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The Impact of a cognitive training program using Virtual Reality in young adults with Intellectual Disability: Pilot Study

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Dissertação apresentada para cumprimento dos requisitos necessários à obtenção do grau de Mestre em **Terapia Ocupacional**/Área de Especialização em **Pediatria** pela Escola Superior de Saúde do Instituto Politécnico do Porto.

This study was carried out within the scope of a broader project, called "Virtualiza-te", which received financial support from the Instituto Nacional para a Reabilitação (INR, I.P.), based on the "Financing Program for projects by INR, I.P. for Non-Governmental Organizations of People with Disabilities", granting the necessary resources to conduct the research.

Resumo

Indivíduos com incapacidade intelectual apresentam atraso persistente no desenvolvimento das funções executivas. A realidade virtual é cada vez mais uma ferramenta de intervenção cognitiva e tem demonstrado eficácia nesta área. Esta dissertação tem como objetivo investigar o impacto do treinamento cognitivo baseado em Realidade Virtual Imersiva nas funções executivas, como memória de trabalho, atenção sustentada e controlo inibitório em adultos jovens com Deficiência Intelectual. Trata-se de um estudo quasi-experimental do tipo pré-teste-pós-teste de grupo único e pré-teste duplo (O1 O2 X O3). Os participantes (N=15) completaram 24 sessões utilizando jogos baseados em realidade virtual do programa Enhance VR. A intervenção incluiu 3 jogos: Whack-a-mole, React e Memory Wall. Os participantes foram submetidos a avaliações pré e pós-intervenção utilizando o E-Prime® 3.0 da Psychology Software Tools (Corsi Block-Tapping Task; Stop Signal Task; Simple Reaction Time). Os resultados demonstraram que houve melhorias significativas nos resultados da memória de trabalho (p=0,001) e do controlo inibitório (p=0,043), sendo também significativo o valor da interação entre intervenção com o tempo (p=0,010). Enquanto que para a atenção sustentada não foi considerado estatisticamente significativo. De acordo com estas descobertas, as intervenções de jogos sérios baseadas em VR (Enhance-Virtuleap) podem ser valiosas para estimular funções executivas em indivíduos com incapacidade intelectual.

Palavras-chave: incapacidade intelectual; realidade virtual; treino cognitivo; jogos sérios; funções executivas

Abstract

Individuals with intellectual disability have a persistent delay in the development of executive functions. Virtual reality is increasingly a cognitive intervention tool and has demonstrated effectiveness in this area. This dissertation aims to investigate the impact of cognitive training based on Immersive Virtual Reality on executive functions, such as working memory, sustained attention and inhibitory control in young adults with Intellectual Disability. A quasi-experimental study with a one-group pretest-posttest design and double pretest (O1 O2 X O3) was conducted. The participants (N=15) completed 24 sessions using virtual reality-based games from the Enhance VR program. The intervention included 3 games: Whack-a-mole, React and Memory Wall. The participants underwent pre and post-intervention evaluations using the E-Prime® 3.0 from Psychology Software Tools (Corsi Block-Tapping Task; Stop Signal Task; Simple Reaction Time). The results demonstrated that there was a significant improvement in the results of working memory (p=0.001) and inhibitory control (p=0.043), and the value of the interaction between intervention and time was also significant (p =0.010) while the sustained attention was not found to be statistically significant. According to these findings, VR-based serious game interventions (Enhance-Virtuleap) may be valuable for stimulating executive functions in individuals with intellectual disabilities.

Keywords: intellectual disability; virtual reality; cognitive training; serious games; executive functions

Índice

1. Introduction

Neurodevelopmental disorders are neurobiological alterations in typical child development that usually manifest themselves in early childhood and can affect personal, social, academic and professional functioning (1, 2). Intellectual disability (ID) is one of these neurodevelopment disorders, characterized by the presence of intellectual, functional and adaptive deficits in the conceptual, social, and practical domains (2). ID is a clinical condition that manifests itself during the developmental period and generally persists throughout the person's life (1). The etiology may be multicausal due to biomedical, social, behavioral, educational factors that interact over time and may happen due to prenatal, perinatal or postnatal causes (3). Depending on the causes and surrounding components, different levels of severity of ID will emerge, these being mild, moderate, severe and profound that emerge from different levels of cognitive and adaptive impairment (2). Intellectual disability is often associated with other developmental disorders such as Cerebral Palsy, Autism Spectrum Disorder, Down Syndrome, Fragile X Syndrome, among other syndromes (4).

Difficulties experienced by individuals with ID can be explained by several factors, such as difficulty concentrating on relevant stimuli, processing information, memorization, or self-regulation. In this sense, cognitive and adaptive behavior deficits create obstacles to acquiring and developing sociocultural standards, compromising autonomy and independence in one or more aspects of daily life (2, 3, 5–7).

