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Case Report

The Robotic Construction Kit as a Tool for Cognitive Stimulation in Children and Adolescents: The RE4BES Protocol

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Abstract: Through numerous experiences, the robotics has been demonstrated to have good potential in the field of strengthening social skills in children with Special Educational Needs and in particular with autism spectrum disorder. There are still not many experimental studies on the cognitive enhancement and social skills of children with special needs conducted with robotics construction kits that, requiring both the construction of the robot body and the programming of its "mind", bring into play a multiplicity of cognitive and social skills. For the aforementioned reasons our team from the University of Palermo and from the Center MetaIntelligenze ONLUS developed the treatment protocol RE4BES, which is a collection of guidelines for realizing robotics personalized activities for children with special needs. In this paper, two studies will be described concerning the first application of activities drawn from the RE4BES protocol. The first study concerns the use of the robotic construction kits for the stimulation of visuo-spatial abilities; in the second study the robot construction kits have been used to stimulate the attentional abilities in a child with severe difficulties on focused attention tasks.

Keywords: educational robotics; cognitive stimulation; cognitive rehabilitation; learning disorders; special needs

1. Introduction

The term educational robotics (ER) is used to refer to the application of robotics in the educational and cognitive field. A growing number of studies have investigated several applications of technology-based intervention with children, especially in the field of autism. For example, some researchers showed that the use of Lego® kits during therapeutic groups for children with autism leads to an improvement in social skills and playing abilities (e.g., [1–3]).

Robots have been also widely used in cognitive training for people with intellectual disabilities. In one of our studies, we have documented a significant improvement in academic performance and some cognitive-motivational aspects of learning in a student with intellectual disability [4]. Other studies [5] showed that cognitive abilities, such as logical reasoning and working memory, are important prerequisites for programming the sequence of actions that are needed to adapt the robot to its environment. Furthermore, Fridin and Yaakobi [6] have showed that robotics can help to improve memory and attention in children with ADHD.

Finally, Caci, D'Amico, and Chiazzese [7] demonstrated that LEGO® and Kodu Game Lab [8] involve cognitive and academic skills and may be effective in the improvement of visual-spatial working memory and La Paglia, Caci, La Barbera and Cardaci, demonstrated the efucacy of robotics labs in stimulating metacognition [9].

In the ER field, two main typologies of robot are used. Some of these are humanoid or zoomorphic robots, like NAO [10] or Pepper [11]. These robots are mainly used in order to study human–robot interactions or to improve social skills in children, since they are able to reproduce human or animal-like interactive behavior. However, in this case, the user cannot modify the robot body, and, in order to program the robot behavior, a very high amount of expertise in computer programming is required. Another kind of tool is represented by the robotics construction kits, such as LEGO kits: they give to the user the opportunity to build small mobile robots using bricks, sensors, and motors and to program robot behavior using a very simple block programming language. These tools stimulate creativity and manipulation, and may be used in order to perform several activities and to teach different skills to children and adolescents. For these reasons, in this paper, we focus our interest in the use of robotics constructions kits as a tool for intervention in children with special needs.

2. The RE4BES Protocol

The RE4BES is a treatment protocol that was designed with the aim to improve cognitive, neuropsychological, behavioral, and social skills in children and adolescents with special needs. Basing its theoretical background on scientific literature about cognitive processes and psychological development, RE4BES foresees activities aimed at improving visual perception, attention, memory, linguistic abilities, thinking and reasoning, as well as motivational and emotional processes [12].

Moreover, RE4BES methodology is based on two further theoretical models: constructionism [13] and embodied cognition [14].

Constructionism considers learning as an active process that takes place in hands-on learning contexts, as opposed to methods that are exclusively based on the transferring of knowledge from the teacher to students.

Moreover, robots allow to set "authentic activities" [15,16], which require students to solve complex tasks over an extended period of time, offering them the opportunity to examine the task from different perspectives, using a variety of resources and providing the opportunity to collaborate and reflect.

The second theoretical model related to RE4BES is embodied cognition (EC), a multidimensional and interdisciplinary construct developed with contributions from different scientific disciplines such as neuroscience, psychology, philosophy, and the cognitive sciences.

