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Virtual Reality-Based Cognitive Stimulation to Improve Cognitive Functioning in Community Elderly: A Controlled Study

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Abstract

The advantages of using naturalistic virtual reality (VR) environments based on everyday life tasks for cognitive intervention in the elderly are not yet well understood. The literature suggests that the similarity of such exercises with real life activities may improve generalizability by extending the transfer of gains of training to everyday living. This study aimed to investigate the gains associated with this ecologically-oriented virtual reality cognitive stimulation (VR-CS) versus standard cognitive stimulation in the elderly. Forty-three healthy older adults were divided into two groups: an experimental group underwent a VR-based cognitive stimulation and an active control group underwent a paper-and-pencil cognitive stimulation. The outcomes assessed at the pre-treatment and posttreatment assessment consisted in well-established tests for cognitive and executive functioning, depression, subjective well-being, and functionality. The results showed positive outcomes on dimensions of general cognition, executive functioning, attention, and visual memory in the group that underwent VR-CS. Improvements in executive functioning in this group was supported by consistent evidence of increases in attention abilities but little evidence of increases in memory abilities. Both effects may have contributed to improvements in general cognition. Further studies are needed to test whether these effects may extend to well-being and functionality in cognitively impaired older adults.

Keywords: cognitive stimulation, elderly, serious games, daily life activities

Introduction

An aging population has been a well-established demographic trend in industrialized countries for several decades. Portugal is no exception: the ratio between older adults and young people was 1:1.53 in 2017 compared with 1:0.45 in 1981,[1] a trend that is common to other European countries. This trend places challenges on these countries' health care systems due to increases in age-related disorders. Cognitive decline and impairment are among the disorders most associated with aging,[2] and thus developing cost-effective programs for prevention and treatments of these disorders should be a priority for the health care systems of these countries.

There is evidence that engagement in cognitively stimulating activities increases resilience to cognitive decline during normal aging processes or even prevents pathological aging by reducing the risk of cognitive impairment and dementia.[3] This has motivated researchers to develop cognitive interventions for the elderly with the aim of improving cognitive performance in both normal and pathological aging.[4,5] Such interventions rely on the principles of neuroplasticity, which imply that cognitive stimulation in enriched environments will lead to the structural or functional reorganization of the brain, which in turn is crucial to support the ability to learn new skills and behaviors. Evidence of neuroplasticity following cognitive training has also been found in studies with healthy older adults[5] and individuals with mild cognitive impairment.[6]

The number of cognitive-based interventions has been growing in recent years, supported by consistent evidence from systematic reviews reporting gains in cognitive performance following cognitive training.[7] Such cognitive interventions may be delivered in different formats. Cognitive stimulation or rehabilitation may involve individual or group formats to promote cognitive functioning and socialization in a nonspecific manner, whereas cognitive training is designed to capture specific cognitive functions with systematic training with cognitive exercises.[8]

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Based on these assumptions, the use of technology and virtual reality (VR) may provide several advantages over traditional cognitive interventions, namely treatment flexibility in adapting the exercises according to users' needs and cognitive status.[9] In addition, VR interventions rely mostly on the use of serious games, which may be more motivating to participants.[10] Another important advantage is ecological validity. The similarity of the exercises in virtual environments to actual activities of daily living may increase the likelihood of transfer of the skills learned in training to everyday life.[11] Some authors argue that VR-based interventions relying on functional tasks offer the potential for more effective training given that training is conducted in more naturalistic settings than traditional interventions. This function-led approach[12] for neuropsychological tools may provide advantages over traditional paper-and-pencil approaches by extending the transfer of gains to the performance of activities of daily living.[13,14]

A systematic review on the use of computerized or VR-based cognitive training (CCT) in older adults without cognitive deficits suggests comparable and better improvements at postassessment for CCT interventions in comparison to traditional interventions or video game interventions.[10] Median pre/post training effect size were reported in this study for intervention in memory, working memory, visuospatial abilities, and processing speed, with memory being the most consistent improvement across studies, while effect size was larger for processing speed. It has been found also that in older adults at high risk of cognitive decline, along with improvements in executive functioning, attention and memory (visual and verbal), improvements in anxiety and depressive symptoms have also been reported.[9] A subsequent meta-analysis on CCT in clinical population of older adults with mild cognitive impairment or dementia reported small-to-moderate effects on global cognition and specific cognitive functions such as attention, memory, or executive function as working memory,[15] effects that may be due to an increase in hippocampal connectivity, although a more complete understanding of the underlying mechanisms of effects on cognition is still lacking.[16]