Prior research suggests that there is a persistent delay in the development of Executive Functions (EFs) and that the rate of acquisition is slower for individuals with ID (8, 9). EF refers to a set of higher-order cognitive mechanisms responsible for planning, organizing and executing our actions in the most appropriate way to achieve a specific purpose (10–14). EFs include several domains, such as working memory, processing speed, attentional control, planning, inhibitory control, solving problems that require decision-making processes for the selection of a functional response, and cognitive flexibility as a response to environmental contingencies (11–13, 15–17). Other investigations, such as the one carried out by Menghini et al. (2010) report that individuals with ID often have deficits in working memory, inhibitory control and verbal fluency, Danielsson et al. (2010) report deficits in cognitive planning, Hooper et al. (2018) report in processing speed, and Lanfranchi et al. (2010) report in attention and shifting/cognitive flexibility (9, 11, 18, 19).

EFs are extremely important, as they allow maintaining and manipulating information, ignoring distracting stimuli to maintain focus and inhibiting automatic responses, allowing a considered and non-impulsive response (19, 20). Visuospatial short-term memory is widely recognized as an essential component of the working memory system, playing a fundamental role in supporting diverse cognitive functions (21). Sustained attention allows the individual to interact effectively with the environment, paying attention to repeated stimuli that appear over some time (22). Inhibitory control allows you to control impulsive responses and is extremely important for cognitive aspects and adaptive behavior (23). As the EFs fit into the regulatory aspects of cognition, deficits in their functioning will influence the ability to face the intellectual challenges necessary for autonomy in daily activities (24).

Cognitive Training (CT) is an essential therapeutic intervention for individuals with ID, which is used to improve cognitive functions or delay the decline of executive functions, such as memory, attention, processing speed and contextual learning (25-27). In the traditional CT, several activities can be used in the sessions, such as reminiscence dynamics, attention and memory tasks (e.g., word and number games, categorizing objects), orientation tasks, discussion of topics of interest and using money (28, 29). However, through traditional cognitive interventions, individuals do not often receive real-time feedback, making it more difficult to reinforce progress and motivation during intervention (27).

New technologies, allow more innovative interventions, which has led to an increase in the number of professionals that resort to new technological tools (30, 31). Among these, Computerized Cognitive Training (CCT) can be used for cognitive training of specific functions, making it possible to adapt the exercises to the individual's performance, which has an advantage over paper and pen formats. However, the lack of ecological validity in the screen-based CCT can make it difficult to transfer the acquisitions into individuals' daily lives (32).

The use of Virtual Reality (VR) has grown in the scientific community, as it is increasingly used as a research tool in neuroscience and intervention. It has demonstrated effectiveness in the face of various deficits, including intervention in the cognitive area (15, 25, 31-37).

VR is, therefore, a technology with many interactive possibilities, especially in an immersive approach. Thus, in immersive VR (IVR) systems, a head-mounted display with integrated head-tracking is used, which allows interaction in the environment according to the user's movement, including a sensorimotor system, generating the idea of embodiment in a virtual body (32). Thus, this technology presents many advantages for its users. IVR is a non-invasive technology, where environmental scenarios are produced with a high degree of control, it provides several multisensory experiences in real-time, making it an ecologically valid tool (32, 38, 39). Being a safe environment, IVR allows patients to accept and face challenges better, practicing skills more calmly, as they feel more easily that they are in control over the learning process (38, 40, 41). The programs used can provide insights into brain activity and behavioral information during virtual tasks, achieving efficient performance feedback (32). The interactivity produced by the stimuli supports motivation and involvement in therapy (42). IVR also has advantages for the therapist's clinical practice, since interventions are programmed, and it is possible to be more objective and replicate sessions consistently. Furthermore, tasks can be graded in difficulty according to each individual skills (41, 43). Particularly in Executive Functions, VR, in addition to intervention, has also been used as an effective assessment tool in ecologically relevant and standardized conditions (17, 34, 35, 42).

The combination of VR with Serious Games (SG) revealed positive results for learning and improving certain skills. Operations with specific objectives can be carried out through SGs while the player believes that it is just entertainment (44, 45).

When dealing with ID, it is very important to use cognitive interventions that motivate participation, that allow the grading of the complexity of tasks and that allow for the assessment of acquisitions. Perhaps then, using SG with VR will become a potential rehabilitator for individuals with ID (34, 40).

Most articles about VR cognitive training have shown that studies are predominantly conducted in patients with traumatic brain injury, stroke, mild cognitive impairment and dementia (27, 43, 46). VR studies targeting individuals with ID have mostly focused on physical activity, daily life skills (e.g. supermarket, shopping) and job skills (41). Interventions for the development of executive function components in individuals with ID is an area that has barely been researched (6, 47). If it is assumed that greater sensory immersion promotes greater cognitive processing and learning, then the use of virtual environments may be the solution to stimulate executive functions in this population (12).

In Portugal, the benefits of applying the ENHANCE VR program to people with intellectual disabilities have not yet been studied. Thus, the present study aims to explore the effects of cognitive training based on Immersive Virtual Reality on executive functions, such as Working Memory (WM), Sustained Attention (SA), and Inhibitory Control (IC), in young adults with ID.