The EC approach overcomes the debate about the role of brain/body or environment for the development of the human mind [17] and considers the body and the environment as an "extension" of the mind. In EC's perspective, every kind of human cognition is embodied: to understand the mind is important to consider parameters such as the body and its interaction with the environment. The body ensures the coordination between cognition and action and can facilitate or hinder specific cognition. In this sense, educational robotics could be considered as one of the best ways for allowing children to work with artificial extended minds.

Moreover, RE4BES takes advantage of the strong impact that construction kits have on children and young people, in terms of motivation and involvement.

Even if ER has been already used as a tool for rehabilitation in some studies [1–4,6], RE4BES is the first attempt to develop a complete treatment protocol that can be applied to children and adolescents with different types of cognitive difficulties. Following RE4BES guidelines, operators could use robotic construction kits as "toolboxes" in order to realize personalized activities for cognitive empowerment and cognitive rehabilitation.

Here, we describe the first applications of the RE4BES protocol with an adolescent and a child with special needs.

3. Case 1

The first study involved M., a 15-year-old boy attending the third class of upper secondary school.

M. showed low levels of self-esteem, school difficulties, and need for support in the study activities, especially those related to visuo-spatial skills (mathematics, geometry, physical education, etc.). Since childhood, he had been showing difficulties in expressive language and a delay in psychomotor development. He preferred activities that require the use of the verbal channel and he avoided activities that involve visuo-spatial or memory skills.

The cognitive profile, assessed using WISC-IV scale [18] resulted in a total QI score of 75. M. showed an inhomogeneous trend in different WISC-IV indices: verbal comprehension (90), visual-perceptual reasoning (74), working memory (70), and processing speed (88). Thus, we decided to focus our intervention on the empowerment of the most impaired areas, such as (1) spatial abilities, which in general are less developed than verbal ones (as evidenced by the difference between the verbal comprehension and visual-perceptual reasoning indexes), and (2) working memory, intended as the ability to maintain and to elaborate verbal and visual spatial information [19].

3.1. Method

In order to verify the influence of the treatment on M.'s verbal and spatial working memory abilities, he was assessed before and after the intervention.

Material and Procedure

Working memory abilities were assessed using the PML test (Prove per la misurazione della Memoria di Lavoro) [20], an Italian validated test battery that is composed of nine short-term memory and working memory tasks, using both verbal and non-verbal information, and five supplementary tasks for measuring executive processes and the rate of processing. In this study, we used only the nine short-term memory and working memory tasks. The tasks are as follows: non-word repetition; digit span; word span; short-term visual memory span; short-term spatial memory span; short-term sequential memory span; working memory word span; working memory number span; working memory visuo-spatial span.

All of them have an excellent level of apparent and content validity since they have already been used in other studies [21–24] and use similar procedure of other tasks widely used in scientific literature [25,26].

The non-word repetition task requires repeating a set of non-words orally presented, and the relative score corresponds to the number of phonemes that have been correctly repeated.

All the other tasks use a methodology of serial recall: people are presented with a set of digits, words or pictures, and are required to recall them in the same order as the presentation. The total span score corresponds to the sum of the serial lists that have been correctly recalled.

3.2. RE4BES Intervention

M. followed an RE4BES protocol aimed at enhancing visuo-spatial abilities and visuo-spatial working memory. Moreover, in order to improve his self-esteem and self-efficacy [27], the intervention was integrated with a variety of cognitive-behavioral techniques [28].

They consisted in specific learning experiences designed to teach M. to monitor his negative, automatic thoughts (cognitions), to recognize the connections between cognitions, affect, and behavior, and to examine the evidence for and against his distorted automatic thoughts.

Each of M.'s achievements during the activities was adequately reinforced in order to reduce devalued thoughts and to improve his motivation. The activities are detailed in Table 1.

A therapist (the RE4BES instructor) conducted the treatment, and a psychologist (the observer) monitored its effects. The activities were performed using a Lego EV3 kit and an IN-o-Bot robot.

Table 1. Activities included in theM's. RE4BES treatment protocol.

