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Using educational robotics to support motor, cognitive, and social skills in a child with spinal muscular atrophy. A single-case study

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ABSTRACT

This study reports the results of a single-case intervention involving a child with spinal muscular atrophy. The aim of the study was to promote fine motor skills, visual-motor integration, attentional behaviors, and learning. The treatment was based on the RE4BES protocol, which consists of a set of guidelines for conducting tailored educational robotics activities designed for children with special needs. We employed an experimental single-case ABA design, including Baseline 1 (A1), Treatment (B), and Baseline 2 (A2), with eight sessions per phase. The treatment phase involved activities with Blue-Bot and LEGO® WeDo 2.0. Results showed significant improvements in gross and fine motor skills from baseline to the treatment phase, with these gains maintained after the intervention. Moreover, in alignment with the main goals of school inclusion for people with special needs, results demonstrated that the intervention also improved awareness, flexibility, cooperation, and initiative within the classroom. Despite the study's limitations, the findings support the effectiveness of the RE4BES protocol and suggest that educational robotics can be a valuable tool in special education settings.

1. Introduction

The integration of digital technologies into educational settings has led to the emergence of innovative approaches that transform traditional learning paradigms. Among these, Educational Robotics (ER) has gained increasing recognition for its ability to combine practical, experiential learning with the development of cognitive, social, and emotional competencies (Di Lieto et al., 2017). ER refers to an innovative teaching approach based on the use of robots in schools and it is aimed at enhancing cognitive functions as well as making teaching more engaging, motivating, and effective (Anwar et al., 2019). ER activities typically involve the design, programming, and operation of robots by students, fostering creativity, collaboration, and critical thinking. This approach aligns with contemporary pedagogical models that emphasize active participation, inclusivity, and the cultivation of 21st-century skills (Alimisis, 2013). In recent years, educators and researchers have explored the application of ER not only in mainstream classrooms but also in special education contexts (Daniela & Lytras, 2019). As inclusive education gains prominence globally, there is a growing need to identify and implement strategies that can effectively support learners with diverse needs (Papakostas et al., 2021). ER has shown promise in addressing this challenge, offering accessible, engaging, and adaptable learning experiences for students with various disabilities, including cognitive, developmental, and motor impairments (Nanou & Karampatzakis, 2022; Papakostas et al., 2021; Syriopoulou-Delli & Gkiolnta, 2021).

This paper contributes to this evolving field by presenting a single-case study focused on a child with Spinal Muscular Atrophy (SMA), a rare neuromuscular condition (Kolb & Kissel, 2011). Through the implementation of the RE4BES protocol (D'Amico & Guastella, 2018; 2019; Guastella et al., 2020), the study examines the potential of ER to support the development of motor, cognitive, and social skills in a personalized and inclusive manner. The research aims to provide preliminary evidence for the effectiveness of ER-based interventions in supporting meaningful participation and learning among children with complex physical needs.

1.1. Literature review

In recent years, ER has gained significant traction as a transformative pedagogical tool that merges technological engagement with cognitive, motor, and social-emotional development. Rooted in constructivism and

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embodied cognition theories (Bada, 2015; Bruner, 1997; Narayan et al., 2013; Papert, 1980, 1993; Shapiro, 2019), ER facilitates active learning through hands-on experiences involving the design, programming, and manipulation of robotic devices. These experiences stimulate a variety of skills, from problem-solving and critical thinking to collaboration and emotional regulation (Anwar et al., 2019). ER activities foster curiosity, motivation, and engagement by supporting learning through play and hands-on experience (Anzai & Simon, 1979). There is an extensive literature documenting the effectiveness of ER applied in normal learning/teaching contexts (Athanasiou et al., 2019; Caci et al., 2013; Fahimirad & Kotamjani, 2018; Uslu et al., 2022). While ER has traditionally been applied in mainstream STEM education, recent studies have expanded its scope to include learners with Special Educational Needs (SEN), recognizing its potential for inclusion and personalized learning (Papakostas et al., 2021). Through collaborative robotics activities, students with cognitive, developmental, or motor disabilities can improve communication, social interaction, and self-efficacy in an engaging and accessible learning environment (Nanou & Karampatzakis, 2022; Papakostas et al., 2021; Syriopoulou-Delli & Gkiolnta, 2021). In addition, there are interesting contributions in the field of cognitive rehabilitation or, more generally, cognitive process enhancement for children with SEN (Catlin & Blamires, 2019; Di Lieto et al., 2020). Evidence shows that ER interventions conducted in the school context improved school performance and motivation in children with intellectual disabilities (D'Amico & Caci, 2005). Fridin and Yaakobi (2011) enhanced attentional and memory skills in children with ADHD by successfully using ER activities. In addition, other studies (Diehl et al., 2012; Robins et al., 2005) showed that ER increased social skills, communicative competences, and playing abilities in children with autism spectrum disorders (ASD). Overall, the growing body of evidence clearly demonstrates the potential of ER to function both as a cognitive artifact and as a social tool, particularly within inclusive educational settings (Nanou & Karampatzakis, 2022; Papakostas et al., 2021; Syriopoulou-Delli & Gkiolnta, 2021).

Despite growing interest in the use of ER, only a limited number of studies have explored how adapted robotic systems can serve as motivating and effective educational tools for children with complex physical needs, such as those with rare neuromuscular disorders like Spinal Muscular Atrophy (SMA) (for a review, see van den Heuvel et al., 2016). SMA presents unique educational challenges due to severe limitations in voluntary muscle control, affecting both fine and gross motor functions (Kolb & Kissel, 2011). Children with SMA face unique challenges in fine and gross motor coordination, attention, and visual-motor integration—areas that ER interventions may support.