A comprehensive meta-analysis providing moderators of CCT efficacy on overall cognition determined that dosage (less or equal to 20 hours vs. more than 20 hours), session length (30 vs. 31–60 minutes or more than 60 minutes), or training frequency (one session/week vs. two to three sessions/week) provided significant but similar effects on overall efficacy of training. On the other hand, home-based cognitive training with limited clinical guidance or trainings with more than three sessions/week did not provide any significant outcomes on overall cognition.[17] Furthermore, there is also agreement that multidomain training may be more effective in improving neuroplasticity mechanisms.[16]

A more recent meta-analysis assessing immediate and long-term effects of CCT on cognition and executive functions determined large improvements in trained cognitive domains related to executive functions following CCT, whereas small near-transfer (i.e., effects on untrained tasks from same trained domain) and far-transfer (i.e., effects on untrained tasks from untrained cognitive domains) outcomes.[18]

A lack of clinical guidelines and standardized treatment protocols may limit the potential for a broader implementation of these solutions,[19] along with the need for further studies to include functional and quality-of-life measures to assess whether gains of training extend beyond cognitive functioning to everyday life.[9]

In this study, we wanted to combine the benefits of approaches based on cognitive training (i.e., standard systematic training) with those of cognitive stimulation (i.e., group training while promoting socialization and overall adjustment) in a mixed-multidomain CCT approach consisting in VR. Thus, a group consisted of virtual reality cognitive stimulation (VR-CS) based on the Systemic Lisbon Battery (SLB), which consists of a multidomain set of VR functional tasks describing activities of daily living that were conducted in group sessions for cognitive stimulation, in which the content and perceptions about each task and its outcomes were discussed during the sessions. We compared this group with a control group consisting in paper-and-pencil cognitive stimulation (PP-CS) that followed a similar format, but the sessions were prepared using paper-and-pencil materials. This study was conducted in an A-B design using measures related to global cognition, executive functions, attention, memory, self-reported depression and satisfaction with life, and functionality. Given the function-led approach of the VR-CS, we expected larger improvements in this group, mostly at the level of executive functioning.

Methods

Participants and procedure

This study was approved by an Ethics Committee of the Host Institution of this study. Fifty participants were recruited at a daycare center in Lisbon, Portugal, where they had enrolled for a local multidomain program targeting social isolation and cognitive decline in the elderly with social activities, use of Internet and social media, and cognitive training. The inclusion criteria for recruitment were: (1) being above 65 years of age; (2) being able to read or speak fluently in Portuguese, and (3) without language deficits. After providing informed consent, participants underwent two 1-hour neuropsychological assessment sessions during the first week of study. In the second week of study, they were divided in two different groups: one group received Cognitive Stimulation using VR (VR-CS), and one group received PP-CS. We also included participants in the program irrespective of their psychiatric or neurological history, so as not to deprive these patients of the treatment program, but participants were excluded from the analyses if they had a history of neurological or psychiatric disorders, or if they reported severe depression in the self-reports. Seven patients were excluded from this study. The final sample for the study included 43 of the 50 participants in the program (34 female), between 67 and 87 years of age (mean [M] = 75 years; standard deviation [SD] = 5.43 years).

The session plan was similar in the experimental and control conditions. The exercises planned for each session were matched to target the same cognitive domain in both conditions. The VR-CS used the SLB, which consists of a set of tests designed to train and/or measure different cognitive domains. The PP-CS intervention was conducted using traditional paper-and-pencil materials for cognitive stimulation.