Activity	Description	Abilities	Time
Seeking for the Pieces	This is the starting activity of every educational robotics work with a construction kit. The subject has to identify the pieces useful for building the robot. This activity stimulates different perceptual processes in various subtasks: piece search (shapes and colors selection), classification of pieces in the box, order determination (classification according to shape or color), etc.	Short-term memory, visual and tactile memory, fine motor, attention, visual-perceptual reasoning, multisensory integration	30 min/1 h
Assembling	This commits the subject to the construction of a robot (or other) that can be assembled following univocal criteria. The pieces often are very small and require strong motor efforts, especially in cases where there are also slight motor deficits. This work can stimulate different perceptual processes in various subtasks: physical and mental rotation, placing pieces in the right position, planning, assembling pieces in the right sequence, etc.	Short-term memory, procedural memory, mental rotation, fine motor skills and prassies, attention, visual-perceptual reasoning	30 min/1 h
Programming	The basic programming tasks easily explore all the functions of the robot (effectors and sensors). For example, the simple programming of a robot may stimulate an understanding of cause/effect relationships, analysis of the surrounding environment (e.g. light conditions), analysis of the movement surfaces, and awareness of the presence of risks/obstacles in the environment. In programming, the same behavior can be programmed in different ways, more or less efficiently, and this stimulates both the creativity and the possibility of acting for trials and errors and of having an instant confirmation of performances.	Computational thinking, logic, abstraction, attention, metacognition, communication	1 h
Span H/R	This is an activity inspired by the span tasks, in which the subject has to reproduce a sequence of items after viewing them for a few seconds. In this case, a sequence of cards that reproduces certain behaviors is presented for a few seconds. The subject then has to reproduce them by activating the related programming blocks in the robot. It starts with sequences from 2 or 3 cards. The subject starts to perform sequences of behaviors ranging from 2 upwards; after three attempts with at least one correct answer, the sequence increases by one item; when he collects three consecutive errors in recalling the sequence, the activity stops.	Visuo-spatial working memory, attention, memory, computational thinking	30/45 min
Spatial Orientation with Array	The robot is inside a two-dimensional array and the subject has to program its movement in order to reach a goal represented by specific coordinates. Every square of the array corresponds to one step of the robot. The difficulty of the routes increases after each success.	Working memory, attention, visual-perceptive reasoning, computational thinking, planning, metacognition	30 min
Spatial orientation without array	In this activity, the subject has to program the robot to move across a path to reach a pre-established goal in an open field. This activity requires the subject to plan the path using his/her mental imagery and then to reproduce it using the programming interface.	Working memory, attention, visual-perceptive reasoning, computational thinking, planning, metacognition	30 min

3.3. Re-Test Phase

Seven days after the end of the treatment, M. was re-tested using the PML in order to monitor any improvements compared to the initial condition. Graph 1 shows the differences in each PML task score before and after treatment.

3.4. Results and Discussion

The graph (Figure 1) shows that, compared to the pre-intervention assessment phase, M. showed improvements in digit span, short-term spatial memory span, short-term sequential memory span, and working memory number span.

On the contrary, there were no improvements in working memory word span or short-term visual memory span, and there was a worsening in word span. Finally, there was no effect on non-word repetition, where M.'s performance reached a ceiling effect.

Although in this study it was not possible to construct an experimental design due to the lack of multiple measurements in the baseline condition, results evidenced an improvement in 4 out of 9 working memory abilities measured, and this was definitely a good result, considering the short period of intervention.

Moreover, we should stress that, even if the RE4BES protocol used was aimed at enhancing visual-spatial abilities, M. improved also his abilities in some of the verbal tasks, as demonstrated by results in digit span and working memory number span [29].

