the least possible expense (25€ max). All exercises took place on a HP Intel® Core™2 Quad Processor Q6600 PC equipped with a GeForce GT 220 and a 21'' Asus VE228D screen display (1680 X 1050 pixels of screen resolution).

## 3. RESULTS

Our aim was to identify the normative values in each of the tasks: (1) Wardrobe; (2) Memory game; (3) Virtual Kitchen Test (4) Recall task; (5) Shopping. The first task analyzed was the Wardrobe task, where the participants were instructed to choose 3 pieces of clothing. The average hit rate on this task was 81.4% for 3 corrected pieces. The average execution time was of 0.56s. Only a small percentage of participants failed to achieve the maximum score, namely 15.3% achieved 2 corrected pieces and 3.4% for 1 corrected piece of clothing. In the Memory Game, the average execution time was of 30s in an 8-fruit matching trial. The average number of attempts was 14.79 moves ($SD$ = 2.80; ranged between 10 and 26 moves), whereas a hit rate of 94.5% was found for this task. The Virtual Kitchen Test consisted of two different sub-tests. The first sub-test (breakfast) took on average 13s ($SD$ = 21s), whereas the second sub-test (baking of a cake) was completed in 14s ($SD$ = 11s) with a hit rate of 98.3% in choosing the 5 ingredients. In the recall task, on average the participants correctly recalled 7 of 15 news pieces completed in 15 minutes (including encoding phase). In the shopping task, 58.5% of the participants had accomplished the main goal, which was to spend the least possible money (12.05€). None of the participants spent more than 15€. The execution time in the shopping task ranged from 2 minutes to 14 minutes with an average 6.9 minutes in task completion ($SD$ = 3.90). Moreover, the overall execution time of the aggregated tasks was on average 19.78 minutes ($SD$ = 2.44).

The effect of previous videogame experience on the execution of these tasks was also analyzed through an independent $t$ Student test. The results showed statistically significant differences between the participants with and without previous video-game experience on most of the dependent measures ($p < .05$), as shown in Table 1. No statistically significant effects of age and education were found.

**Table 1. Effects of previous video-game experience on task execution time**

| Measures | With VGE | Without VGE | t-test |
|---|---|---|---|
| Execution(s)-T1 | .78(.54) | 1.56(.83) | -4.23* |
| Hits - T1 | 2.90(.30) | 2.50(.70) | 2.32* |
| Execution(s)-T2 | .29(.74) | .35(.75) | -2.30* |
| Moves-T2 | 14.5(2.16) | 15.5(3.82) | -1.07 |
| Hits-T2 | 7.95(.32) | 8.00(.00) | -.67 |
| Execution(s)-T3a | 8.01(7.48) | 23.00(34.09) | -2.71* |
| Execution(s)-T3b | 11.20(10.06) | 18.00(9.05) | -2.65* |
| Hits-T3b | 5.00(.00) | 4.94(.23) | 1.00 |
| Execution(m)-T4 | 15(.00) | 15(.00) | 0.00 |
| Hits-T4 | 7.50(1.61) | 7.37(1.56) | .30 |
| Spent €-T5 | 12.21(.24) | 12.15(.12) | 1.04 |
| Execution(m)-T5 | 4.50(2.28) | 8.28(3.47) | -4.89* |
| Total time(m) | 23.10(2.11) | 29.12(2.63) | -3.04* |

Legend: * $p < .05$; in brackets (standard deviation); VGE – video-game experience; T1 – Wardrobe task; T2 – Memory game; T3 – Virtual Kitchen Test; T4 – Recall; T5 – Shopping.

## 4. CONCLUSION

The aim of this study was to produce normative data for a variety of indicators from performance on several daily life tasks from a VR-based serious games approach designed to improve specific cognitive abilities and overall functionality in patients with cognitive impairments.

The results of a descriptive analysis showed no floor or ceiling effects in each of the tasks performed, which supports the suitability of the tasks. The lack of education effects on task execution measures are of interest and suggest these exercises are robust measures not affected by education level, which is also the case of validated traditional paper-and-pencil tests [16-19]. On the other hand, the execution of these tasks in a VR setup *is* affected by previous computer experience. Even with an initial session of training, most of the dependent measures were influenced by video-game practice. This result suggests previous video-game experience is an important confounder of task execution in VR-based setups and would suggest a distinction in normative values as a function of video-game practice. This may mean that patients with no video gaming proficiency will need previous training in order to become more skilled when interacting with the computer and the 3D applications. However, this problem will gradually disappear as the older generations will be replaced for younger ones, fully skilled in human computer interaction.

One possible limitation to our results is related to the sample size and characteristics. Although we found no effects of age and education, a larger and more representative sample should be considered for further investigation.

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