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Cognitive Stimulation of Elderly Individuals with Instrumental Virtual Reality-Based Activities of Daily Life: Pre-Post Treatment Study

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Abstract

As the demographic structure in western societies ages, the prevalence and impact of cognitive decline rises. New solutions to tackle this are thus required. The use of ICT-based cognitive exercises has emerged in the last few decades, although with inconsistent results. This paper reports a pre-post treatment study that contributes to this field. We designed a set of virtual reality exercises that mimic activities of daily living, in which the patient can train different cognitive domains. 25 participants aged 65-85 underwent 12 training sessions between a pre and a post assessment. Results on some of the neuropsychological measures show significant increases (in visual memory, attention, and cognitive flexibility scores). Results also suggest that participants with lower baseline cognitive performance levels improved most after these sessions. ▲

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Introduction

As the population ages in developed countries, namely in Europe (in 2030 approximately 25% of EU citizens will be over 65 years old (1)) new challenges arise from the growing burden of age-related conditions and diseases on national health systems and consequent needs to develop better treatments for those conditions. The negative impact of aging on cognitive functioning, which is our focus, is well-known (2).

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Studies testing traditional techniques to improve cognitive functioning have shown some success with therapeutic measures. A systematic review (3) found that cognitive stimulation, particularly in dementia, promotes gains in cognitive function also both general wellbeing and Quality of Life (QoL). Similar results were found in another review (4).

One alternative to traditional strategies and exercises consists in the use of ICT (Information and Communication Technologies) programmes. The evidence to support ICT-based solutions to overcome age-related cognitive decline is, nevertheless, not yet very robust (5): modest improvements were found in studies involving computerized cognitive training (CCT); cognitive domain and design choice were the primary factors behind the efficacy of the specific technique used (6). A set of 7 randomized controlled trial studies (RCTs) tested a variety of techniques to enhance memory, executive reasoning, and processing speed; a meta-analysis of its results showed that cognitive training had some long-lasting effects on performance (7).

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A review of the literature found that only half of the 10 RCTs included showed cognitive improvement, with no visible long-lasting or crossover effects in domain functionality, and concluded that there was no evidence showing structured cognitive interventions to be effective (8). Another systematic review on cognitive and memory training in adults at risk of dementia highlighted some promising results but suggested that more RCTs are required to provide robust support for the success of these techniques (9). Another review highlighted the significant effect of such therapies on working memory, with clearer results in patients with less prior training; importantly, the results show promising effects in the transfer of skills from the training context to everyday living (10). A review devoted specifically to computer-based approaches (11) also found interesting results, but warned against using these solutions outside of a broader

rehabilitation program supervised by specialists. A more positive outlook is presented in a review that concludes that the results of computerized training are at least as effective as traditional solutions, that most of the issues raised when addressing computer-based solutions are not confirmed by the results, and that these solutions provide a swifter and more effortless and effective alternative to traditional approaches (12).▲

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It is now common to find Serious Games (SG) allied to Virtual Reality (VR). These games, while keeping all the properties of their less-serious cousins, are designed not for the entertainment of players, but to produce a positive impact on their mental and physical health (13). VR/SG apps are surrogates of real life environments, providing an ecological validity to assessment and stimulation that is lacking in traditional paper-and-pencil instruments. They also monitor and record participants' performance during the VR activities, providing behavioural indicators to the therapist (14). For a review of the advantages and disadvantages of ICT-based procedures for mental health purposes see (15).