1.2. The current study

This study aims to explore the effects of a ER intervention on multiple developmental domains in a child with SMA. Specifically, it investigates the impact of a tailored ER intervention — the RE4BES protocol (D'Amico & Guastella, 2019) — involving a 6-year-old child with SMA. Previous studies have shown that the RE4BES protocol is effective in promoting social-emotional skills, visuospatial abilities, and behavioral regulation in children with intellectual disabilities, borderline cognitive functioning, attention difficulties, and autism spectrum disorder (D'Amico & Guastella, 2018; 2019; Guastella et al., 2020). The protocol integrates cognitive, social, and motor objectives into a unified framework and seeks to evaluate its effects on motor coordination, visual-motor integration, attentional behavior, cognitive and social engagement. The research questions guiding this study were as follows:

- RQ1: Can the RE4BES protocol promote the development of fine and gross motor skills in a child with SMA?
- RQ2: Can the intervention enhance visual-motor integration and attention-related behaviors?
- RQ3: Are there observable improvements in the child's social and cognitive engagement during the robotics activities?

By providing empirical evidences, this study aimed to contribute to the advancement of inclusive education practices and support the development of tailored interventions for learners with complex disabilities.

2. Method

2.1. Participant

V. was a 6-year-old female child with SMA, who was attending the first class of primary school at the time of intervention. She showed motor impairment and memory difficulties. She built positive relationships with both the class group and the teachers, and she took part enthusiastically in class activities and interacted without difficulties. In addition, she presented good language skills, communicated clearly and without any difficulties. In terms of autonomy, she showed good ability in making both educational and personal choices. Finally, she showed good perceptual ability, motivation to study and learn, and was able to keep attention for proper times. Parents of the child involved in the study read and signed an informed consent.

2.2. Measures

To measure the effectiveness of the RE4BES protocol in improving attentional behaviors, motor skills, and social and cognitive attitudes we used observational rating scales completed by experimenters. Moreover, before and after treatment, visual-motor integration was assessed using a performance test. Rating scales and performance test are described below.

Attentional Behaviors (Fedeli & Vio, 2017) is a 16-item rating scale that assesses four dimensions (i.e., attentional activation, attentional maintenance, working memory and selectivity) on a 4-point scale. The ratings range from 0 (absence of attentional behavior impairment) to 3 (presence of attentional behavioral impairment). The scale produces three scores: total, energy (attentional activation, attentional maintenance), and organization (working memory and selectivity).

Motor Skills (Fedeli & Vio, 2017) is a 16-item rating scale for the assessment of impairment in gross and fine motor skills on a 4-point Likert scale (from 0 = never to 3 = always). The scale produces one total score so that high score suggests impairments in motor skills.

Social and Cognitive Attitudes is a 24-item scale that was created ad hoc for the study which assesses difficulties in the dimensions of autonomy, cooperation, awareness (i.e., social attitudes), flexibility, initiative, planning (i.e., cognitive attitudes). The response scale is a 4-point Likert type scale (from 0 = never to 3 = always). The scale produces six scores, one for each dimension.

Developmental Test of Visual-Motor Integration (VMI; Beery, 1997) is a performance test aimed at analyzing how the child integrates her visual and motor skills. The test requires to copy a developmental sequence of geometric shapes. The complete form consisting of 27 items was administered. In addition, the two supplementary tests were administered: the VMI of Visual Perception, where the child within 3 min had to identify, among a series of alternatives, the shape identical to the presented stimulus (equal to the VMI stimuli) for a total of 27 shapes; the VMI of Motor Coordination, where the child within 5 min had to trace the stimulus shapes with a pencil without leaving the edges of the printed path. Even in this case, there are a total of 27 shapes to draw. Raw scores for VMI and supplementary tests are computed by assigning one point for each correct answer. The raw scores are then converted to standard scores (Mean 100, SD 15).

2.3. Study design

This study adopted a single-case experimental design (SCED) with an ABA structure: Baseline 1 (A1), Treatment (B), and Baseline 2 (A2), with eight sessions per phase. This design is particularly well-suited for research in special education, rehabilitation, and clinical fields—especially when the target population includes individuals with rare or complex conditions for whom group designs may not be feasible (Horner et al., 2005; Ledford & Gast, 2018; Smith, 2012). In this study, the SCED framework allowed for detailed, repeated observation of changes in the child's performance across time, phases, and intervention exposure.

SCEDs are recognized for their methodological rigor as they allow the establishment of a functional relationship between the intervention and the outcome variables through repeated, systematic measurement and manipulation of the independent variable within subjects (Horner et al., 2005; Kazdin, 2021). SCEDs can demonstrate strong internal validity, especially when dependent variables are well-defined, reliably measured, and assessed across multiple baseline and intervention phases (Smith, 2012).

In our study, the dependent variables—attentional behaviors, motor skills, and socio-cognitive attitudes—were operationalized clearly and assessed repeatedly across the three phases. This enabled an evaluation of both level and trend changes that could be attributed to the RE4BES intervention. The use of a SED in this study is particularly suited to the specific characteristics of the participant and the individualized nature of the intervention.

2.3.1. Experimental procedure

Activities took place in school, during classes, and were performed by the experimenter G.P., a special needs teacher who was trained for ER and in particular for the application of RE4BES protocol. To evaluate the effectiveness of the treatment in improving attentional behaviors, motor skills, and social and cognitive attitudes, an experimental single-case ABA (baseline 1 = A1, treatment = B, and baseline 2 = A2) type study was designed, in which the child was observed, and the experimenter completed the rating scales during each meeting. Baseline 1 and 2 phases involved 8 meetings each, whereas treatment phase involved 8 meetings (4 for Blue-Bot, and 4 for LEGO® WeDo 2.0), with a total of 24 meetings (1 h per each) and 24 observations (Fig. 1). On the contrary, since VMI is a performance test that was completed by the child, it was administered only one time before and after the treatment (during meeting 1 and meeting 24). Overall, the study lasted two months.