Both conditions were matched for the dose of cognitive intervention through the total number of hours of cognitive intervention, but with different frequency of sessions/week. In the VR-CS group, participants underwent two 30-minute sessions per week over a period of 6 weeks, whereas in the PP-CS group participants underwent one 60-minute session per week over the same period of 6 weeks. Training frequency either in VR-CS and PP-CS was kept at levels producing statistically significant effects on cognition outcomes. As shown in a previous meta-analysis, training frequency of either one session/week or two to three sessions/week produced similar estimates (i.e., medium effects) in training outcomes.[17]

The initial session in the VR-CS groups was preceded by a short training with the computer mouse. Interaction in the SLB was done exclusively with the mouse. Two trained psychologists assisted each participant throughout the sessions (one for each condition).

The SLB consists of a virtual environment depicting a city in which participants must accomplish different daily life tasks. These tasks were designed to involve different 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. 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 available a pre-established amount of money. The same rationale was used for the PP-CS group, which followed a systematic and gradual approach, by engaging in traditional cognitive stimulation tasks, based on a collection of standard exercises.

Participants underwent a postintervention assessment in the week following the completion of the intervention.

Measures

The main focus of this study was at the level of cognitive functioning, including global and domain-specific. The Montreal Cognitive Assessment (MoCA)[20] is widely used as a cognitive screening test and has been validated for the Portuguese population,[21] thus providing normative scores according to age and education. The cutoffs for cognitive deficits were set at 1SD below the mean normative score considering age and education. These authors provide both the cutoffs for clinical samples to detect mild cognitive impairment or major neurocognitive disorders, as well as the cutoffs based on the normative scores that may be used as cutoffs for cognitive deficits being stratified by age and education. The cutoffs of 1SD, 1.5SD, and 2SD from the mean normative scores are provided in this article.[21] Considering that we were not seeking to compare clinical and nonclinical scores, but only cognitive performance between participants with higher and lower cognitive skills so as to obtain well-balanced groups below/above cutoffs, the less conservative level (1SD) was chosen for this analysis.

The Frontal Assessment Battery (FAB)[22] is a brief test to assess executive functions that has been validated for the Portuguese population,[23] thus also offering normative scores. The same rule was followed for the FAB total score, with cutoffs for executive dysfunction being set at 1SD below the mean normative score considering age and education. Memory was assessed using the Wechsler Memory Scale-Revised—WMS-R,[24] which allows a brief assessment of memory ability. This test is scored in a General Memory Index, which results from each individual subtest.

We also used two domain-specific cognitive function tests: the Rey Complex Figure (RCF) test and the d2 test. The Rey Complex Figure[25] was used to assess visuoconstructive abilities and visual memory, whereas the d2 was used to measure attention/concentration.[26] The performance in this test is assessed according to the total number of characters processed (TC), total number of hits (TH), processing efficiency (PE), concentration index (CI), variability index (VI), and error percentage (E%).

Psychological adjustment was evaluated with the Geriatric Depression Scale-15 (GDS-15)[27] and the Satisfaction with Life Scale (SWLS), translated and adapted to Portuguese[28] with the following cutoffs: 0 to 5: absence of depressive symptomatology; 6 to 10: mild depressive symptomatology; and 11 to 15: severe depressive symptomatology. The five-item SWLS was used to assess subjective well-being.[29] Finally, functionality was evaluated with the Lawton Instrumental Activities of Daily Living Scale (IADL),[30] and the Portuguese validated version was used.[31]

FIG. 1. SLB cognitive stimulation tasks. The *upper row* depicts tasks in the virtual apartment (from *left* to *right*—General view of the apartment, bathroom, wardrobe, and shoe closet tasks), whereas the *bottom row* depicts tasks outside the virtual apartment (from *left* to *right*—virtual city, grocery store, pharmacy, and the art gallery task). SLB, Systemic Lisbon Battery.