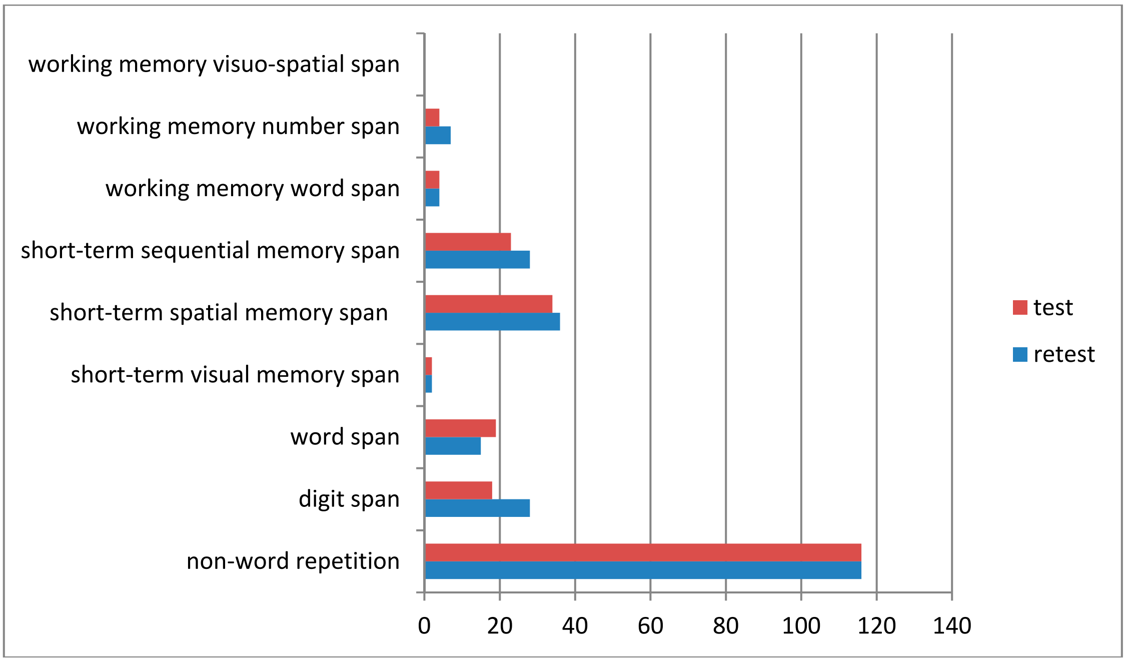

Figure 1. Comparison between pre-test and post-test for PML results.

4. Case 2

Study 2 involved S., a 10-years-old boy, with an intellectual disability and behavioral problems related to inattention/hyperactivity. S. attended the third class of Italian primary school and had many school difficulties. S. also refused to undergo any traditional activity that was proposed to him, including testing activities.

4.1. Method

Differently from Study 1, in Study 2, an A-B-A single case quasi-experimental design was used, in which the participant was repeatedly pre-tested (baseline phase or B1), repeatedly tested (treatment phase or T) during the treatment, and repeatedly re-tested at the end of the treatment (second baseline or B2).

In this case, the RE4BES protocol was aimed to reduce the behavioral problems. The treatment was carried out for one month with two meetings per week. Similarly to Study 1, a therapist (the RE4BES instructor) conduced the activities and a psychologist (the observer) monitored the effects of the training. The activities were performed using a Lego EV3 kit and a LEGO We-Do 2.0 kit.

4.2. Assessment

A questionnaire was administered to the parents 5 times during the week before starting the treatment (B1), 16 times during the treatment (T), and 5 times after the treatment (B2).

The questionnaire was realized for the aims of the study, by adapting the questionnaires for parents included in the Italian Battery for ADHD [30]. The BIA's questionnaires are based on the co-morbid models for ADHD [31–33] and on the diagnostic criteria described in the DSM-IV for ADHD [34].

The final questionnaire was composed of 40 items exploring the five main areas of inattention/hyperactivity problems: (1) inattention; (2) hyperactivity/impulsivity; (3) aggressiveness/oppositive behaviors; (4) depression/anxiety; (5) social behaviors. For each item, the parents had to assign a score from 0 (none) to 4 (much) in a Likert scale.

4.3. Baseline

Parents assigned to S. high scores in the areas of inattention (mean score 8.6), hyperactivity/impulsivity (mean score 6.6), and social behaviors (mean score 8.6). On the contrary, they assigned zero-order scores in the areas of depression/anxiety (0.6) and aggressiveness/oppositive behaviors (1.2), since S. did not present these types of behaviors.

4.4. Treatment Phase

S. followed an RE4BES intervention protocol aimed to reduce the intensity and frequency of problem behaviors in eight meetings over one month (2 per week), lasting 1 h each. The activities proposed aimed firstly at capturing the child's interest. The use of a construction kit that combines educational aspects with playful ones quickly achieved this aim. During the course of the activities, we tried to set the basic rules of social and turn-taking skills integrating robotics activities with cognitive-behavioral strategies [35]. The robot was used as a tool to mediate the learning of new positive behavioral models, not only for cognitive stimulation. Thus, we guided S. to inhibit impulsive behavior and to respect the rules, and to extinguish problem behaviors (throwing objects, interrupting activities). At the same time, we reinforced positive behaviors such as completing tasks, listening to suggestions, and using language to express requests and needs. The activities are showed in Table 2.