2. Methodology

2.1. Study design

This study used a quasi-experimental one-group pretest-posttest design with a double pretest (01 02 X 03). Participants were their own control group, where each was assessed before, during, and after the intervention (48, 49) .

The Ethics Committee of the Escola Superior de Saúde do Politécnico do Porto (CE0109C/2022) approved the study, and all procedures followed the Declaration of Helsinki (50).

2.2. Participants

A convenience sampling method was used in collaboration with Associação de Pais e Amigos Centrada na Inclusão – APACI, which is located in Barcelos, Portugal.

This study included 15 individuals who attended the services of Centro de Atividades e Capacitação para a Inclusão from the APACI.

Inclusion criteria included: 1) young adults diagnosed with mild or moderate Intellectual Disability; 2) age between 18 and 35 years old (51); 3) with understanding of orders and instructions in Portuguese; 4) understanding how to use commands/mouse to play and 5) with motivation to participate in the study. The exclusion criteria were defined as 1) health condition that interferes with the participation in the program (epilepsy; severe vision and hearing problems that make it impossible to play the game; motor deficits that prevented the use of the intervention equipment); 2) behavioural problems that could prevent participation in activities; 3) difficulties to understand the dynamics of the games and 4) individuals that were receiving a similar intervention.

2.3. Data acquiring instruments

2.3.1. Sociodemographic Questionnaire

A sociodemographic questionnaire was developed by the research team, including questions necessary for sample characterization. The questions cover gender, age, academic qualifications (literate or not), diagnosed comorbidities, medication, presence of clinical conditions that may make participation in the study impossible (e.g., presence of epilepsy) and previous contact with the Virtual Reality ("Have you ever tried virtual reality?" and "If yes, how many times?").

2.3.2. E-Prime® 3.0 from Psychology Software Tools

For the assessment of executive function variables, the tests provided by E-Prime® were used. E-Prime® is a software package used to design and run psychological experiments, with a focus on psychological and cognitive science, and to acquire and analyse data. This tool incorporates several tests that allow you to evaluate different functions (52-54). It is a research tool commonly used in university environments and has a variety of cognitive tests compatible with this study.

To operate the E-prime tool, a PC with Windows 10 version, Intel® Core™ i7-6500U processor with a 15-inch screen, together with a USB mouse was used. During the application of the tests, the PC was at the level of the field of vision of the participants at an average distance of 50cm.

Three different tests were selected to assess visual-spatial working memory, sustained attention and inhibitory control.

2.3.2.1 Corsi Block-Tapping Task (CBTT)

The CBTT is a test that measures visuospatial short-term and working memory (WM). In this task, nine squares appear on the blue computer screen that "light up" in yellow, one by one, in a variable sequence. After presenting the stimulus, participants must reproduce the sequence by clicking on each of the squares that turned yellow. The sequence starts simple, but becomes more complex as the participant accomplishes the tasks, and only decreases when the participant's performance begins to suffer (55, 56).

During the test, the participant is exposed to 20 different sequences. A correct answer was considered when the participant got all the numbers in that sequence right. Thus, the number of correct answers was used as measure of performance.

2.3.3. Stop Signal Task (SST)

The SST is a test that measures inhibitory control (IC). This task combines two different stimuli, a stimulus that requires a response (go-task) and a stimulus that signals participants to inhibit their response on that trial (stoptask) (57, 58). Thus, participants need to respond as quickly as possible to the presentation of a left or right arrow using the "q" and "p" keyboard keys, respectively (go-task). During the task, from time to time, the stimuli appear surrounded by a "red light" and the participants cannot press any key (stoptask). Feedback is given after each attempt (59).

Due to the characteristics of the population, it was decided to identify the keys on the keyboard with the response to the stimulus. In this sense, the "q" key was marked with "←" and the "p" key with "→".

During the test, the participant is exposed to 151 of the stimuli mentioned above. A correct response is considered when the participant produces the necessary action for this stimulus. Thus, the number of correct answers was used as a performance measure.

2.3.4. Simple Reaction Time (SRT)

The SRT is a test that allows to assessment of sustained attention (SA) and processing speed (PS) (the interval of time between the perception and evaluation of a stimulus and the corresponding answer) (60, 61) . In this task, a single stimulus (star shape) is repeatedly presented at the same location on the screen. As the stimulus appears, participants must press the "1" key as quickly as possible. The time interval between stimuli varies throughout the task (62).

During the test, the participant is exposed to 60 stimuli that require a response as quickly as possible. Thus, the number of correct answers when the stimulus appeared was used as a performance measure.

2.4. Intervention program: Enhance VR – Virtuleap

For cognitive training, three games available on the Enhance VR platform were used. Enhance VR is an app consisting of a library of cognitive exercises, developed by Virtuleap (Virtuleap, United States, virtuleap.com) (32). The games were performed by all participants always in the same sequence (React, Memory Wall and Whack-a-mole) to carry out an identical study protocol. The intervention protocol consisted of three 20-minute sessions per week for eight consecutive weeks and took place at the APACI.