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Table 1. Neuropsychological Outcomes for Virtual Reality Cognitive Stimulation vs. Paper-and-Pencil Cognitive Stimulation

		VR-CS		*PP-CS*	
		M	*SD*	*M*	*SD*
RCF copy trial score	Pre	26.55	5.33	25.50	3.99
	Post	29.45	4.90	27.67	3.09
RCF copy trial ET	Pre	4.34	2.63	4.65	1.06
	Post	3.92	1.61	4.12	0.72
RCF memory trial score	Pre	**11.59**	**5.38**	12.92	6.38
	Post	**15.50**	**6.14**	11.17	9.05
RCF memory trial ET	Pre	**1.57**	**0.68**	**2.04**	**0.77**
	Post	**2.76**	**1.20**	**4.38**	**4.04**
WMS-R	Pre	**51.79**	**8.98**	**43.08**	**10.92**
	Post	**53.36**	**9.76**	**49.67**	**10.21**
d2 TC	Pre	**290.00**	**110.83**	320.90	147.44
	Post	**322.82**	**101.08**	307.90	156.40
d2 TH	Pre	**100.77**	**38.40**	122.00	95.47
	Post	**118.05**	**33.52**	108.80	64.93
d2 PE	Pre	**264.32**	**100.46**	285.60	139.82
	Post	**296.86**	**94.72**	279.70	156.63
d2 CI	Pre	**95.64**	**41.19**	115.10	97.65
	Post	**110.27**	**39.12**	98.30	72.28
d2 VI	Pre	15.32	6.10	16.30	9.70
	Post	15.41	5.39	12.50	3.75
d2 E%	Pre	8.61	8.09	11.89	10.79
	Post	8.29	6,88	10.75	8.67
GDS15	Pre	3.23	2.76	4.64	4.03
	Post	3.81	3.09	3.71	4.16
SWLS	Pre	24.29	6.67	27.17	4.57
	Post	22.95	7.37	25.58	6.59
IADL	Pre	8.32	0.75	8.50	0.94
	Post	8.76	2.07	8.71	1.14

Bold comparisons are $p < 0.05$.
d2, d2 attention test total number of characters processed (TC), total number of hits (TH), processing efficiency (PE), concentration index (CI), variability index (VI), and error percentage (E%); ET, execution time; GDS15, Geriatric Depression Scale 15; IADL, Instrumental Activities of Daily Living Scale; PP-CS, paper-and-pencil cognitive stimulation; RCF, Rey Complex Figure execution time (minutes); SD, standard deviation; SWLS, Satisfaction with Life Scale; VR-CS, virtual reality cognitive stimulation; WMS-R, Wechsler Memory Scale-Revised.

Statistical analyses

The total scores on MoCA and FAB were recoded to dichotomous variables (0 = below the cutoff vs. 1 = above the cutoff), which allows us to calculate the relative benefit (RB) and the odds ratio (OR) associated with intervention/treatment. The RB and OR are effect measures that are used to understand the impact of a given treatment compared with standard treatment or control condition. The proportions for these variables at pretreatment versus posttreatment were tested with chi-square tests for each intervention condition (new treatment VR-CS vs. standard treatment PP-CS) as in self-reported depression. The other interval data were tested with repeated measures ANOVAs using the intervention group (VR-CS vs. PP-CS) as factor.

Results

Psychological adjustment

Depression scores were categorized according to the cutoff for absence of depression (0–5), mild depression (6–10), and severe depression (11–15). There were no differences between intervention groups in depressive symptomatology; the comparisons between pre- and posttreatment assessments showed no statistically significant differences for depression in either group ($p > 0.05$). The same trend was found for the perceived well-being as measured by SWLS. We thus did not consider these as confounders in further analysis (Table 1).

Effect measures on general cognition and executive functioning

The data were first categorized in two new variables for global cognition (MoCA) and executive functions (FAB) according to the cutoffs provided for the Portuguese population. The cutoff for the FAB was defined for 1SD scores below the mean of the normative score given age and education.[23] The cutoff for the MoCA was defined according to the same criterion.[31] The scores below the cutoff were classified as scores describing poorer cognitive/executive function.

The data for these groups were used to calculate the RB of the new treatment (VR-CS) versus standard treatment (PP-CS) for both domains. For global cognition, (MoCA) the RB = 1.14 and the OR = 2.71 suggest that the VR-CS was better than PP-CS in 14% for improving global cognition. For executive functioning, the RB = 1.13 suggested an improvement of 13% for VR-CS (OR = 1.68). A significant increase was found at the posttreatment for the VR-CS group in the proportion above the cutoff for the MoCA [$X^2(1) = 4.627$; $p = 0.031$] and FAB [$X^2(1) = 8.622$; $p = 0.003$] compared with the PP-CS group (Figs. 2 and 3).