2.3.2. The RE4BES protocol

The RE4BES protocol (D'Amico & Guastella, 2019) is a structured set of guidelines designed to support professionals in planning and delivering personalized ER activities for children with SEN. It is based on the premise that the mere availability of a robot or construction kit is not sufficient to ensure an effective and inclusive learning experience. Instead, successful implementation requires careful adaptation of the activities to the developmental level, functional profile, and specific characteristics of each child. The protocol is grounded in principles of task analysis and the classification of robotics activities according to the cognitive, motor, and socio-emotional functions they are intended to stimulate.

RE4BES offers a digital platform that provides a library of ER activities, each annotated with detailed information about its objectives, required skills, type of robot involved, and suitability for different profiles of learners with SEN. The protocol categorizes ER activities into different types—preliminary, construction-based, and programming-focused—and further distinguishes between levels of complexity, degrees of required autonomy, and areas of competence addressed (e.g., visual-motor coordination, attention, memory, planning, problem-solving, and social interaction).

In the present study, the RE4BES framework was used to select and organize all intervention activities, ensuring that each task was appropriate for the child's neuromuscular condition and educational goals. For example, during the preliminary phase, the participant engaged in graphomotricity exercises, memory games, and basic construction tasks using traditional LEGO® bricks (Table 1), which aligned with RE4BES recommendations for building foundational visual-perceptual and fine motor skills before introducing robotic tools. These preliminary tasks also supported attention, sequencing, and visuoconstruction—skills

Table 1
Preliminary activities for planning and construction.

Activity	Description
Orientation 1	Implementation of graphomotricity paths, following the graphic sign or reproducing the corresponding graphic sign with the use of finger paints, colored pencils, and markers.
Left and right	Play the same sequence of directional cards after displaying them a few seconds.
Copy	Reproduction of the robots made by the experimenter with LEGO® constructions.
Orientation 2	Guided routes using the workbook with the help of directional arrows.
Creation	Free construction with LEGO®s; finding and assembling the bricks with visual support of the various steps needed to make the previously chosen robots.

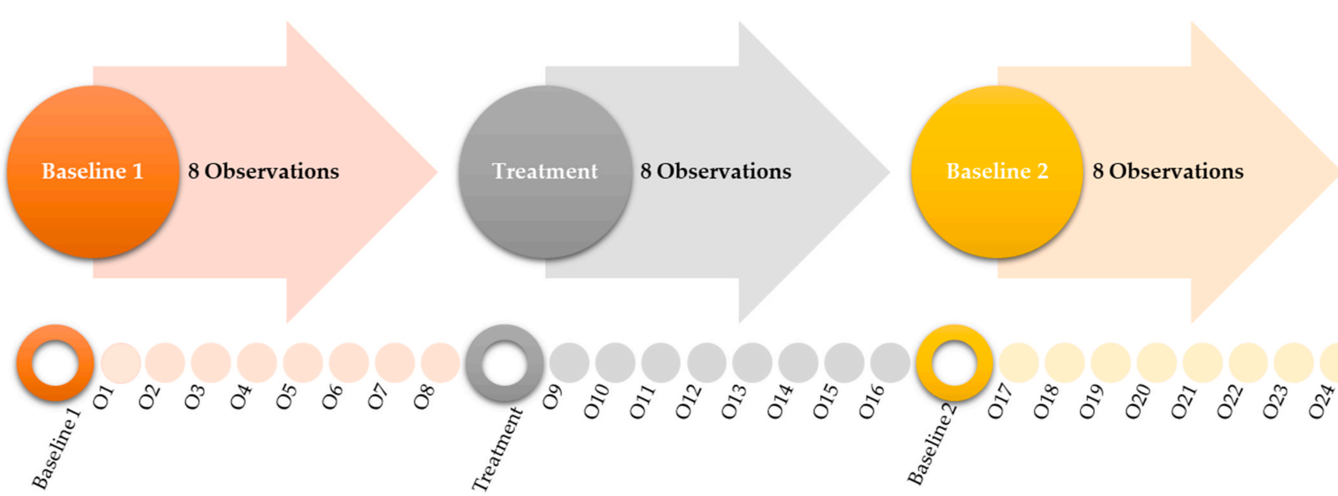


Fig. 1. Research design and data collection procedure.

targeted by the protocol as prerequisites for successful ER engagement.

Following this preparatory stage, Blue-Bot was introduced as the first programmable robot. Consistent with RE4BES guidelines, Blue-Bot was selected for its ease of use, visual clarity, and adaptability to children with limited motor strength. Activities such as “Space” and “Robotics: Orientation with Math” (Table 2) were chosen to develop spatial reasoning, planning, working memory, and attentional control. These tasks required the child to visualize routes, sequence commands, and engage in turn-taking and collaboration during free play with peers—all of which are competencies explicitly targeted in the RE4BES task classification system.

In the second part of the intervention, LEGO® WeDo 2.0 was employed for its greater complexity and versatility. As indicated in the RE4BES protocol, construction-based kits such as WeDo are ideal for stimulating visuospatial abilities, symbolic reasoning, fine motor precision, and executive functions. Activities such as “Seeking for the Pieces” and “Assembling” (Table 3) directly implemented RE4BES recommendations by promoting tactile and visual memory, part-whole relationships, spatial coordination, and multisensory integration. Furthermore, the “Coding” and “Free Activities” tasks involved cause-effect reasoning, logical sequencing, error correction, and creativity—again, functions targeted in the RE4BES protocol’s matrix of activity profiles.

