Effects of virtual reality on theory of mind in children with ADHD

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Abstract

The DSM-5 defines ADHD as a chronic neurological behavioral disorder characterized by a persistent pattern of inattention and/or hyperactivity and impulsivity. Hyperactivity and inattention interfere with cognitive functioning and participation in various activities. Recent technological advances have demonstrated the utility and potential of virtual reality (VR) as an intervention hypothesis for neurodevelopmental disorders, in particular VR acts on the TOM and supports social and practical skills. Virtual reality represents "an artificial environment through which one experiences sensory stimuli (such as images and sounds) provided by an opposite viewer and in which it is possible to perform actions in the environment". VR also provides security and unlimited everyday contexts for practicing social scenarios. In this study we compare two types of intervention to enhance social skills: a traditional emotional training, performed individually with the therapist (group 1) and an emotional training obtained through the use of VR (group 2). Specifically, in this study we compared the two types of intervention, with the aim of identifying the intervention with the shortest acquisition times for the proposed social tasks. In particular, this work supports the hypothesis that the intervention based on the use of virtual reality allows a faster acquisition of social tasks.

Keywords

ADHD, theory of mind; virtual reality; VR; emotional training

1. Introduction

Attention deficit hyperactivity disorder (ADHD) [1] is a chronic disorder with a neurological basis characterized by a persistent pattern of inattention and/or inappropriate or disruptive hyperactivity and impulsivity. The onset of hyperactivity occurs at age 3 or 4. The DSM-5 defined symptom onset as before age 12 because it wanted to capture a cohort of pediatric patients who have symptoms of inattentiveness and do not exhibit obvious functional impairment at baseline [2]. The treatment of ADHD is based on a combination of cognitive-behavioral interventions and psychopharmacological interventions that produce excellent response rates [3]. Hyperactivity and inattention through self-control difficulties interfere with the child's psychological development and hinder the performance of common daily activities. [4]. A major condition that afflicts children with ADHD is social interaction. More specifically, some recent studies report that the main social difficulties experienced by children with ADHD are aggression towards peers and authority figures (parents and teachers), disruptive behavior (i.e., conduct disorder [CD], oppositional defiance disorder and substance use disorder [SUD]), destruction of other people's property, interference in conversations, high frustration in gaming scenarios, and frequent rule breaking [5]. This is mainly explained as a neurodevelopmental disorder of the prefrontal lobe, affecting the development of executive functions during childhood. Executive Functions (EF) are understood as a set of capabilities that regulate, control, and plan behavior and capabilities cognitive skills, so that independent, proactive and productive activities can develop [6]. EFs include planning, working memory, inhibition, control, cognitive flexibility and self-change, [7]