A meta-analysis (16) was conducted specifically on the use of VR as a therapy for adults with brain trauma. The reported outcomes ranged from fully immersive systems to cheap online games or videogames. In before-after comparisons, improvements in balance emerged in four case studies and two small-randomized control trials. Between-group comparisons in these randomized control trials showed no difference between VR and traditional therapy. While the authors found that the VR applications improved cognitive function and participants rated them more positively than traditional techniques, they found no difference in success rate between VR-based and traditional techniques in the experiments studied. A more specific review of VR rehabilitation shows, however, very promising results with this approach, with significant clinical improvements in both memory and attention outcomes (17). A review found a significantly positive effect of these computer solutions, that are evident in the long-term, in cognitive performance and psychological outcomes, but indicated the need for larger samples, quality of life assessment, and longitudinal design (18). These concerns were also voiced in another review (19), which further pointed out the lack of clinical guidelines and standardized treatment protocols, limiting the potential for a broader implementation of these solutions. Most

reviews, however agree on the potential for effective use of VR/SG solutions. Moreover, a comparison between SG/VR and traditional solutions shows better results in the former, with faster and better results of these interventions in cognitive rehabilitation (20).

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In order to provide a structured program for cognitive intervention focusing on the elderly, the current study explored the effects of a cognitive stimulation using VR/SG within a multidomain program that also includes social skills promotion and informatics training for elderly people.

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Methods

Sample

25 participants (21 women) of the Day Care Centre of the Benfica Parish, Lisbon, between the ages of 65 and 74 ($M = 74$; $SD = 5.27$; ranging from 65 to 85 years) were recruited at the Centre and participated in this study. Their average education level was 6 years of school ($SD = 2.42$; ranging from 4 to 12 years). Exclusion criteria were: 1) having been clinically diagnosed with a psychiatric or neurological disorder; 2) a history of alcohol or substance abuse. Two participants were excluded due to depression and one participant due to transient ischemic attack.

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Measures

The neuro/psychological measures used in this study are all well-established measures with good psychometric properties: the Montreal Cognitive Assessment – MoCA (21), used for cognitive screening; the Frontal Assessment Battery – FAB (22), a set of six subtests that assess executive functioning; the Wisconsin Card Sorting Test – WCST (23), commonly used to assess executive functions and cognitive flexibility; the Rey Complex Figure (24), used to assess visuo-constructive abilities and visual memory, and d2 (25), used to measure attention/concentration. Depression and functionality were assessed with self-report scales: The Beck Depression Inventory II - BDI-II (26) for depressive symptoms, and the Everyday Competence Questionnaire (27) for functionality.

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Procedure

This study was carried out between April and June 2017. The participants were selected for cognitive stimulation after enrollment in the multi-domain *Memória Ativa Senior* (MAS)

programme. The MAS is a project of the Psychology Department of the *Junta de Freguesia de Benfica*, (one of 24 civil parishes of Lisbon, Portugal). The MAS has three main activities: 1) Informatics - teaching computer abilities that will allow the participants to earn basic computer skills and use social networks to chat with their relatives; 2) Cognitive Stimulation – promoting cognitive functioning through training in daily life activities in VR/SG based scenarios; 3) Social skills – training skills for recognizing and managing emotions, for communication, and for problem solving.

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After the initial assessment with the neuropsychological measures (2 1-hour sessions), the participants were familiarized with the desktop VR (non-immersive) system during two 20 minutes-sessions. The same system used for training was used for the intervention. A desktop system is better for older patients because due to on average weaker eyesight, they are more prone to cybersickness when using HMD VR headsets. The virtual environments were developed using Unity3d. The application was run on a 15.6'' Asus X555L laptop with 2GB Geforce 920M graphic board. One training scenario consisted of a maze in which the participants had to find their way to the exit, while collecting several items throughout the scenario. In the other scenario, the participants had to navigate a virtual city following directions for specific locations. The cognitive intervention was performed for 12 30-minute sessions twice-weekly. One of two trained psychologists assisted each participant throughout the sessions.