Overall, the RE4BES protocol served not only as a general framework but also as a specific guide in the design, adaptation, and progression of all intervention phases. Each activity was purposefully selected based on the child’s profile, and aligned with the protocol’s task-function mapping, ensuring a comprehensive, developmentally appropriate intervention across motor, cognitive, and social domains.

2.3.3. Types of robots employed

For the study we employed two types of robots were used (see Fig. 2): Blue-Bot (TTS Group, n.d.) and LEGO® WeDo 2.0 (LEGO, n.d.). Blue-Bot is a programmable floor robot that helps developing logic processes, lateralization, visualization of paths in space. Blue-Bot allows con-structing composite programs by using the Blue-Bot app via digital devices or by selecting arrows placed on the robot’s shell in the correct order for performing planned paths. The commands both on the app and robot’s shell involve direction (forward and backward), rotation (90° to the right or left), and control (start, pause, cancel). Confirmation of commands is done by emitting sounds and lights. LEGO® WeDo 2.0 is the educational robotics set that enables coding and programming small robots using LEGO® bricks. It helps developing logic, problem-solving, attentional processes, visuo-spatial orienting, fine motor skills, and learning. Each set consists of a container with a handy tray for sorting the pieces, with labels for cataloguing the different com-ponents, motor, sensors (motion and tilt), and bricks. Compared to Blue-Bot, LEGO® WeDo 2.0 can be assembled in a variety of ways, shapes, and sizes to build the robot body. Therefore, children are requested to use visuo-construction abilities which involve the coordination of fine motor skills with spatial abilities. Moreover, LEGO® WeDo 2.0 allows to create more complex and articulate programs that involves the programming of motion and tilt sensors. Lastly, robots created with LEGO® WeDo 2.0 are programmable via Bluetooth by LEGO® WeDo 2.0 software or Scratch 3 free software.

Table 2
ER activities with Blue-Bot.

Activity	Description
Space	The participant must be able to orient by planning a path on top of a board following the directions represented by the colored directional arrows provided in sequence by the professional. After each success, through the addition of arrows and obstacles, the difficulty of the path is increased.
Robotics: Orientation with Math	Tags are placed on the table with addition operations. The participant, using the tablet interface, must program the robot to reach the tag and then calculate the second addend of the addition.
Free Activities	The participant is free to play with Blue Bot, using the tablet interface together with classmates.
Robotics: Orientation, Listening, Comprehension	Pictures representing a story are arranged by the professional on a double-entry table. The participant, after listening to the story, must, with the use of the tablet interface, program the robot to reach the pictures according to the time order.
Robotics and English	Using the tablet interface, the participant must program the robot to reach a specific box where a color is written in English with the help of the classmates.

Table 3
ER activities with LEGO® WeDo 2.0

Activity	Description
Seeking for the Pieces	The participant must find the pieces needed to build the robot. This activity stimulates different perceptual processes in different sub-tasks: classifying the pieces in the box, sorting by shape and color, determining the order of the pieces, again by shape and color, etc. This type of activity can stimulate different cognitive and metacognitive skills, such as short-term memory, tactile and visual memory, fine-motor skills, attention, visual-perceptual reasoning, and multisensory integration.
Assembling	This activity engages the child in building a robot or something else that can be assembled following unique criteria. The pieces are often small and require a lot of motor effort. This work can stimulate different perceptual processes in various subtasks: physical and mental rotation, placing the pieces in the right position, assembling the pieces in the correct sequence, etc.
Coding	Basic coding activities easily explore all robot functions (effectors and sensors). Simple coding can stimulate understanding of cause/effect relationships, analysis of the surroundings (e.g., multiple lighting conditions), analysis of motion surfaces, and awareness of the presence of hazards and obstacles in the environment. In coding, the same behavior can be set in diverse ways, and this stimulates both creativity and the ability to act by trial and error and to have immediate confirmation of performance. This activity can be used to stimulate computational thinking, logic, abstraction, attention, metacognition, and communication.
Free Activities	The same task described in Table 2 was performed, but this time using WeDo 2.0.

2.3.4. Experimental process

In this study, activities were implemented specifically for strengthening and developing gross and fine motor skills, given the neuromuscular disorder. Observations for baselines 1 and 2 took place in the classroom during school time. V. conducted regular educational activities as the rest of the classmates. During the first phase of the treatment, to create the prerequisites necessary for the introduction of ER, the participant did some preliminary activities based on graphomotricity, memory skills, construction, and coding activities, intended as the assignment of a code (rule or command) which allows the robot to act or move. The construction activities were performed using traditional LEGO®© bricks, with which she had to re-produce the robots made by the experimenter. The activities performed are described in Table 1.