The access to the games in Enhance VR platform was done through a Meta Quest 2 head-mounted display (HMD), Qualcomm snapdragon 835 processor, 4Gb RAM, 128 Gb internal memory, resolution per eye in pixels: 1.400 × 1.600, with a refresh rate of 72 Hz and motion controllers.

2.4.1. React

The "React" game was designed to train task switching and response inhibition skills and is based on the mechanisms of the Wisconsin Card Sorting Test (63) and the Stroop Task Mechanisms (64). In React, the player needs to categorize approaching objects according to their shape and color, throwing them into two portals, which only accept matching objects. During the game, the participant needs to adapt to dynamic contexts, as the portals can change their position and the required objects at different times during the levels. The difficulty increases by introducing distractor objects that must be ignored (32).

2.4.2. Memory Wall

The "Memory Wall" game works short-term visuospatial memory and was inspired by the Visual Patterns Test (65) . In this game, the participant is required to memorize the positions of the illuminated cubes in a three-dimensional grid that appears in their field of vision, for 3 seconds, and as soon as the pattern disappears, he must reproduce the pattern that saw. The difficulty of the task increases with each level, depending on the size of the grid and the number of cubes that make up the illuminated pattern (32).

2.4.3. Whack-a-mole

The "Whack-a-mole" game focuses on sustained attention and was inspired by the Psychomotor Vigilance Test (66). In this game, some moles come out of holes where they are hiding, at random intervals and different positions, and the objective is to hit them with the hammer before they return to the hole. This required that the player maintain concentration on the task and react as quickly and accurately as possible to the presentation of the stimulus. The difficulty increases as the speed at which the moles activate increases and as multiple moles are allowed to rise simultaneously (32).

	Game	Category	Neuropsychological test	Game description
	**React**	Cognitive Flexibility and Response Inhibition	Wisconsin Card Sorting Test (63) and Stroop Task (64)	Throw objects into portals according to their shape and color. Ignore distracting objects that don't belong in portals.
	**Memory Wall**	Memory	Visual Patterns Test (65)	Memorize and reproduce a pattern of cubes.
	**Whack-a-mole**	Attention	Psychomotor Vigilance Test (66)	Hit the moles as they pop up from the arcade.

Figure 1: Enhance VR games used in the intervention (32)

2.5. Procedures

In the first phase, collaboration was requested from APACI to participate in the research study. After approval by the APACI and the Ethics Committee, the study was presented to potential participants and their legal representatives, requesting their authorization to participate in the study voluntarily. After their agreement, the sample was selected between those who agreed to participate and the established inclusion and exclusion criteria were applied. Obtaining the consent of the participants and collecting the sociodemographic data took place during March 2023. After this moment and before the pre-tests were carried out, three possible participants abandoned the study.

Still, in March, the researcher applied the three cognitive assessment tests of the E-Prime® 3.0 from Psychology Software Tools (assessment 1). Eight weeks after the first assessment, they were again evaluated, using the same instruments (assessment 2). Between these two assessments, there was no intervention with the individuals to establish a baseline of their performance over the same period as the intervention.

After assessment 2 and before starting the intervention program, all participants underwent a single teaching session on the use of Enhance VR Games- Virtuleap. In this session, the use of virtual reality commands was explained, and an Enhance VR Games-Virtuleap game was demonstrated (different from the intervention program games), to guarantee the participant's autonomy in using the VR. Furthermore, before each game was played for the first time, participants went through a benchmark session that established the baseline that determined the level at which they would start the game.

The intervention program started in May and lasted eight weeks with three appointments a week, making a total of 24 sessions, each lasting 20 minutes.

After the intervention, the three cognitive assessment tests were again applied (assessment 3).

All data referring to the participants were coded to maintain confidentiality. In this study, data was collected in digital format for the cognitive assessment through E-prime, and in paper format for the sociodemographic questionnaire. The data will be stored for 10 years and under the responsibility of the principal investigator (67)

During the intervention sessions, the playing position was mainly standing. However, if participants felt tired, they were allowed to play "Memory Wall" sitting down as it did not require as much movement. The games were performed by all participants in the same sequence (Figure 2) to keep the study protocol identical for all.

The researcher responsible for the intervention was present during the sessions to assist participants, if necessary, with VR equipment and access to the platform.