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The cognitive stimulation in the VR environment included several daily life activities designed to train cognitive functions, such as: attention tasks (i.e. select ingredients to bake a cake), working memory tasks (i.e. shopping at a grocery store), auditory memory tasks (i.e. listen and remember news on TV), executive functions (i.e. select the appropriate clothes to wear, arrange shoes in a shoe closet), as shown in Figure 1 – from top-left clockwise, the bathroom, living room in the apartment, virtual kitchen test, shoe closet test, bedroom, outdoor environment, pharmacy, and art gallery test. The level of difficulty within each of the tasks was gradually increased throughout the sessions, so that during the first session the participants had simply to complete a daily hygiene task, and during the last session they had to buy several items at a

grocery store from a list of items for which they had a pre-established amount of money. The detailed description of the intervention protocol is presented in Supplementary Table 1. ▲

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Statistical analysis

To uncover significant changes in actual individual outcomes, we calculated Reliable Change Indices (RCI) individually for each neuropsychological outcome (28). The RCI approach standardizes individual changes according to the standard error of difference, which accounts for test-retest stability in the calculation of a standardized change between test scores (29).

Test-retest scores were then calculated for each neuropsychological variable to estimate the stability over time of each measure used in the calculation of the RCI. This approach was developed as an alternative to the limitations of between-subjects' comparisons, or in situations where it is difficult to match cases with controls in their individual characteristics (30). ▲

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The resulting Z-score in RCI measures the performance of the participant at post-treatment assessment relative to their baseline for each of the outcomes. Accordingly, a change exceeding $Z \pm 1,96$ ($p < 0,05$) reflects a reliable neuropsychological change between test scores for a 95% confidence interval (2,5% a positive direction and 2,5% in a negative direction for a two-tailed test – ($\alpha/2$ at 95% CI). ▲

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The RCI is given by the following expression (26):

$$RC = \frac{x_2 - x_1}{S_{diff}}$$

where x_2 and x_1 are the scores in each neuropsychological measure respectively for post- and pre-treatment assessments, where S_{diff} reflects the standard error of difference for test scores: ▲

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$$S_{diff} = \sqrt{2(S_E)^2}$$

which accounts for the standard error of measurement (S_E): ▲

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$$S_E = S_1 \sqrt{1 - r_{xx}}$$

where the S_1 is the standard deviation at pre-treatment, whereas r_{xx} represents the test-retest reliability.

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The RCIs were calculated individually for each neuropsychological outcome. Finally, and considering the small sample size, the correlations between the RCI and variables such as age, education and global cognitive ability at pre-treatment were estimated with 95% confidence intervals based on 1000 bootstrap samples.

Results

Mean change in each neuropsychological domain for the overall sample

Means and standard deviations were calculated for both the pre-treatment and the post-treatment assessments to provide an understanding of the mean change in the overall sample (Table 1). The change in the mean values for the neuropsychological measures suggested that most of these changes occurred in the expected direction. The mean scores of the screening measures (i.e., Montreal Cognitive Assessment - MoCA and Frontal Assessment Battery – FAB) increased slightly although non-significantly from pre- to post-treatment, specifically in the FAB, where the mean total score changed from a clinical score at pre-treatment to a normative score (i.e. above 15 points) at post-treatment assessment. The differences in all the mean scores were tested with a paired samples *t*-test, which showed significant differences between pre- and post-treatment assessments for the number of perseverative errors of WCST ($t(21) = 2,493$; $p = 0,021$), the score in the memory trial of RCF ($t(22) = -3,991$; $p = 0,001$), error percentage ($t(16) = 3,463$; $p = 0,003$) and concentration index of d2 ($t(16) = -2,926$; $p = 0,010$).

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Test-retest reliability scores

Test-retest was conducted in this sample with a 3-month interval. The same neuropsychological instruments were used in both assessments. The measures used in this study are well-established neuropsychological instruments that have been extensively studied in the geriatric population. Table 1 depicts the test-retest scores (r_{xx}) for our sample. These scores were below acceptable ($< 0,50$) for some neuropsychological dimensions. The significant outcomes had acceptable scores

for test-retest reliability ranging from 0,51 (number of p errors of WCST) to 0,80 (score in memory trial of RCF).