Once the participant became familiar with the activities, the robots were introduced. To ensure a gradual approach to ER activities, Blue Bot was used first, which is a robot produced by TTS Group Limited in Britain in 2006 and it is intended for preschoolers. Blue Bot is shaped like a bee and requires no assembly operations. By successively pressing the directional buttons that are placed directly on the robot’s back, the child can simply program its path. However, in this case V. interacted with Blue-Bot by tablet due to difficulties in pressing buttons placed upon the robot (Fig. 3A). The activities, involving Blue-Bot are described in Table 2 V Conducted most of the activities individually. However, with the aim to promote the inclusion and social relationships with the

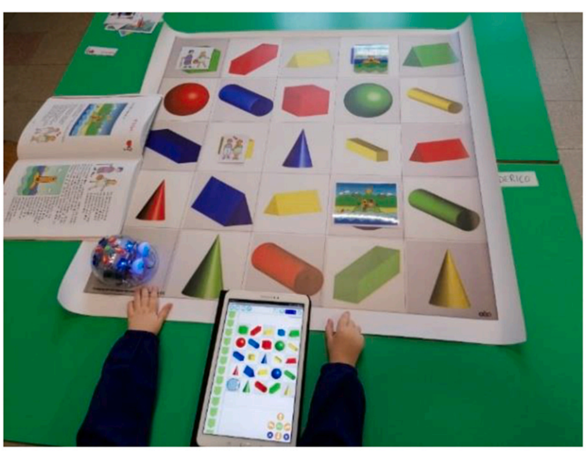
Note. From TTS Blue-Bot Bluetooth Programmable Floor Robot [Image], by TTS Group, n.d. (https://www.tts-group.co.uk/tts-blue-bot-bluetooth-programmable-floor-robot-single/IT10082.html). Copyright TTS Group.

(A)

*Note. F*rom LEGO® Education WeDo 2.0 Core Set 45300 [Image], by LEGO, n.d. (https://www.lego.com/it-it/product/lego-education-wedo-2-0-core-set-45300). Copyright LEGO.

(B)

Fig. 2. Robots used for the educational robotics activities: (A) Blue-Bot; (B) LEGO® WeDo 2.0.



Note. Photo taken by the authors. Product shown: TTS Blue-Bot Bluetooth Programmable Floor Robot (TTS Group, n.d., https://www.tts-group.co.uk/tts-blue-bot-bluetooth-programmable-floor-robot-single/IT10082.html).

(A)

Note. Photo taken by the authors. Product shown: LEGO® Education WeDo 2.0 Core Set (LEGO, n.d., https://www.lego.com/it-it/product/lego-education-wedo-2-0-core-set-45300).

(B)

Fig. 3. Experimental setting during treatment phase: (A) activities with Blue-Bot; (B) activities with LEGO® WeDo 2.0.

classmates V. also performed several free activities with Blue-Bot in collaboration with the classmates. In the second part of treatment phase, the LEGO® WeDo 2.0 Building Kit was used, which is more complex than Blue Bot because it offers the opportunity to build robots by choosing from several predefined types of robots or by choosing new ones (see Fig. 3B). Compared to Blue Bot, the LEGO® WeDo 2.0 has a limitation since it can only move back and forth and is not able to turn around. Since the main goal of the intervention was to improve hand fine motor skills, grasping skills and correct manipulation of everyday objects, a lot of time was spent on this activity. Table 3 presents the activities conducted using LEGO® WeDo 2.0. Once again, V. shared only free coding activities with her classmates.

2.3.5. *Data analysis*

Tau-U analyses were conducted to determine whether significant effects of the intervention occurred across the three phases of the single-case ABA design (Baseline 1 = A1, Treatment = B, and Baseline 2 = A2). Tau-U is a nonparametric statistical method that combines two widely used techniques: the Mann–Whitney *U* test, which assesses non-overlap between phases, and Kendall's Rank Correlation, which accounts for monotonic trends within and between phases (Parker et al., 2011). This approach is particularly appropriate for small-sample, time-series data, as it does not require assumptions of normality or independence.

In our analyses, we performed the following comparisons: (1) Baseline 1 vs. Treatment (A1 vs. B), (2) Treatment vs. Baseline 2 (B vs. A2), and (3) phase contrasts with trend adjustments (e.g., A1 vs. B + trend B – trend A1) to better isolate treatment effects from underlying trends. The Tau coefficient (ranging from −1 to 1) and associated p-values were calculated for each contrast, and effect sizes were interpreted using conventional thresholds: small (<0.20), moderate (0.21–0.60), large (0.61–0.80), and very large (>0.80) (Parker et al., 2011; Vannest & Ninci, 2015).

The variables analyzed included the total and subscale scores of the Attentional Behaviors scale (total, energy, and organization), the total score of the Motor Skills scale, and the six subdimensions of the Social and Cognitive Attitudes scale (autonomy, cooperation, awareness, flexibility, initiative, and planning).

All Tau-U analyses were conducted using an open-access online platform for single-case design analysis (https://mirisola.shinyapps.io/TolmanItaDEV/), ensuring transparency and replicability.

Concerning visual-motor integration, the child was assessed before (A1) and after (A2) the intervention using the Beery–Buktenica Developmental Test of Visual–Motor Integration (VMI) and its two supplemental tests. Raw scores were converted to standard scores (Mean = 100, SD = 15), and clinical interpretation was based on the magnitude and direction of score changes across the two time points.

3. Results

3.1. Tau-U analysis results

Table 4 presents results of Tau-U analyses for all the scales divided by phase comparisons. Fig. 4 displays the distribution of T-scores across 24 observation units, divided into three phases (A1, B, A2). The data were converted into T-scores (mean = 50, SD = 10) to allow for comparison across variables measured on different scales. The top-left panel shows the domain of Attentional Behaviors, including the subcomponents Total, Energy, and Organization. The top-right panel illustrates the Motor Skills domain as a single trajectory. The bottom panel represents Social and Cognitive Attitudes, with six subcomponents: Autonomy, Cooperation, Awareness, Flexibility, Initiative, and Planning. Each colored line corresponds to one subcomponent, depicting its variation over time and across the three experimental phases.