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and are crucial in everyday life. Theory of Mind (ToM) is the ability of an individual to ascribe intentions, desires and beliefs both for others and for oneself [8]. ToM is a fundamental function for social interactions as it allows knowledge about the minds of others and emotional states, thus allowing the deduced subject to act accordingly [9]. ToM constructs are associated with social functioning, and deficits in both can lead to difficulties interacting with others, as is the case for individuals with Attention Deficit Hyperactivity Disorder (ADHD). EF and ToM are associated primarily through three aspects: neuroanatomical proximity, developmental development, and the link that occurs between both processes in some mental and neurodevelopmental disorders. Neuroanatomically speaking, independent cortical networks are activated in FE and Tom. The EF network is composed primarily of the prefrontal cortex, which is involved in planning, working memory, verbal fluency, complex problem solving, cognitive flexibility, hypothesis generation, serialization, and sequencing; the orbitofrontal cortex, involved in the processing and regulation of emotions and emotional states and in the control of behavior; the medial frontal cortex, involved in inhibition, conflict detection and resolution, and in the regulation of attention efforts, aggression and motivational states [10]. On the other hand, the ToM network includes the medial prefrontal cortex, temporoparietal union, posterior cingulate and precuneus, and orbitofrontal cortex participation, especially in affective attribution and wishful type tasks. It is the temporoparietal union that is specifically activated when an individual is thinking mental processes of others (that is, thinking about what others are thinking), exchanging information between their own mental states and the mental states of others with the participation of the medial prefrontal cortex. The prefrontal area of both the medial frontal cortex and the orbitofrontal cortex are common; the former is involved in inhibitory control, while the latter is involved in processing information with emotional content. The developmental perspective highlights that in preschool age, the development of understanding of mental state occurs simultaneously with the improvement of executive functions [10]. Infants can discriminate animate from inanimate objects and generate joint attention (both processes considered precursors of ToM). By age 2, working memory and inhibition systems improve, and children can understand pretend play (i.e., pretend play); at 3 years, both systems continue to develop and children begin to understand affective decisions; by age 4 to 5, with more developed and specialized inhibition and working memory systems and as cognitive flexibility begins to mature, children can perform first- and second-order false-belief tasks; by age 6 to 7, working memory, inhibition, cognitive flexibility, and planning are better established; children's ToM is sophisticated to the extent that it functions similarly to that of adults [11]. For example, inhibitory control, working memory, and planning have been reported to correlate with ToM [12]; correlations between inhibitory control, cognitive flexibility, and planning are conserved cross-culturally with these EFs involving ToM. Furthermore, longitudinal studies have determined that inhibition, working memory, and alternating attention processes correlate with ToM and predict its appearance [13]. Several studies suggest that Virtual Reality is a technology that acts effectively on TOM deficits in children with ADHD. There are several systematic reviews of the use of technologies, both for assessment and for intervention, especially on virtual reality (VR) with children with ADHD [14]. VR was first applied in healthcare in the 1990s [15]. The application of VR systems, especially in the field of childhood, consists of tasks that consist in playing a game. Virtual reality is commonly regarded as a technology that induces virtual immersion in a digital world through the use of computer graphics simulation that allows users to immerse themselves in an interactive three-dimensional world filled with various sensory and emotional experiences [16]. Immersion allows children with ADHD to improve vigilance tasks and sustained attention, it also helps reduce the number of omissions and increase the number of adequate responses to target stimuli. The most notable effect is on alertness, but several studies suggest a positive effect on impulsivity [17], inhibitory control [18] and anxiety [19]. The growing number of research publications on the role of virtual reality (VR) technologies in the field of special education indicates that VR applications are gaining attention as promising intervention tools for children with neurodevelopmental disorders, physical disabilities, and learning in ADHD [20]. Its implementation also allows to avoid some elements that could hinder the child or adult with ADHD such as hyperactivity and inattention [21]. In this regard, in this study we compare two types of intervention to improve social skills: a traditional emotional training, performed individually with the therapist and an emotional training obtained through the use of virtual reality. In both cases, the intervention proposed the accomplishment of four social tasks, aimed at subjects with ADHD, namely: a) recognition of primary or basic emotions, b) recognition of secondary emotions, c) emotions and situations linked to primary emotions, d)

emotions and situations for secondary emotions. Specifically, in this study the two types of intervention were compared, with the aim of identifying the intervention with shorter acquisition times for the proposed social tasks. In particular, this work supports the hypothesis that the intervention based on the use of VR allows a more rapid acquisition of social tasks.

2. Materials and methods

2.1 Participants (Inclusion criteria)

In this study, 32 subjects diagnosed with ADHD were recruited and divided into two groups. All subjects came from the same geographical area (city of Caserta) and had parents with a homogeneous socio-cultural context. Family/environmental background was not considered as a factor influencing education in both groups. All subjects undertook the Wechsler Intelligence Scale for Children (WISC IV) [22] to exclude intellectually impaired subjects. The inclusion criteria were as follows: a) age between 9 and 10 years, b) diagnosis of ADHD c) absence of nosographically defined comorbidities, d) IQ $\geq$ 97. After confirmation of the diagnosis, and the possibility of inclusion in the sample, we divided the subjects into two experimental groups of 9 subjects each. The subdivision was performed randomly: the subjects included in both groups had the same inclusion criteria and did not present socio-cultural differences. The two groups underwent two different types of treatment, as will be discussed in the next paragraph. The first experimental group (Gr1) composed of 16 subjects (10 males and 6 females) with a mean age of 9.5 years (age M = 9.5) and a mean IQ of 105.21. The second experimental group included 16 subjects (12 males and 4 females) with a mean age of 9.7 (M age = 9.7) and a mean IQ of 105.72. Therefore, no significant differences in age or QIT were found in the two groups. The data were collected at the FINDS Neuropsychiatry Clinic by certified psychologists, in collaboration with the University of Naples Federico II, Department of Psychology and University of International Studies of Rome (UNINT).