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Reliable Change Index

The RCIs were calculated for the significant outcomes according to statistical approach used to measure change (28). The resulting variables in which the better treatment outcomes were given by a decrease in test scores (i.e. error percentages) were reverse-scored, so that positive scores would describe improvements while negative scores would describe deteriorations.

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Figure 2 shows an asymmetry in the distribution of positive and negative changes across measures, reflecting a higher proportion of positive change across the outcomes of the study. The proportion of positive and negative changes that were unlikely to occur by chance considering the 95% CI is depicted in Table 2. A positive ($Z > 1,96$) and negative ($Z < -1,96$) change exceeding these thresholds in more than 2,5% ($\alpha/2$ for two-tailed predictions) would probably be due to a treatment effect, because only the extreme outcomes were considered a significant change. Table 2 shows that improvements above $Z > 1,96$ were observed in 9% of the sample for WCST (perseverative errors), 22% for the RCF (score in the memory trial), 12% in error percentage, and 13% in concentration index of d2. None of the cases showed a significant negative change in neuropsychological outcomes.

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Correlates of cognitive performance

We also explored whether these improvements were related to individual characteristics as age, education, or general cognitive ability at baseline. Bivariate correlations were used with bootstrap sampling. The results show a significant correlation between the improvements in error percentage d2 and the total score of the MoCA, $r = -0,44$; bootstrapped 95% CI [-0,23, -0,74]; SE = 0.13, which suggests that the magnitude of improvements is highest for individuals with lower levels of cognitive functioning at baseline.

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Discussion

Our study was carried out with elderly participants without a clinical diagnosis of cognitive deficits, to test whether a 3-month cognitive stimulation program would help improve cognitive functioning in this population, which is generally vulnerable to cognitive declines. The results showed statistically significant improvements in attention (d2), visual memory (Rey Complex Figure), and on two indicators of cognitive flexibility (WCST), as shown by group analysis. However, considering the lack of a control group that would allow us to discriminate the effects of confounding variables (e.g., practice effects) on treatment outcomes, we adopted a more conservative statistical approach based on the Reliable Change Index (26), which has been used in a variety of clinical research studies due to its ability to detect how much each individual has changed between pre- and post-treatment assessment, while controlling for standard error of difference between test and retest (29; 30). This change results in a standardized score, in which scores above/below $Z = 1,96$ are less likely to occur by chance (i.e., only in 5% of the sample for a 95% CI). A higher percentage than 2,5% ($\alpha/2$) of improved cases was observed on cognitive flexibility (9%), attention/concentration (12% to 13%) and visual memory (22%). These results show that there were strong improvements in main domains involved in the VR/SG program. The tasks that were used in the cognitive stimulation program are general tasks that mimic daily life activities, not being specific, focused, tasks for any of these domains. However, the specific functions in which significant differences were observed, i.e. attention, memory and cognitive flexibility, are ubiquitous functions in daily activities of everyday, such as shopping at the supermarket, preparing food, choosing the right clothes to wear, etc., which were trained in most of the sessions of this program. Conversely, no significant differences were observed on the screening tests (MoCA and FAB) that assess general functioning, suggesting also that these improvements were restricted to specific domains of cognitive functioning, consistent with the results of recent reviews showing improvements in attention and memory as specific effects of ICT-based interventions (17). This contrasts with a previous study conducted with a similar VR/SG approach but with a clinical sample with cognitive deficits, in which we found significant improvements in executive functioning as assessed with the FAB (31). However, in that study the sample consisted of

patients undergoing community treatment for alcohol use disorder, which has a different pattern of cognitive deficits than the sample in our study. ▲

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The data set was also further explored to determine the relationships between the RCI's and individual characteristics such as age, education, and general cognitive functioning, and the results suggest that the improvements found in attention (through the decreases in error percentage in d2) were negatively associated with general cognitive functioning at baseline. This suggests that if improvements in attention are the main aim, the most efficient use of this program is to target patients showing some signs of cognitive decline. No effects of age or education were found on RCIs within the limited range of both in our sample. ▲