Regarding the attentional behaviors, results show a moderate improvement only in the energy dimension (*Tau* = −.45, *p* < .05) between baseline 1 and intervention phases and within intervention phase even when controlling for baseline 1 trend (*Tau* = −.34, *p* < .05). However, when comparing the intervention and baseline 2 phases there was no statistically significant difference between these phases. Results show a substantial improvement in gross and fine motor skills between baseline 1 and treatment phases (*Tau* = −1, *p* < .001) with an overall significant improvement considering phase contrasts and intervention phase trend, and also control-ling for baseline 1 trend (*Tau* = −.63, *p* < .001). In addition, results show an overall moderate change when comparing intervention phase and baseline 2 (*Tau* = −.43, *p* < .01), which indicates that the gains achieved have been maintained in the post-intervention phase. Regarding the social and cognitive attitudes, results showed a substantial improvement in cooperation (*Tau* = .97, *p* < .01), awareness (*Tau* = 1, *p* < .001), flexibility (*Tau* = 1, *p* < .001), and initiative (*Tau* = 1, *p* < .001) between baseline 1 and treatment phase also when controlling for baseline 1 trend. Nevertheless, results for intervention and baseline 2 phases showed a moderate overall reduction in the gains achieved in the post-intervention phase for the dimensions of flexibility (*Tau* = −.43, *p* < .05) and initiative (*Tau* = −.48, *p* < .01). For the dimensions of cooperation and awareness there was no statistically significant difference between intervention and baseline 2 phases. Finally, concerning the dimensions of autonomy and planning V. obtained the maximum score (ceiling effect) in all phases (A1, B, and A2) so there were no differences over time.

3.2. VMI results

Fig. 5 presents standard scores of Visual-Motor Integration test, and Visual Perception and Motor Coordination supplementary tests measured one time both during pre-test (baseline 1) and post-test (baseline 2). In this case, raw scores were converted to standard scores with a mean of 100 and a standard deviation of 15. Analyses of VMI scores show that, after the ER activities: V. significantly improved her performance (27 standard points) in the visual-motor integration area; she slightly im-proved her performance in the visual perception area (1 standard point); she showed a considerable increase (8 standard points) in the motor coordination area.

4. Discussion

This study represents the first application of the RE4BES protocol for the stimulation of motor, attentional, visual-motor, and socio-cognitive skills in a child with Spinal Muscular Atrophy (SMA). The research aimed to evaluate the effectiveness of a robotics-based educational intervention tailored to the child's specific needs, by adopting a single-case ABA design and monitoring multiple outcome variables through structured observations and standardized assessments. As expected, both the ratings from observation scales and the child's performance on the VMI test demonstrated that the intervention positively influenced

Table 4
Tau-U analyses results.

Scales	Subscales	A_1 vs. B						B vs. A_2					
		A_1 vs. B		A_1 vs. B + trend B		A_1 vs. B + trend B – trend A_1		B vs. A_2		B vs. A_2 + trend B		B vs. A_2 + trend B – trend A_2	
		Tau	*p*	*Tau*	*p*	*Tau*	*p*	*Tau*	*p*	*Tau*	*p*	*Tau*	*p*
Attentional Behaviors	Total	−.25	ns	−.40	ns	−0.31	ns	−.34	ns	−.24	ns	−.01	ns
	Energy	−.38	ns	−.45	.025	−.34	.036	−.19	ns	−.13	ns	.04	ns
	Organization	−.13	ns	−.32	ns	−.24	ns	−0.5	ns	−.35	ns	−.09	ns
Motor Skills	Total	−1	.000	−.83	.000	−.63	.000	−1	.000	−.70	.001	−.43	.009
Social and Cognitive Attitudes	Autonomy	/	/	/	/	/	/	/	/	/	/	/	/
	Cooperation	.97	.001	.47	.029	.42	.018	.53	ns	.21	ns	.32	ns
	Awareness	1	.000	.91	.000	.70	.000	−.25	ns	−.17	ns	−.30	ns
	Flexibility	1	.000	.83	.000	.63	.000	−.84	.002	−.42	.041	−.43	.013
	Initiative	1	.000	.92	.000	.71	.000	−.55	.046	−.39	ns	−.48	.005
	Planning	/	/	/	/	/	/	/	/	/	/	/	/

Note. ns = not significant.