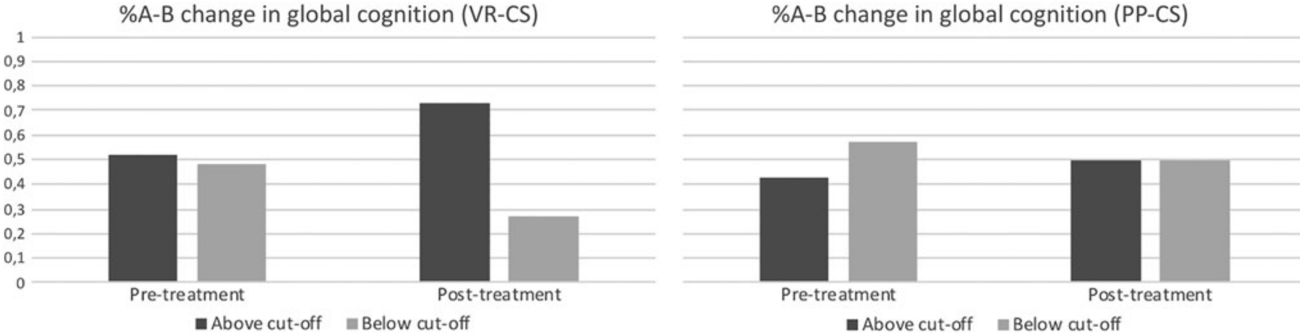

FIG. 2. Proportions of cases above/below the thresholds for the MoCA. MoCA, Montreal Cognitive Assessment.

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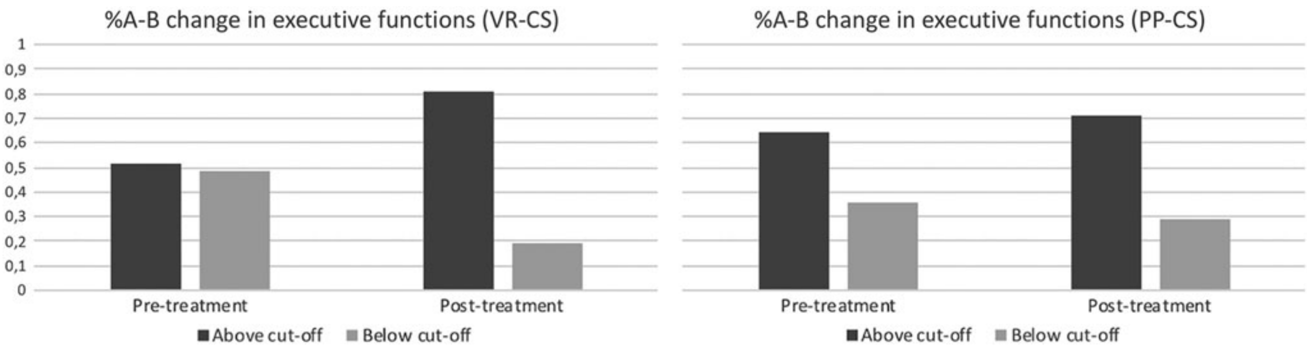

FIG. 3. Proportions of cases above/below the thresholds for the FAB. FAB, Frontal Assessment Battery.

Comparisons between pre- and posttreatment for specific cognitive tests, functionality, and subjective well-being

The effects of the treatment on the scores of the specific cognitive tests for attention and memory were tested using repeated measures ANOVAs. These ANOVAs showed a statistically significant main effect in the scores of the WMS-R for general memory [$F(1, 18) = 7.050$; $Eta^2_p = 0.281$; $p = 0.016$], suggesting an improvement throughout the study. As for the score in the memory trial of RCF, a significant interaction effect was found [$F(1, 30) = 4.574$; $Eta^2_p = 0.234$; $p = 0.049$], indicating an improvement only in the VR-CS group (simple effects analysis). However, a main effect was observed also for execution time in the RCF for visual memory [$F(1, 13) = 6.441$; $Eta^2_p = 0.331$; $p = 0.025$] but suggesting an increase in execution time from pre- to post-treatment assessment in both groups.