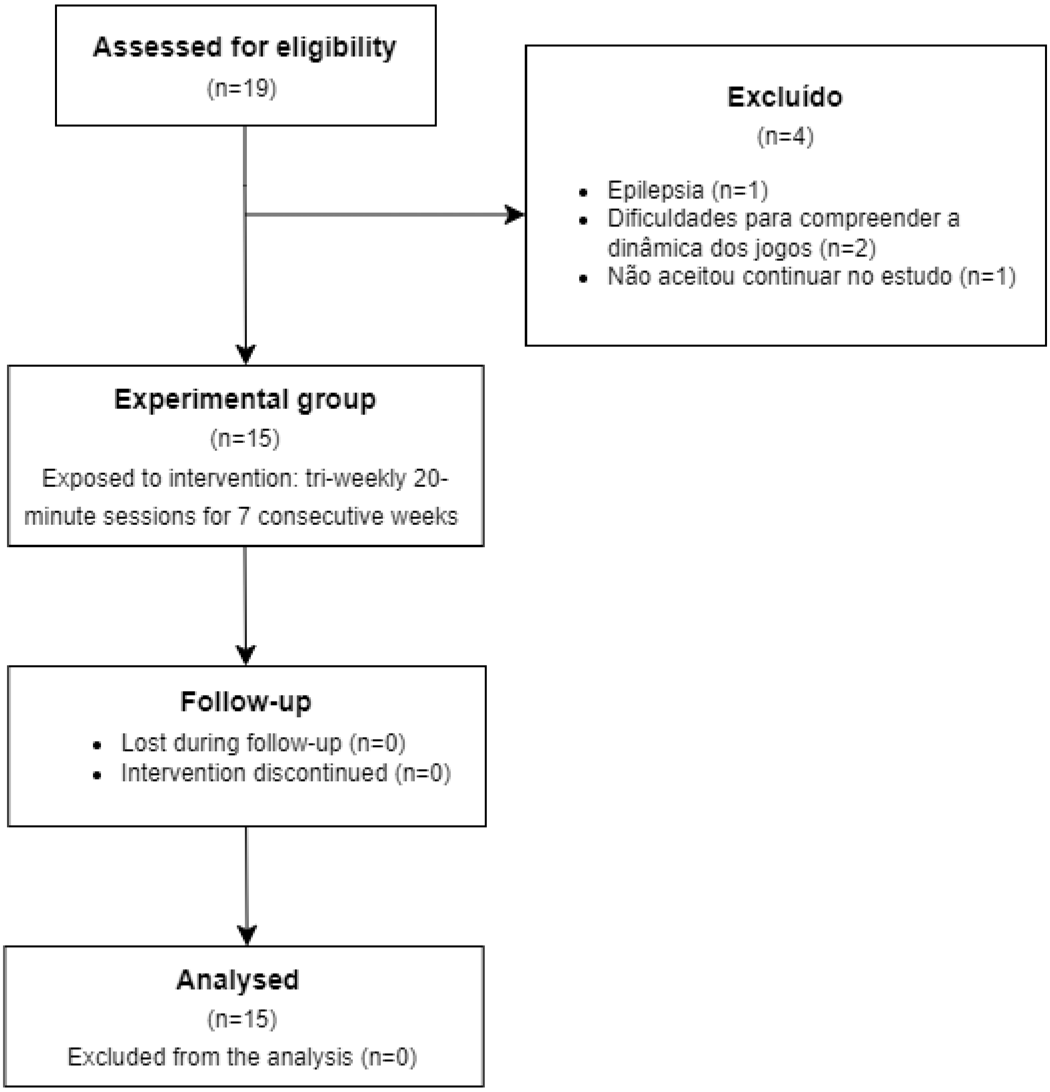

Figure 2: CONSORT diagram of study design

2.6. Data analysis

To carry out the statistical analysis of the collected data, an Excel document was used to create a database containing information about the different variables. Next, for data processing, the data were exported to the IBM Statistical Package for the Social Sciences (SPSS) 28.0 (68), considering a significance level of 0.05 for all statistical tests performed (69). Descriptive statistics were used to characterize the sample using measures of central tendency and dispersion: mean (x) and standard deviation (sd) for continuous or discrete variables and relative frequencies (%) for nominal or ordinal data. To test normality of the variables, the Shapiro-Wilk test was used for the variables 1SRT (reaction time); 2CBTT (correct answer); 2SRT (reaction time); 2SST (correct answer); 3CBTT (correct answer); 3SRT (reaction time); 3SST (correct answer) (69). For inferential statistics, parametric tests were used whenever data distribution was deemed approximately normal using threshold criteria for skewness and kurtosis - less than |2.0| and |9.0|, respectively (70). Additionally, one-way repeated-measures ANOVAs were implemented for comparing the pre-post conditions. For these models, sphericity was tested using Mauchly's test. The Huynh-Feldt correction was employed whenever this assumption was not met and the epsilon was higher than .57; otherwise, the Greenhouse-Geisser correction was used (70).

3. Results

3.1. Sociodemographic characteristics of participants

As described in Table 1, our sample had fifteen participants (n=15), aged between 22 and 34 years old, with the mean age being 28.07 and the standard deviation being 3.97. The majority of this group was male (66.70%). The distribution of participants by mild and moderate levels of ID is almost similar, with eight participants (53.30%) presenting mild level. Out of the total sample, seven participants are literate (46.70%). None of the participants had a previous experience with virtual reality (0.00%).