Table 2. Activities included in the S.'s RE4BES treatment protocol.

Title	Description	Abilities	Time
Search for the Pieces	This is the starting activity of every educational robotics work with a construction kit. The subject has to identify the pieces useful for building the robot. This activity stimulates different perceptual processes in various subtasks: piece search (shapes and colors selection), classification of pieces in the box, order determination (classification according to shape or color), etc.	Short-term memory, visual and tactile memory, fine motor, attention, visual-perceptual reasoning, multisensory integration	30 min/1 h
Assembling	This commits the subject to the construction of a robot (or other) that can be assembled following univocal criteria. The pieces often are very small and require strong motor efforts, especially in cases where there are also slight motor deficits. This work can stimulate different perceptual processes in various subtasks: physical and mental rotation, placing pieces in the right position, planning, assembling pieces in the right sequence, etc.	Short-term memory, procedural memory, mental rotation, fine motor skills and prassies, attention, visual-perceptual reasoning	30 min/1 h
Programming	(See the same activity in Table 1).	Computational thinking, logic, abstraction, attention, metacognition, communication	1 h
Tidy	The reordering activity is also important at the end of each meeting because, besides stimulating a series of cognitive abilities, it has an educational value correlated to the respect of the rules. Especially with young children, it is very important that any positive behavior is adequately reinforced.	Short-term memory, visual and tactile memory, fine motor, attention, visual-perceptual reasoning, multisensory integration	10/15 min

4.5. Data Analysis

In order to verify the effect of the treatment, the C test was used. It quantitatively evaluates changes based on the treatment in the time series data [36,37]. Through the C test, it is possible to compare B1/T phases, B1/B2 phases, or T/B2 phases and identify any statistically significant changes or trends.

If the treatment was effective, the comparisons between temporal series relative to B1/T or B1/B2 should be statistically significant. On the contrary, the comparisons between temporal series relative to T/B2 should not show statistically significant changes.

4.6. Results and Discussion

Results showed that S. significantly reduced his problem behaviors for the effect of the treatment. Indeed, while the comparison between T and B2 phases, as expected, shows a stable trend, there are significant differences between the B1 phase and the T phase. This result refers to the total score (p < 0.05, see Table 3), as well as the inattention (p < 0.05) and hyperactivity/impulsivity scores (p < 0.01).

Table 3. C test results comparing B1/T phases, B1/B2 phases, and T/B2 phases.

	B1/T/B2		B1/T		T/B2		B1/B2	
	C	Z	C	Z	C	Z	C	Z
Total scores	0.63	3.04 *	0.6	3.00 *	0.23	1.11	0.61	2.16
Inattention	0.65	3.14 *	0.61	2.94 *	0.25	1.20	0.6	2.89 *
Social behaviors	0.51	2.46	0.58	2.80	0.22	1.06	0.46	2.22
Hyperactivity/impulsivity	0.66	3.19 **	0.6	3.00*	0.19	0.91	0.59	2.85 *
Depression/anxiety	/	/	/	/	/	/	/	/
Aggressive/oppositional behaviors	/	/	/	/	/	/	/	/

* = p < 0.005 ; ** = p < 0.001.

Figure 2 shows the total scores obtained in the questionnaire compiled by parents during each day of the three phases. Results demonstrated that parents observed a global decrease in S.'s inattentive or hyperactive behaviors. On the contrary, the treatment had no effects on the social behavior scores. Concerning the depression/anxiety or aggressiveness/oppositive behavioral scores, S. obtained a floor effect in all phases (B1, T, and B2) since, in the parents' evaluation, he did not present these types of behaviors.