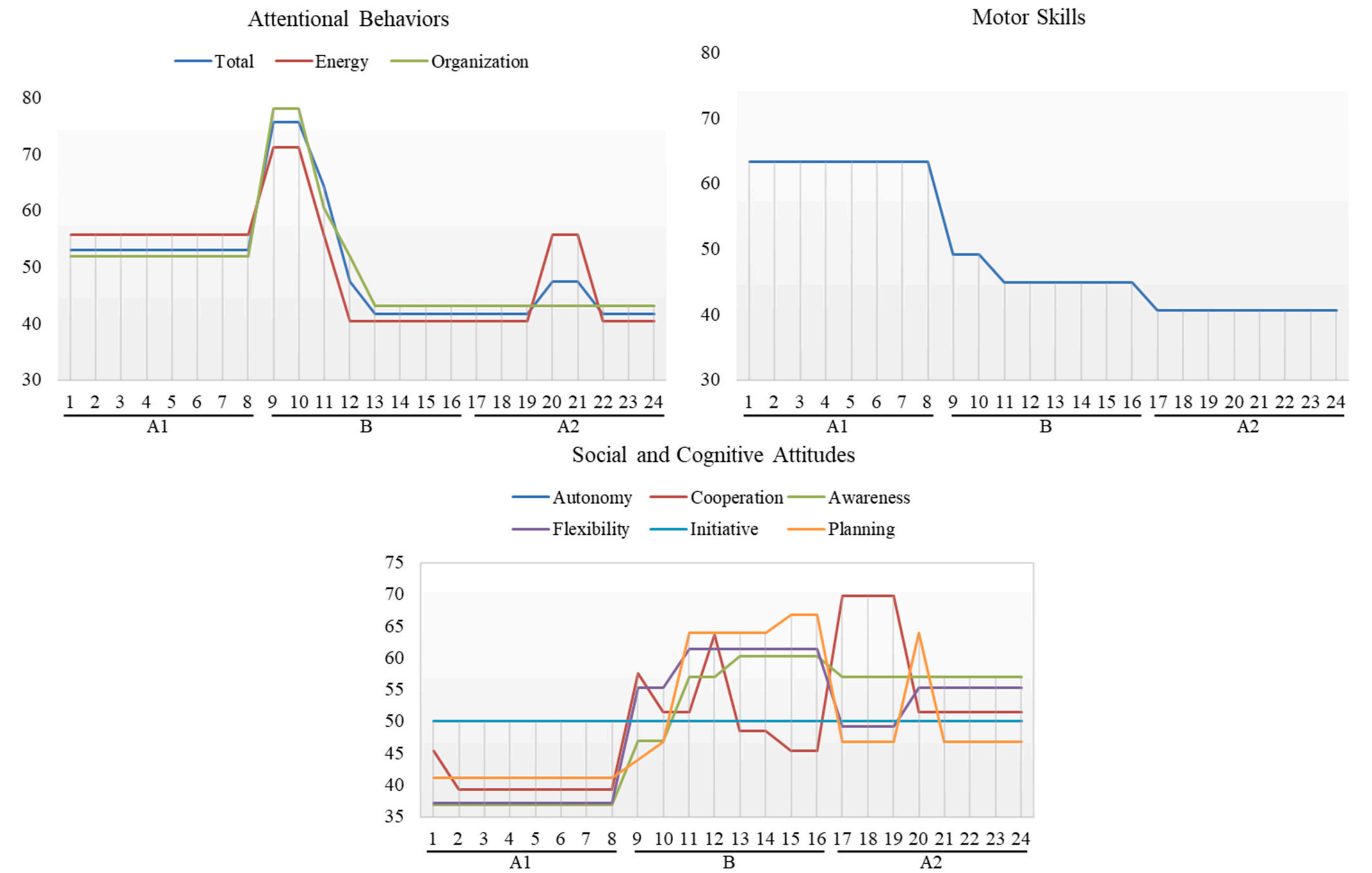


Fig. 4. T-score trends across 24 observation units divided into three phases (A1, B, A2), for the domains of Attentional Behaviors (top left), Motor Skills (top right), and Social and Cognitive Attitudes (bottom). Each line represents a subcomponent within the corresponding domain.

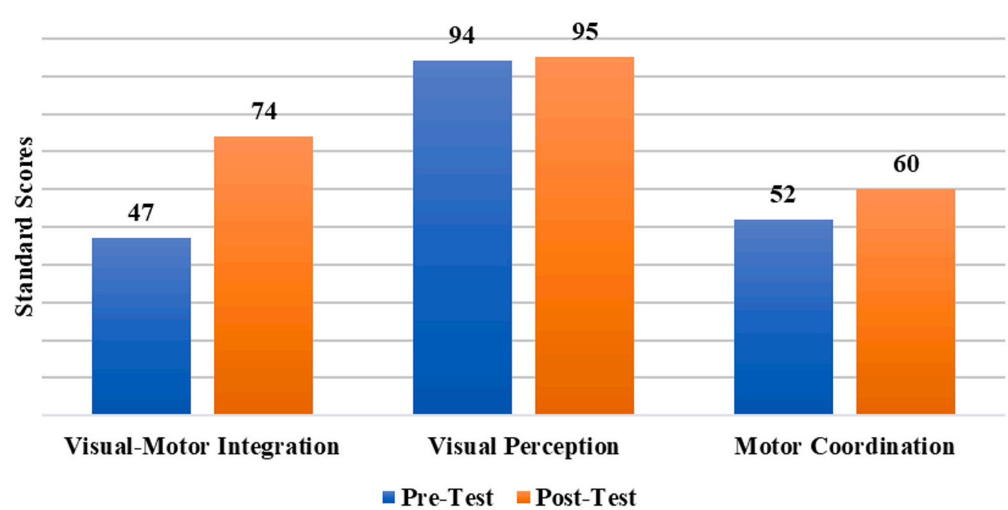


Fig. 5. Standard scores of Visual-Motor Integration test and supplementary tests of Visual Perception and Motor Coordination measured during pre-test (baseline 1) and post-test (baseline 2).

visual-motor integration, gross, and fine motor skills. These improvements are consistent with previous findings regarding the benefits of ER for children with neurodevelopmental disorders, where robot-mediated activities have been shown to promote motor engagement and physical participation (Nanou & Karampatzakis, 2022; Papakostas et al., 2021; Syriopoulou-Delli & Gkiolnta, 2021). The intervention provided tasks that required spatial coordination, sequencing, and object manipulation—elements known to promote visual-motor integration. These findings are in line with studies that have demonstrated improvements in visual-motor coordination through ER in children with disabilities (D'Amico & Guastella, 2019; van den Heuvel et al., 2016), and support the application of robotics in rehabilitative educational contexts.