Table 1– Sociodemographic characterization of the sample groups regarding age, gender, levels of ID, literate and previous experience with VR.

Demographic characteristics		**Sample (N=15)**	
		$\bar{x} \pm \sigma$	min.-máx
Age (years)		28.07 ± 3.97	22 -34
		N	%
Gender	Male	10	66.70%
	Female	5	33.30%
Levels of ID	Mild	8	53.30%
	Moderate	7	46.70%
Literate	Yes	7	46.70%
	No	8	53.30%
Previous experience with VR	Yes	0	0%
	No	15	100%

($\bar{x}$ - mean; σ– standard deviation; N- Absolute frequency; % - Relative frequency)

3.2. Impact of an IVR-based cognitive training on executive functions in young adults with ID

To verify the impact generated by the Enhance VR program, it was verified whether there are significant differences between the scores differences obtained in the three evaluation moments, whose results are described in Table 2.

Table 2– Score differences between pre-tests and post-test in CBTT, SRT and SST

	test1 $\bar{x} \pm \sigma$	test2 $\bar{x} \pm \sigma$	test3 $\bar{x} \pm \sigma$	p-value	Power
CBTT (WM)	11.53 ± 2.03	11.07 ± 2.54	13.93 ± 1.91	0.001*	0.960
SRT (SA)	55.86 ± 5.41	53.47 ± 11.21	57.73 ± 3.57	0.101	0.373
SST (IC)	90.40 ± 22.76	90.87 ± 23.89	99.53 ± 27.58	0.043*	0.545

($\bar{x}$ - mean; σ– standard deviation; p-value - Within-subjects p-value;*p<0.05)

Analyzing the results in test1, test2 and test3 for the CBTT, SRT and SST, we observed that there are statistically significant differences in the scores of the CBTT- Working Memory (p=0.001) and SST-Inhibitory Control (p=0.043), suggesting that the group's performance improved over time. The SRT-Attention test was not significantly different over time (p=0.101) although, a trend towards better performance can be perceived when comparing scores at different moments.

3.3. Influence of gender and level of ID on the performance obtained in Working Memory, Sustained Attention and Inhibitory Control.

The values obtained for the test 1, test 2 and test 3 are shown in Table 3. Analyzing the influence of gender and ID level on the results of the assessment Corsi Block-Tapping Task, Simple Reaction Time and Stop Signal Task, in the three assessment moments, we verified that statistically these 2 variables do not influence the tests results.

Table 3- Influence of demographic characteristics on the evaluation of executive functions at the pre-tests and post-test.

	Gender									
	Male			Female			p-value[a]	p-value[b]	power[a]	power[b]
	Test1 $\bar{x} \pm \sigma$	Test2 $\bar{x} \pm \sigma$	Test3 $\bar{x} \pm \sigma$	Test1 $\bar{x} \pm \sigma$	Test2 $\bar{x} \pm \sigma$	Test3 $\bar{x} \pm \sigma$				
CBTT (WM)	11.10±2.18	11.60±2.8	3.80±2.20	12.40±1.52	10.0±1.58	14.20±1.30	0.004*	0.500	0.893	0.099
	Levels of ID									
	Mild			Moderate			p-value[a]	p-value[b]	power[a]	power[b]
	Test1 $\bar{x} \pm \sigma$	Test2 $\bar{x} \pm \sigma$	Test3 $\bar{x} \pm \sigma$	Test1 $\bar{x} \pm \sigma$	Test2 $\bar{x} \pm \sigma$	Test3 $\bar{x} \pm \sigma$				
CBTT (WM)	11.63±2.26	11.25±3.28	14.50±2.33	11.43±1.90	10.86±1.57	13.29±1.11	0.002*	0.418	0.949	0.121
	Gender									
	Male			Female			p-value[a]	p-value[b]	power[a]	power[b]
	Test1 $\bar{x} \pm \sigma$	Test2 $\bar{x} \pm \sigma$	Test3 $\bar{x} \pm \sigma$	Test1 $\bar{x} \pm \sigma$	Test2 $\bar{x} \pm \sigma$	Test3 $\bar{x} \pm \sigma$				
SRT (SA)	54.10±5.86	51.70±13.37	57.20±4.10	59.40±1.34	57.00±3.74	58.80±2.17	0.256	0.102	0.196	0.370
	Levels of ID									
	Mild			Moderate			p-value[a]	p-value[b]	power[a]	power[b]
	Test1 $\bar{x} \pm \sigma$	Test2 $\bar{x} \pm \sigma$	Test3 $\bar{x} \pm \sigma$	Test1 $\bar{x} \pm \sigma$	Test2 $\bar{x} \pm \sigma$	Test3 $\bar{x} \pm \sigma$				
SRT (SA)	55.25±5.44	56.88±4.58	56.88±4.58	56.57±5.71	57.00±3.32	58.71±1.80	0.112	0.818	0.352	0.055
	Gender									
	Male			Female			p-value[a]	p-value[b]	power[a]	power[b]
	Test1 $\bar{x} \pm \sigma$	Test2 $\bar{x} \pm \sigma$	Test3 $\bar{x} \pm \sigma$	Test1 $\bar{x} \pm \sigma$	Test2 $\bar{x} \pm \sigma$	Test3 $\bar{x} \pm \sigma$				
SST (IC)	92.1± 27.03	92.6± 27.71	95.80± 30.53	87± 12.10	87.40±15.69	107± 21.44	0.010*	0.057	0.800	0.489
	Levels of ID									
	Mild			Moderate			p-value[a]	p-value[b]	power[a]	power[b]
	Test1 $\bar{x} \pm \sigma$	Test2 $\bar{x} \pm \sigma$	Test3 $\bar{x} \pm \sigma$	Test1 $\bar{x} \pm \sigma$	Test2 $\bar{x} \pm \sigma$	Test3 $\bar{x} \pm \sigma$				
SST (IC)	99.63± 27.33	98.75± 28.91	103.38± 29.84	79.86± 9.67	98.75± 28.91	95.14±26.34	0.032*	0.168	0.605	0.272