2.2 Instruments

In this study, the following tests were used to recruit participants: WISC-IV (Wechsler Intelligence Scale for Children) [22], BIA (Battery Italian for ADHD) [23], La Conners Rating Scale - Revised, (CRS-R) [24], K-SADS-5 [25].

WISC-IV: individual clinical trial, to evaluate the cognitive abilities of children aged between 6 and 16 years. The test allows you to calculate the intelligence quotient (IQ) to assess the child's overall cognitive ability. Specifically, the IQ is obtained by combining four different scores, namely: Verbal Comprehension Index (VCI), Visual Perceptual Reasoning Index (PRI), Working Memory Index (WMI) and Processing Speed Index (PSI). .

BIA: (Battery Italian for ADHD) offers a range of useful tools for understanding the specific problems presented by inattentive and hyperactive children and/or with difficulties in executive processes, control of response, attention and memory. These tools can be used for the diagnosis and specification of difficulties in children with ADHD/ADHD profile (Attention Deficit Hyperactivity Disorder) and have been standardized on a total population of children greater than 10,000 units. The tests include questionnaires for observing children's behavior at home and at school, tests for the assessment of visual and auditory sustained attention, tests for the assessment of impulsive behavior and control processes, and a test for the assessment of memory strategies: for each instrument a theoretical and practical presentation and the reference normative data are provided.

La Conners Rating Scale - Revised (CRS-R):
is a long-used and widely used tool to evaluate children with ADHD. The CRS-R is composed of a number of items ranging from 27 to 87, depending on the length of the version. There is a version of

the scale intended for parents, another for teachers (CTR-S), and a third for behavioral self-assessment for adolescents, used directly by them to recognize problem behavior. The parent and teacher rating scales can be administered to individuals aged 3 to 17, while the self-assessment measures are suitable for adolescents aged 12 to 17. The parent and teacher scales include the following subscales: Oppositional, Cognitive-Problems/Inattention, Hyperactivity, Anxiety, Shyness, Perfectionism, Social Problems, Psychosomatic Disorders (Parents' version only), Conner's Global Index (includes Restless-Impulsive and Responsibility emotional), ADHD index and DSM-IV symptoms (including inattentive, hyperactive-impulsive). Parents and teachers must evaluate, on a 4-point Likert scale (0=never; 4=too often), the frequency with which the behaviors described in each item are implemented. The Adolescent Self-Rating Scale (CASS: L) includes the following subscales: Conduct, Cognitive, Family, Anger Control, Emotional Problems and Hyperactivity, ADHD Index, and DSM-IV Symptoms.

K-SADS-5: diagnostic interview for the evaluation of psychopathological disorders (past and present) in children and adolescents, according to DSM-5 criteria. In particular, the interview allows to identify the presence of mood disorders, psychotic disorders, anxiety disorders, attention deficit disorders and disruptive behavior, substance abuse..

2.3 Procedures

All subjects were evaluated by WISC-IV for the assessment of intellectual functioning (inclusion criterion IQ $\geq$ 95). For the diagnostic evaluation of hyperactivity and inattention disorder (ADHD), we used BIA, CRS-R and K-SADS-5. Eighteen subjects were randomly selected and divided into two groups that received two different interventions. The two intervention modalities used in this study were as follows:

Individual intervention with the therapist – IIT: emotional training that requires children and adults using 76 photos in sequence. The first 38 sequences were created by recruiting specially trained actors. The subject with ADHD was shown photographs, specifically 14 photographs for the recognition of 7 primary emotions (2 for each primary emotion, one for children and one for adults) and 24 photographs for the recognition of 12 secondary emotions (2 for each emotion, one for children and one for adults). For each sequence, the child was asked to recognize the emotion represented in each photo by alternating the adult actors with the child actors. Subsequently, a sequence of 38 photos was administered to subjects with ADHD to whom the description of the scenario in the photo was first introduced, followed by the image depicting the emotion corresponding to the situation (14 photos were associated with primary emotions and 24 photos have been associated with secondary emotions).