Throughout the intervention, an increase in attentional dimensions was observed, especially regarding activation, maintenance, and selectivity. The protocol's progressive structure and the use of motivating and interactive tasks supported the child's sustained focus and goal-directed behavior. Prior work has also identified attention improvements as a frequent benefit of ER use in special education settings (Di Lieto et al., 2020; D'Amico & Guastella, 2019). The intervention also improved social and cognitive outcomes, such as autonomy, flexibility, cooperation, and initiative. These dimensions are central to the inclusive aims of educational practice with children with special needs, and their development aligns with the broader goals of the RE4BES protocol. Previous applications of the protocol have emphasized its impact on motivation and engagement, as robots tend to capture children's interest and facilitate learning in ways that traditional tools may not (D'Amico & Guastella, 2018; 2019; Guastella et al., 2020). The results of this study confirm that ER and the structured activities proposed in the RE4BES protocol can be considered useful tools for supporting the development of children with neuromuscular disabilities. Consistent with previous research using ER (Nanou & Karampatzakis, 2022; Papakostas et al., 2021; Syriopoulou-Delli & Gkiolnta, 2021), and specifically with studies applying the RE4BES protocol to children with SEN (D'Amico & Guastella, 2018; 2019; Guastella et al., 2020), this study extends its application to children with complex motor profiles, highlighting its flexibility and relevance in inclusive educational settings. By addressing multiple dimensions — motor, attentional, and socio-cognitive — this study contributes to the growing literature on the use of ER in special education, and supports its value as a pedagogical and rehabilitative resource. These results further support the practical utility of the RE4BES protocol not only as a conceptual framework but also as a structured guide for planning and adapting robotics-based activities adapted to individual profiles and functional goals.

4.1. Limitations

From the perspective of special education the results are quite encouraging though it must be noted that this study has several limitations. The study design could be strengthened in future research by incorporating a control group. Including a comparison with children who share similar characteristics but do not receive ER intervention would allow for a more robust evaluation of the treatment effects. Such designs would enhance internal validity and provide stronger empirical support for the efficacy of the RE4BES protocol in special education contexts. In addition, a limitation of the current study is the lack of an independent observer for data collection and analysis. The experimenter who conducted the intervention also completed the observational rating scales, which could introduce potential bias. Although the experimenter was not involved in data analysis to mitigate this risk, future studies should consider involving independent evaluators to enhance objectivity and reduce potential conflicts of interest. These limitations should be carefully considered when interpreting the results. The single-case design, while allowing for detailed and individualized observation, limits the generalizability of the findings to other children with similar conditions. Without a control group, it is not possible to fully rule out alternative explanations for the observed improvements, such as developmental changes or classroom dynamics. Moreover, the use of a single, non-blinded rater introduces potential bias in the evaluation of outcomes, which could have inflated the perceived treatment effects. As a result, while the findings are promising and align with existing literature, they should be viewed as preliminary and interpreted with caution. This study's limitations can be addressed in future studies: by the application of the RE4BES protocol to a group of children with the same disability to increase sample size; by the inclusion of case or control groups with the same disability who, however, do not receive ER treatment; by the addition of follow-up phases to check how long the progress gained is maintained; by assigning the compilation of the rating scales to an external observer.

4.2. Future directions

Future research could extend the present findings in several meaningful directions. One important step would be to test the RE4BES protocol with larger and more varied samples, including children from different age groups and with diverse developmental profiles. This would help to assess whether the approach can be effectively adapted to a broader range of needs and educational contexts.

It would also be valuable to compare the effects of different types of robotics, such as humanoid robots, different programmable floor robots and construction-based kits, to better understand which formats are most beneficial for specific learning goals or student characteristics. Exploring these differences could inform more targeted and flexible intervention strategies.

In addition, longitudinal studies are needed to examine whether the benefits observed immediately after the intervention are maintained over time. Follow-up assessments could provide insight into the stability of improvements in motor, attentional, and social skills, and whether they contribute to broader developmental outcomes.

Finally, incorporating multiple sources of information, such as teacher reports, parent observations, and direct performance measures, would strengthen future evaluations and provide a richer understanding of how ER interventions work in everyday school settings.

5. Conclusion

This study represents an initial application of the RE4BES protocol to support the development of fine motor skills in a child with SMA. The findings suggest that ER, when integrated into a structured and goal-oriented protocol, may offer a valuable means of addressing the multifaceted needs of children with motor impairments. Improvements observed in visual-motor integration, gross and fine motor coordination, and several social and cognitive domains point to the potential of such interventions in supporting functional development and inclusion within educational settings.

These results, while preliminary, offer relevant considerations for educational and clinical practice. The integration of robotics-based activities within individualized educational programs may serve not only to stimulate motor and cognitive functions, but also to promote motivation, participation, and key social competences such as cooperation, autonomy, and initiative. For educators and therapists, the RE4BES protocol may represent a practical and adaptable tool that aligns with the broader principles of inclusive education.

Consistent with existing literature, the present findings reinforce the value of ER in special education. Nonetheless, further research is required to explore the applicability of the protocol across different populations and contexts, and to assess the stability of its effects over time. Studies involving larger samples, longitudinal designs, and a wider range of robotic technologies would contribute to a deeper understanding of its effectiveness. Continued collaboration among researchers, practitioners, and developers will be essential to advancing the use of ER as a resource for inclusive, evidence-based interventions.

CRediT authorship contribution statement

Antonella D'Amico: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Resources, Methodology, Funding acquisition, Conceptualization. **Giuseppina Paci:** Writing – review & editing, Writing – original draft, Resources, Project administration, Investigation. **Laura di Domenico:** Writing – review & editing, Writing – original draft, Software, Formal analysis, Data curation. **Alessandro Geraci:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Methodology, Investigation, Formal analysis, Data curation.

Data availability statement

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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Declaration of competing interest

The authors declare no conflict of interest.

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