($\bar{x}$ - mean; σ- standard deviation; p-value[a] - Within-subjects p-value; p-value[b]- Interaction *p-value*; power[a] – Within-subjects; power[b]- Interaction; *p-value<0.05)

The CBTT (WM) presents a p-value[a]=0.004 for gender and a p-value[a] = 0.002 for the ID level, which indicates that, although there was an evolution regarding the working memory of participants from the first to the last assessment, this difference is not dependent of gender or ID level (p-value of the interaction with gender was 0,500 and with ID was 0,418).

The SRT (SA) presents a p-value[a]= 0.256 for gender and a p-value[a]=0.112 for the ID level, which indicates that, although there was no evolution of sustained attention of participants, this result was not influenced by gender or ID level (p-value of the interaction with gender was 0,102 and with ID was 0,818).

The SST (IC) presents a p-value[a]=0.010 for gender and a p-value[a]=0.032 for the ID level, which indicates that, although there was an evolution of inhibitory control of participants from the first to the last assessment, this difference is not dependent of gender or ID level (p-value of the interaction with gender was 0,057 and with ID was 0,168).

3.4. Perfomance in Working Memory and Inhibitory Control at different evaluation moments

Through post-hoc tests, it was possible to understand whether the differences previously found would translate into an improvement in performance in test 3 in comparison to test 1 and test 2.

Table 4– Differences in scores of measures across time in Working Memory and Inhibitory Control

	Gender		Level of ID	
	CBTT (WM)	SST (IC)	CBTT (WM)	SST (IC)
	p-value[a]			
Test1 vs. Test2	0.081	0.841	0.450	0.786
Test1 vs. Test3	0.004*	0.010*	0.002*	0.032*
Test2 vs. Test3	<0.001*	<0.001*	0.001*	0.009*

(p-value[a] – Pairwise Comparisons Bonferroni; *p-value<0.05)

In post-hoc tests, for the variable CBTT(WM) e SST (IC), when gender is taken into account, the comparisons between the 1st and 2nd moments showed no differences (p_{CBTT}=0,081; p_{SST}=0,841) but when compared with the 3rd moment the differences are statistically significant (p_{CBTT}=0,004; p_{SST}=0,010). The same happens for the level of ID, verifying that the comparisons between the 1st and 2nd moments showed no differences (p_{CBTT}=0,450; p_{SST}=0,786) but that when compared with the 3rd moment, the differences are statistically significant (p_{CBTT}=0,002; p_{SST}=0,032). Suggesting that participants maintained the same performance on assessment measures while they had no contact with the intervention. Observing that the evolution occurred between test 2 and test 3, it is clear that the cognitive-VR training had an impact on the post-test results.

4. Discussion

This study aimed to assess the effectiveness of a IVR cognitive training intervention on working memory, sustained attention and inhibitory control in young adults with ID from Associação de Pais e Amigos Centrada na Inclusão (APACI).

By using the study group as its own control group, the evolution in the period without intervention with the period after the intervention can be compared. Our findings show that VR-based serious game intervention, specifically Enhance-Virtuleap, can improve WM and IC in adults with ID. This is in line with previous cognitive training studies, and similar results can be observed in studies that involved the use of serious games. To date, few studies have focused on EF training in individuals with ID. The literature shows that therapeutic interventions based on serious games have been shown to be effective in improving cognitive areas in individuals with neurodevelopmental disorders, including ID (44, 47). Regarding the findings of WM, a study demonstrated for the first time that working memory can be effectively trained in adolescents with mild to borderline ID. It consisted of using the "Odd Yellow" computerized cognitive training, with an intervention (tri-weekly 6-minute sessions for 5 weeks). When comparing the pre-tests with the follow-up, it appears that the WM "Odd Yellow" training can increase the ability to process and store information simultaneously in a short space of time for participants in both experimental groups (71). Another study was carried out in children with intellectual disabilities, using the game-based cognitive training program "Neuro-World", with a 24-session intervention (bi-weekly 30-minute session for three months). It demonstrated that the experimental group that trained with Neuro-World showed statistical significance between pre-intervention and post-intervention scores, with improvements in performance in the WM section (72).