As for attention, the ANOVAs on the d2 indices showed statistically significant interaction effects in four indices of the d2 test, namely for d2 TC [$F(1, 30) = 4.401$; $Eta^2_p = 0.128$; $p = 0.044$], d2 TH [$F(1, 30) = 4.480$; $Eta^2_p = 0.130$; $p = 0.043$], and d2 PE [$F(1, 30) = 4.591$; $Eta^2_p = 0.133$; $p = 0.040$], and d2 CI [$F(1, 30) = 4.443$; $Eta^2_p = 0.129$; $p = 0.044$]. These effects were explored with simple effects, which showed a similar pattern for each of these indices, revealing a significant improvement from pre- to posttreatment assessment only in the VR-CS group ($p < 0.05$), as shown in Figure 4.

No significant improvements were obtained for functionality or subjective well-being.

Discussion

The main aim of this study was to assess whether a VR-CS intervention using exercises in functional tasks offers advantages in effectiveness over traditional cognitive interventions using paper-and-pencil materials. We also wanted to test whether the benefits associated with this VR-based approach extended to general improvements in cognition

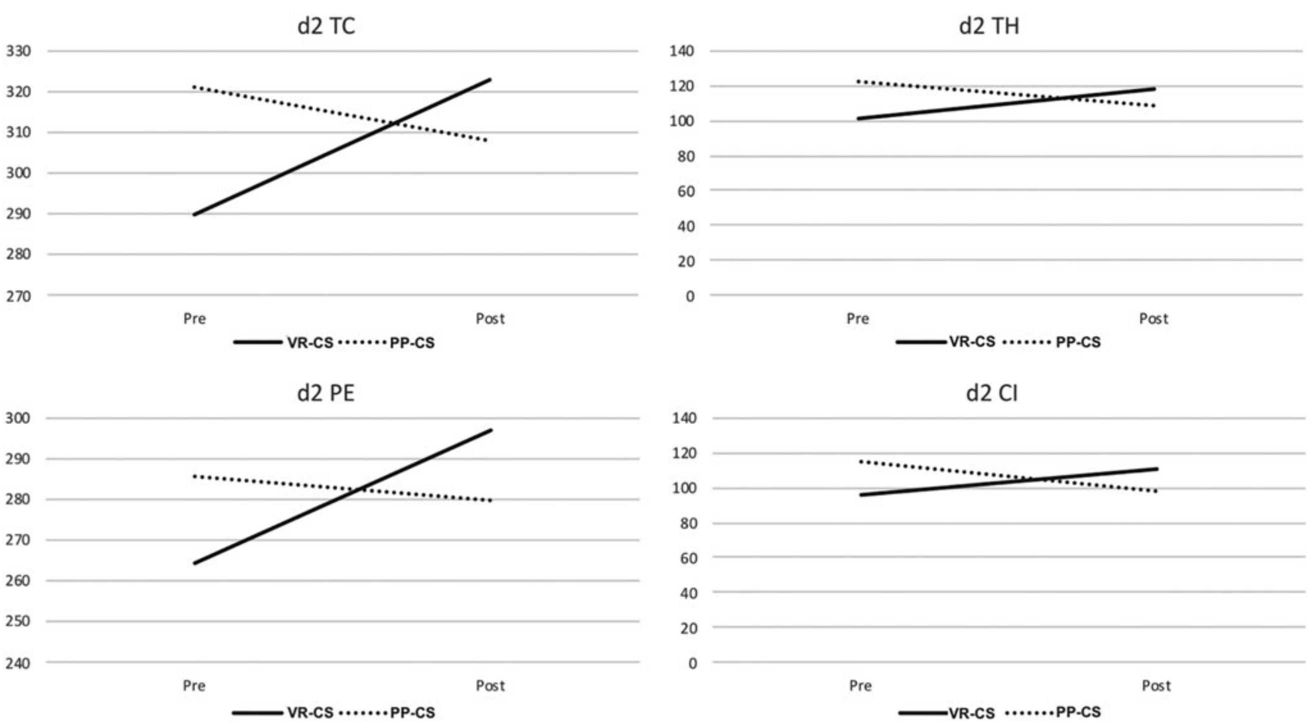

FIG. 4. Interaction effects in the ANOVA for the d2 attention test.