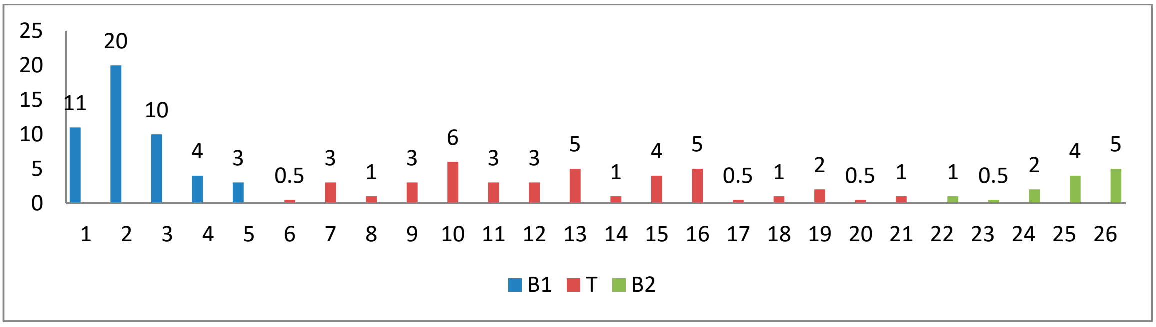

Figure 2. Comparisons between temporal series relative to B1, T, and B2 phases.

5. General Discussion and Conclusions

As above mentioned, the studies described in this paper represent the first application of the RE4BES protocol. Although the studies proposed here have been carried out in a limited time range and have some methodological weakness, the obtained results are encouraging. Results of both studies reinforces the idea RE4BES protocol can be considered a valuable and innovative tool for interventions with children and adolescents with different special needs.

In particular, in Study 1, the RE4BES protocol was used in order to empower particular cognitive skills, and the results demonstrated the effectiveness of intervention both on the target skill (visual spatial abilities) and on verbal short term and working memory.

In Study 2, whose aim was to motivate and to engage a child that, in the early stages, refused to perform any kind of task and activity, we obtained an important effect on motivation and engagement in the activities. Results demonstrated that the playful use of robots has allowed us to lengthen the learning sessions and reduce his inattentive or hyperactive behaviors.

In general, the effectiveness of RE4BES protocol may be due to several reasons: firstly, it may have a motivational base, since robotics increases, in all children, the motivation and the engagement towards learning in situations that are often seen by children as passive and not very stimulating. Engagement and motivation are two closely related concepts very important for learning. Motivation is considered an attribute necessary for the engagement process [38]; at the same time, intrinsic motivation is an active engagement with activities that people perceive as interesting [39]. Motivation and engagement have a bidirectional relationship, which means that motivation could lead engagement and vice versa.

Moreover, the so-called "digital native" generation [40] is particularly interested (thus, motivated and engaged) in digital and multimedia technologies. In this respect, Beran and collaborators [41] have showed that children spend more time playing with technological tools than with "non-technological" ones. Thus, the digital natives are probably more prone to using digital devices than traditional methods since they perceive technologies as games and the time spent using technologies as time spent playing.

Many studies have documented the beneficial effect of using playful activities in educational or therapeutic settings (e.g., gamification or "the use of game design elements in non–game contexts" [42–44]) since these increase user engagement and user experience within a problem solving context.

Another important aspect to stress is that RE4BES protocols combine physical and mental experiences: these particular aspects make robots particularly suitable for children with special needs. Many of them, as is known, have difficulties in manipulating abstract concepts and are facilitated by the use of concrete objects. Robotics kits become, for these children more than for typically developed ones, objects to-think-with [11] and help therapists to create "play-therapy" [45] settings.

Obviously, for an effective use of the RE4BES protocol, it is necessary that the interventions are lead by professionals that know how to use robotics within a therapeutic path and in particular that are able to (1) identify the special needs of the children, (2) know which specific cognitive process is involved in each RE4BES activity, and (3) recognize the cognitive strategies that each children use in order to copy with robotic problem solving activities.

Moreover, RE4BES needs to be improved with more case studies, more activities, and some methodological improvements. Firstly, it will be necessary to design longer-lasting interventions with different follow-up assessments in order to clarify if, behind the motivational boost that robotics exerts in digital natives, these tools allow a more in-depth and meta-cognitive stimulation than traditional methods; second, it would be useful to realize RE4BES interventions that involve small groups of subjects matched for cognitive levels and ages, and that are aimed at improving cognitive, behavioral, and social areas. Indeed, as already shown in Study 2, the social behavior area was the only one in which no significant increase was found. This result is probably due to the "one-to-one" setting used in the study.

Following these suggestions, we are confident that interventions based on RE4BES protocols could bring real benefits in clinical practice and in the rehabilitation of children and adolescents with special needs.

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