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Our results should be interpreted with some caution given the lack of a control group. We sought to minimize this problem by the transforming the outcomes to RCIs, which is a more conservative approach to the analysis of pre-post treatment effects. This does not allow us to discriminate the practice effects on repeated test scores. We should note, however, that practice effects are more likely to occur in measures that involve problem-solving abilities (32), which was not the case at least for memory and attention, as assessed using the RCF and the d2, respectively. Also, the 3-month test-retest interval probably reduces the practice effects of repeated exposure to these tests. One way of overcoming this limitation would be to use a standard regression-based change score approach from an independent normative group drawn from a different study (33) that would account for practice effects, but there were no data available for most of the tests used in the current study. ▲

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The results found on cognitive flexibility, attention, and memory are consistent with recent reviews (17; 18) and highlight the advantages of using VR/SG for cognitive intervention even with populations that may be less familiar with the use of such technology, such as the elderly, and still has a great room for improvement and increased ecological validity as the technology keeps on progressing.

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Table 1. Descriptive statistics and test-retest scores for the neuropsychological variables

	Pre-treatment		Post-treatment		<i>t</i>	<i>r_{xx}</i>
	<i>M₁</i>	<i>S₁</i>	<i>M₂</i>	<i>S₂</i>		
MoCA	22,88	3,05	23,00	4,00	-0,244	0,79
FAB	14,68	2,28	15,48	1,27	-1,528	0,33
WCST Trials	125,42	7,70	119,83	13,83	1,687	0,36
WCST Errors	57,21	20,19	47,00	21,82	1,762	0,18
WCST P Errors	32,21	20,15	23,87	13,26	2,493*	0,51
WCST Categories	2,96	2,01	3,87	1,76	-1,622	0,35
RCF Copy score	28,88	5,42	28,74	5,16	0,763	0,67
RCF Copy time	5,71	3,07	5,96	3,50	0,775	0,57
RCF Memory score	11,98	5,24	14,98	5,74	-3,991**	0,80
RCF Memory time	3,01	1,77	3,35	1,97	-0,609	0,49
d2 Targets processed	337,95	77,13	316,70	79,63	1,106	0,18
d2 Errors %	14,57	14,42	4,23	5,20	3,463**	0,60
d2 Global performance	286,32	55,72	303,91	66,32	-1,087	0,41
d2 Concentration index	86,84	52,74	118,52	23,67	-2,926*	0,57
ECS	35,20	5,16	33,56	3,35	1,459	0,42
BDI II	10,28	6,31	10,78	8,31	0,048	0,79

Note: *M₁* – Mean values at pre-treatment; *S₁* – Standard deviation at pre-treatment; *M₂* – Mean values at post-treatment; *S₂* – Standard deviation at post-treatment; *r_{xx}* – test-retest reliability; * *p* < 0,05; ** *p* < 0,01. ▲
MoCA – Montreal Cognitive Assessment; FAB – Frontal Assessment Battery; WCST – Wisconsin Card Sorting Test (values are percentages, except the number of categories which is the raw score); WCST P Errors – Perseverative errors in the WCST; RCF – Rey Complex Figure; ECQ – Everyday Competence Questionnaire; BDI-II – Beck Depression Inventory-II. ▲

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Table 2. Reliable Change Index

	(+) change Z > 1,96	(-) change Z < 1,96
WCST P Errors	9	0
RCF Memory score	22	0
d2 Errors %	12	0
d2 Concentration index	13	0

Note: Values are in percentages. WCST P Errors - Perseverative errors in the WCST in percentage; RCF Memory core – Rey Complex Figure Memory trial total score.

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Figure captions

Figure 1. Screenshots depicting some of the tasks used in VR/SG cognitive stimulation

Figure 2. Percentages of cases for positive and negative change (RCI)

Formatada: Inglês (Reino Unido)