Virtual Reality Intervention - VRI: in this type of intervention a 3D viewer was recruited for emotional training and for the projection of two sequences of scenes. The actors initially recruited for the sequence of photos of the Gr1 intervention were also employed to film the sequence of scenes with the protagonist. The first sequence comprised 38 scenes, i.e. 14 scenes associated with 7 primary emotions and 24 scenes associated with 12 secondary emotions. The second sequence involved the screening of 38 scenes with 14 scenes related to primary situations and emotions and 24 scenes for secondary situations and emotions. As previously reported, the scenes were projected with the same scenarios used for the IIT intervention photos. In both groups, therefore, the same emotional training was carried out in different ways: in group 1 (Gr1) the training was carried out individually by a therapist and provided for exposure to cartoon images; in group 2 (Gr2) film scenes were projected through a 3D viewer relating to the same emotions and situations presented in the hard cover. To evaluate the acquisition of the skills foreseen by the 4 sequences (recognition of primary emotions, recognition of secondary emotions, primary emotions and situations, secondary emotions and situations) a weekly test was performed with 38 items (7 for the recognition of primary emotions, 12 for secondary emotions, 7 for primary emotions and situations, 12 for secondary emotions and situations), using images that varied from week to week were used as a criterion for acquiring 100% exact answers. At T0 (pre-training phase), no subject had already achieved the acquisition criterion for

the 4 trials. A score of zero on all four tasks was the starting condition required for subjects in the two groups.

3. Results

Data analysis was performed using the SPSS 26.0 statistical survey software [26]. Significance was accepted at the 5% level ($p < 0.05$). The comparison of the means of the measurements was carried out using an analysis of variance test (ANOVA), a parametric test that allows you to compare two or more measurements; the relationship between these variances follows the Fisher F distribution, which allows for testing hypotheses about the significance of the difference between treatment-related and residual variability. In this study we performed an ANOVA to compare the scores that emerged from the measurement of the acquisition times for the 4 proposed tasks. We described the tasks as follows: PE (primary emotions) task 1, SE (secondary emotions) task 2, PE/S (primary emotion/ situations) task 3 and SE/S (emotions/secondary situations) task 4. Both groups at T0 (before the emotional training) did not reach the acquisition criterion in any of the four proposed tasks. Following the literacy intervention (T1), on the other hand, significant differences emerged with respect to the acquisition of times for the four tests proposed between Gr1 and Gr2. In particular, in task 1 no significant differences emerged regarding the acquisition of recognition of primary emotions. This demonstrates that the acquisition times of the two groups regarding primary emotion recognition were similar; both interventions allow rapid acquisition of knowledge of primary emotions. At task 2, significant differences emerged in group 2; this demonstrates that with the use of VRI the recognition of secondary emotions occurs in less time than with IIT. Furthermore, in task 3 significant differences emerged in group 2. This demonstrates that exposure to situations that allow knowledge of primary emotions using VRI guarantees shorter acquisition times, thanks to the direct experience of the subject. Finally, also in task 4 significant differences emerged in group 2. The results show that the training of secondary emotions VRI guarantees shorter acquisition times as it allowed to experience situations directly which instead only the IIT allowed to comment through the use of photographs (tables 1 and 2 and figures 1, 2, 3, 4).

Table 1
Comparisons between the two groups at T0

	GROUP 1		**GROUP 2**	
	T0		**T0**	
	M	*SD*	*M*	*SD*
PE	4.00	0	4.00	0
SE	6.00	1.41	5.50	0.70
PE/S	3.50	0.70	3.00	0
SE/S	5.00	0	4.00	0