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and psychological adjustment, or were restricted to specific cognitive domains as targeted in traditional cognitive training approaches.

We expected that the multidomain tasks involved in the VR-CS would train a diversity of executive skills, such as planning, sequencing, attention, or working memory, providing significantly better improvements in executive functioning, functionality, and psychological outcomes for subjective well-being compared with the improvements obtained with a traditional cognitive stimulation approach.

Our results indicated larger effects of the VR-CS intervention than of the traditional approach on general cognition and executive functions: improvements on general cognition were $\sim$3 times (OR = 2.71) and on executive functions $\sim$2 times (OR = 1.68) as likely to occur following VR-CS than PP-CS. These results were accompanied by consistent evidence of improvements in attention skills as assessed with the d2 attention test. A less consistent result was obtained for memory, indicating a specific effect of VR-CS intervention on visual memory assessed with the RCF.

These results replicate findings of a previous study using the SLB in healthy older adults, which found specific improvements in executive functioning and visual memory.[14] This is consistent also with findings from recent studies that highlight the benefits of CCT at the level of executive functions,[18] although this finding is yet to be demonstrated.[17] The virtual exercises used in the SLB reproduce activities of daily living (ADLs), which require the use of cognitive processes in much the same way as they operate in naturalistic contexts.[12] Additionally, the similarity between the exercises used in training and real-life tasks may have also increased the likelihood of generalizability and transfer of gains to ADLs.[11]

The skills trained with the SLB were mainly related to general cognition and skills involving the frontal lobe, such as attention/concentration or executive functions—for example planning or working memory. It is possible that such an approach involves more effectively the functional aspects of cognition and executive functions, and this could be the crucial aspect that differentiates this intervention from most CCT interventions. In fact, a meta-analysis of the effects of CCT found no effects of training on executive functioning,[17] whereas the effects of the intervention using the SLB at the level of executive functions may be supported by this function-led approach.

Improvements in general functionality were also expected in the VR-CS group due to the similarity between training and everyday activities promoting independence and autonomy. The fact that we did not find these improvements in functionality was probably due to ceiling effects in functionality at baseline.

General improvements in memory were also found for both VR-CS and PP-CS groups, which suggest also a positive role of traditional cognitive stimulation in improving memory abilities. There is evidence in the literature that such effects of cognitive stimulation may extend to overall adjustment and well-being in older adults with dementia,[32] but that was not the case of our study, probably since our sample comprised healthy old adults with less room for improvements.

However, there are some issues that may limit these conclusions. One important aspect was that training frequency was higher in VR-CS that received training in two sessions/week, whereas PP-CS training was conducted in one session/week. However, it is unlikely that such difference produced distinguishable outcomes, because as suggested in a prior meta-analysis,[17] training plans consisting of one session/week or two to three sessions/week yield similar estimates for the outcomes. Despite these differences in training frequency, the number of contact hours (dose) was matched between these groups.

Another limitation concerns the disparity in group sizes, which may have also impacted the statistical analysis. However, most of these conclusions were also drawn from effect measures (OR and RB), in which sensitivity is not directly affected by the number of cases in the analysis as in null-hypothesis statistical testing.

Overall, these results suggest positive outcomes of VR-CS on general cognition, executive functioning, attention, and visual memory. These findings suggest that VR-CS interventions may be more appropriate to improve executive functioning, supported by improvements in attention and memory abilities, while these effects may also extend to general cognition. Nevertheless, such improvements did not impact on perceptions of independence in daily living activities and subjective well-being. Further studies are needed with clinical samples of older adults to explore whether VR-CS can also provide an effective contribution to functionality and well-being and whether the gains in global cognition and executive functions remain stable at follow-up assessments.

Author Disclosure Statement

No competing financial interests exist.

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