Working memory is one of the most explored EFs regarding interventions based on serious games for individuals with ID. Inhibitory control on the other hand is not researched as intensely even though it has been suggested to be included in interventions for people with ID by previous studies (73). Based on this premise, this study evaluated and verified significant improvements in

IC after the intervention period, which is in line with the literature. A quasi-experimental study aimed to examine the impact that a cognitive training program could have on executive function in adults with Down Syndrome who had a mild or moderate level of ID. "Scientific Brain Training Pro" (20 minutes, 5 days a week over 8 weeks) was used in the intervention. Significant improvements were observed in post-intervention results in the Cats and Dogs Stroop measure that assessed inhibition (74). The improvements observed in WM and IC in this study are in line with previous studies such as the one carried out by Thorell et al. (2009) which suggest that these two components of EF are interconnected, with the functioning of one affecting the functioning of the other. This happens because both share the same prefrontal cortex (ventrolateral) activation area for their functioning. Thus suggesting that WM training could lead to improvements in inhibition tasks and vice versa, increasing the potential for improvement in these components (75).

However, the results obtained in the SA variable were below expectations, not demonstrating significant results in our study. This component is rarely evaluated in this population, and of the few studies that evaluated SA, none of them showed significant results. A randomized clinical trial that aimed to study the impact of computerized attention training for children with ID and developmental disabilities using an attention-only intervention with the "Training Attention and Learning Initiative" (25 sessions over 5 weeks, each lasting 20 minutes) concluded that despite observing improvements in selective attention, none were observed regarding SA (76). The lack of results in our study regarding SA can possibly be explained by the fact that the game responsible for training this component is "Whack-a-mole", which has a short duration (± 3 minutes per session). It could be argued that this is not enough time to train SA in individuals with ID, making it necessary for future studies to involve participants in longer training for this component. Furthermore, while the VR game that stimulated SA was dynamic and required constant interaction, the evaluation measure (SRT) always used the same monotonous stimulus which could demotivate the participants.

To our knowledge, this is the first study using a IVR-based intervention specifically targeting Working Memory, Sustained Attention and Inhibitory Control in individuals with ID.
Even though it is not possible to compare the results obtained with VR-based interventions, due to the scarcity of studies in this area, we were still able to see that our results were cohesive with findings from previous cognitive training applied to the ID population. The conclusions of this study, along with others, must be taken into consideration, as they allow us to understand that

the cognitive deficits presented by this population are not exactly fixed and can be improved with appropriate intervention.

The fact that the program presents captivating, dynamic stimuli and allows constant monitoring of the participant's performance, might have helped them to make an effort and be more involved during the games. Prior studies suggest something similar, as they find that VR-based approaches are stimulating and allow more immediate performance feedback promoting more motivation and adherence to treatment (27, 77).

We know that this study was the first to test the Enhance VR program on individuals with ID. Although it was not designed for this specific population, it has proven to be a useful tool for cognitive interventions in individuals with ID. However, to improve the VR-based approaches for this population, it would be pertinent to begin involving individuals from the target population in the development/improvement of VR environments, paying attention to the appreciation and difficulties felt by participants in order to improve the usefulness and acceptability of interventions (39).

This study offers valuable information, but it is important to recognize its limitations and areas for improvement in subsequent research. The sample was based on a convenience selection method and is small, which limits the diversity of the sample and might lead to the generalization of results to larger populations. The research was conducted using specific measures of cognitive performance, which may not fully capture the extent of changes observed in participant's daily functioning. The lack of application of more specific assessment tools for day-to-day activities is a limitation that must be recognized. Therefore, we cannot state that the improvements in executive functions observed in our study were transferred to other contexts.

5. Conclusion

The use of Virtual Reality as a therapeutic approach for individuals with ID is still uncommon and requires further investigation. This study indicates some promising results, demonstrating that this type of intervention has the potential to improve the cognitive indices of this population.

It is suggested for future studies to use more sensitive instruments for the considered population, in order to detect small changes that may occur and find out whether the improvements are generalized to daily life and whether the effect of the intervention lasts over time. It will be important to carry out future studies with more robust methodologies, with larger samples, multiple assessment tools and randomized control to gather more information about the impact of VR interventions on ID. Further research will determine how to best adapt VR interventions to meet the needs of individuals in this type of population.

In summary, it is imperative that we continue to promote and invest in innovative rehabilitation approaches for individuals with ID, breaking down societal barriers and providing them with equal access to a wider range of therapeutic opportunities, thereby promoting inclusion and a better quality of life for these individuals.

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