Table 2
Comparisons between the two groups at T1

	GROUP 1		**GROUP 2**			
	T1		**T1**			
	M	*SD*	*M*	*SD*	*f*	*p*
PE	7.00	0	7.00	0		

SE	12.25	3.13	8.75	3.13	10.000	.000*
PE/S	19.25	3.13	15.75	3.13	10.000	.000*
SE/S	30.19	3.35	21.88	2.39	65.241	.000*

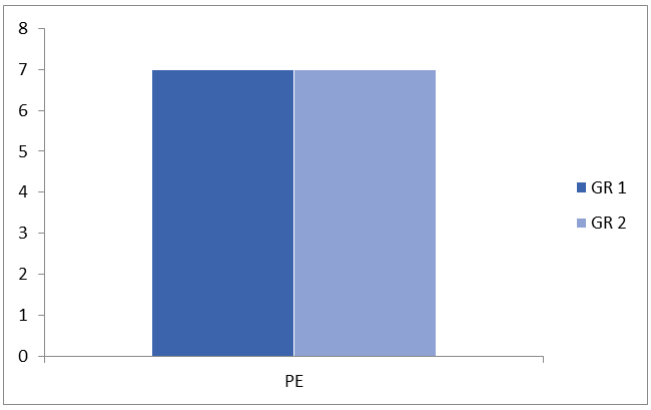

Figure 1: Comparison between the two groups at the PE tasks.

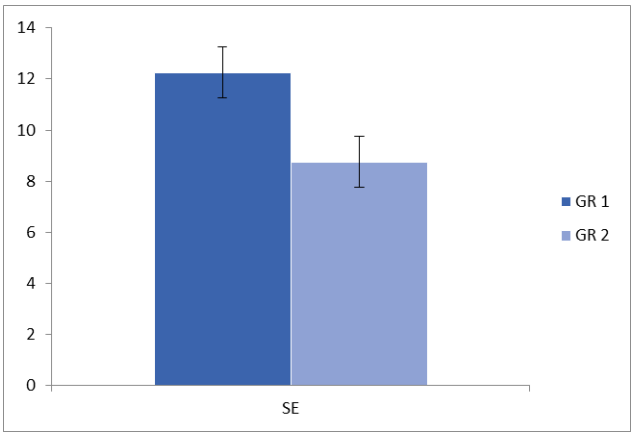

Figure 2: Comparison between the two groups at the SE tasks**.**

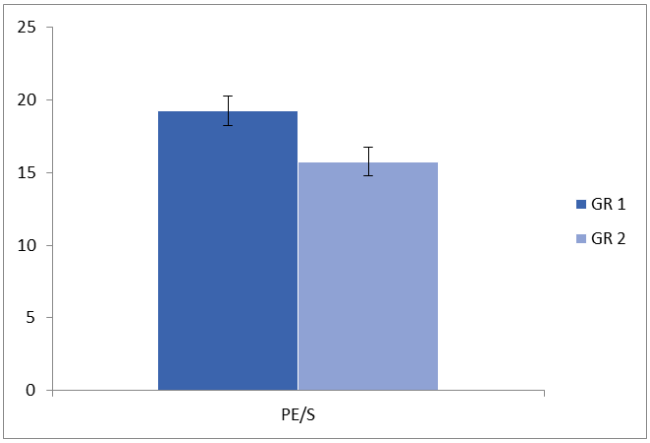

Figure 3: Comparison between the two groups at the PE/S tasks.

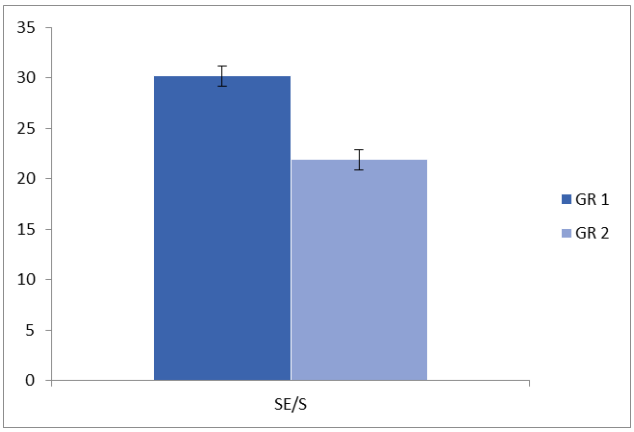

Figure 4: Comparison between the two groups at the SE/S tasks.

4. Discussion

Virtual reality is an "embedded technology" that provides the sensation of immersion in a virtual environment, thanks to a computer graphics simulation that allows users to immerse themselves in an interactive interactive world where different types of sensory and emotional experiences are encountered. For this reason, VR helps improve movements, actions and emotions adapted to the context. VR has been considered an advanced technology useful for the diagnosis of neurodevelopmental disorders and for treatments, especially with ADHD by several authors [27]. Virtual reality (VR) includes all emerging technologies, they are contributing to the expansion of new solutions to various problems. The development of virtual reality has allowed the use of new training and intervention tools that are much more effective and promising than traditional tools. VR environments offer the possibility to simulate real situations; it is possible to create environments that are difficult to live in everyday life [28]. The use of virtual reality has shown positive results in recent years in the context of neurodevelopmental disorders, particularly in ADHD. Some authors have studied the relationship between the use of virtual content and the increase in interest, motivation as well as the increase in sustained attention without distractions [29]. In fact, other studies have shown that children with ADHD thanks to VR are better able to complete attention tasks than traditional techniques. Because participants with ADHD make many mistakes and excessive body movements in their tasks, other studies have shown that VR plays an important role in improving these conditions and reducing symptoms and behavior problems [30]. Virtual reality also acts on the TOM, it also has the ability to clarify some of the cognitive processes, including attention, memory and executive function [31]. Theory of Mind (ToM) is the ability to attribute mental states to others to make sense of their behavior. ToM research has informed understanding of the atypical social behavior present in people with ADHD, and there is growing awareness of the limitations of 'classic' ToM tasks. With the recently developed tasks, however, VR was used to try to measure ToM by examining the accuracy of mental status attribution after watching video clips of social situations via open-ended or multiple-choice questions [32]. Video-based activities require more than simple inference from images or cartoons and instead require the inference of more socially relevant cues. This is designed to reflect inference of mental state in "real" social situations. Recent research demonstrates that new RT- and video-based tasks can successfully measure atypical ToM [33]. Felton e Jackson, underline that emotions are an essential element, it is fundamental to experience and integrate into the world and their study states that virtual reality is a valid tool to improve the recognition of emotions [34]. In summary, although there were a limited number of studies, the results suggest that VR-based interventions help improve the cognitive performance of children and adolescents with ADHD on vigilance and sustained attention tasks and in emotion recognition, by reducing the number of omissions and increasing the number of correct responses to target stimuli with a large effect size. This also suggests a marked effect on alertness and

improvement of impulsivity or inhibitory control with VR. These findings are interesting because they suggest that VR-based interventions could improve inattention symptoms and thus be highly beneficial in children with ADHD of the inattention subtype. On the other hand, the results of the Bioulac study [35] showed that children who received VR-based interventions can better inhibit distractors. Furthermore, they also showed less impulsivity (with fewer omissions). At present, the application of virtual reality technology to clinical practice is still in its infancy. The content and indexes of the VR test still need to be expanded and improved. Health guidelines list possible side effects of virtual reality ranging from headaches, seizures, nausea, fatigue, drowsiness, disorientation, listlessness and dizziness. These symptoms are related to virtual reality diseases, which can endanger your health and life safety, as well as the effectiveness of virtual reality. Cybersickness can become a barrier to the use of training or rehabilitation tools in virtual reality environments. Thus, cyber disease can be prevented or managed by tailoring and customizing to the user's needs a number of device changes such as making the head-mounted display (HMD) lighter and ensuring moderate use of a VR system [35].

5. Conclusion

The results suggest that virtual reality technology, thanks to stable and controlled stimuli, can be very useful in interventions for children with ADHD because it helps to obtain constant progress, adapting to the needs of patients. We can therefore highlight how the use of VR can improve the management of inattention and hyperactivity, influence TOM and improve social skills and practical skills. Furthermore, VR provides safe learning environments that minimize errors, time and costs and is easy to use. However, the evidence for the effectiveness of VR-based treatment in our study is limited. The small sample size and the absence of a follow-up on the maintenance of acquired skills limit the generalization of the study. Our study provides preliminary evidence for the feasibility and use of VRI in preadolescent subjects with ASD even in the preliminary stages of emotional training. The purpose of the subsequent works will be to expand the sample, evaluate retention, establish if there are differences between the emotional training skills acquired in VRI compared to IIT, if any differences will also represent different starting points for the acquisition of further skills in social formation. Indeed, a more robust generalization of basic emotional literacy skills could favor a more stable and rapid acquisition in terms of acquisition and generalization of further social cognition skills.

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