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Robotics Agent Coacher for CP motor Function (RAC CP Fun)

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SUMMARY
Robotics Agent Coacher for Cerebral Palsy motor Function (RAC CP Fun) is an attempt to implement socially assistive robotics, and a motor learning approach in rehabilitating movement disorders with a central origin. The concept and architecture of RAC CP Fun implements the motor learning theory and behavioral approach, i.e. principles of repetition, stages of learning, appropriate feedback, random practice, and enriched environments. Eleven children with cerebral palsy (CP) and fourteen typically developed (TD) children participated in two procedures while interacting with a robot and performing motor exercises. The interaction level and motor performance of children were measured and compared. Children with CP exhibited a higher interaction level; however, their motor performance was lower than that of TD children. RAC CP Fun was found to be feasible to interact with children of pre-school age, to augment the motivation of the children with CP, and to involve the children in motor exercises.

KEYWORDS: Social assitive robotics; Cerebral palsy.

1. Introduction

1.1. Motor rehabilitation of cerebral palsy and motor learning

Cerebral palsy (CP) is the most common cause of motor disability in children. It occurs as a result of insult or injury to the brain in early childhood and leads to aberrant neural connections and disabling impairment of motor power and control.[1] By definition, CP is associated with motor impairment, but other neurological conditions are also frequently present, including deficits in cognition, communication, behavioral abnormalities, and seizures.[2–4]

The focus of rehabilitation treatment has recently shifted to neurological rehabilitation in response to increasing evidence of neuroplasticity[5,6], which may have a lasting effect on both the brain and behavior.

Over the past two decades, findings in animal models of stroke have led to translational clinical trials by numerous approaches, such as constraint-induced movement therapy, robotic-enhanced therapy, body weight-supported treadmill training, and motor coaching.[7–10] These approaches have shown that rehabilitation therapies consisting of intense practice of a meaningful motor task with powerful motivation, feedback,[11] and emotional arousal[12,13] lead to better recovery of motor function in stroke patients and improved motor performance in children.

Learning is a complicated process at all ages and levels of development, which is even more complicated in individuals with significant cognitive delays. As noted, children with CP are at greater risk for physical, cognitive, and emotional difficulties, and the earlier the interventions are initiated, the greater is the likelihood for sustained improvement. Assessment, adaptation, and intervention should target the areas of attention, communication, and social relatedness. Motivation can be seen as an extension of attention.

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Feedback is regarded as a critical variable for skill acquisition and is broadly defined as any kind of sensory information related to a response or movement.[14] When one performs a task, two general types of performance-related information, or feedback, are available: intrinsic and external feedback. Intrinsic feedback is response-produced—it occurs normally when a movement is made and the sources may be internal or external to the body. Typical sources of intrinsic feedback include vision, proprioception, and audition. External feedback is augmented information provided by an external source, in addition to intrinsic feedback. 'Augmented' refers to adding to or enhancing task-intrinsic feedback with an external source. The external source may be a therapist or a device such as a biofeedback system or a social robot. Sullivan *et al*.[15] concluded that during motor learning, normal children use feedback in a manner different from that of adults and benefit more from feedback. To optimize motor learning, children may require longer periods of practice, with feedback reduced more gradually.[16] More recently, adding verbal coaching to traditional physical therapy resulted in significantly greater gains in gross motor performance and more importantly, mastery of those tasks generalized to unstructured environments.[10]

There is evidence that processes involving consolidation of novel or improved tasks are enhanced if the training session includes emotional arousal, given that emotionally arousing experiences have been shown to be more memorable than neutral experiences.[17] Indeed, emotional arousal appears to play an important role in enabling the significance of an experience to regulate the strength of the memory of that experience,[12] probably by activating neurobiological processes that modulate the consolidation of memories of recent experiences.[13]

1.2. Socially assistive robotics (SAR)

Assistive Robotics (AR) is a broad class of robots whose function is to assist users in their daily activities. SAR[18] is a class of robots that assist users primarily through social, rather than physical, interaction. SAR is an advanced field of robotics that merges challenging state-of-the-art research of machine learning algorithms, artificial intelligence, and real-time control issues.[19–21] It is used to address critical areas in medical care by automating supervision, coaching, motivation, and companionship aspects of interactions with vulnerable individuals. Currently, the main populations where SAR is used are the elderly, patients with dementia and cognitive/motor disorders,[22,23] and children with autism.[24–29] Unlike computer technology-based treatment, e.g., video instruction[30] and virtual peers using the Internet,[31] SAR not only provides the opportunity to learn from a non-threatening, three-dimensional inanimate object, it also presents the opportunity to learn through interaction, thus encouraging autonomous social behavior.

AR, but not SAR-mediated therapy, has been increasingly utilized in the last few years, especially with children having CP. In particular, it appears to be beneficial for hand training, motivation, and perception.[32–35] Robotic systems used for training children with CP by forced repetition and supporting movement error reduction were found to be useful.[36–37] The elements of SAR mediated therapy have been,[38–39] or not tested on children with CP,[40–41] or tested subjectively and qualitatively.[42]

1.3. Objectives

The main purpose of this paper was to describe the newly developed concept of the Robotics Agent Coacher for CP motor Function (RAC CP Fun), a novel robotic computational interactive system for therapeutic motor training, which acts by implementing the motor learning approach and augments the motivation of children.

The paper demonstrates feasibility of RAC CP Fun approach by presenting the experiments, aimed at determining how children with CP interact with robots having different team decompositions, as well as how they perform different motor and cognitive tasks. These activities will be compared to the interaction of typically developed children.

2. Concept

2.1. RAC CP Fun

Assistive robot-mediated therapy is based on physical activity including CP interventions. It appears to be beneficial for hand training, as well as for enhancing motivation and perception.[32] Robotic

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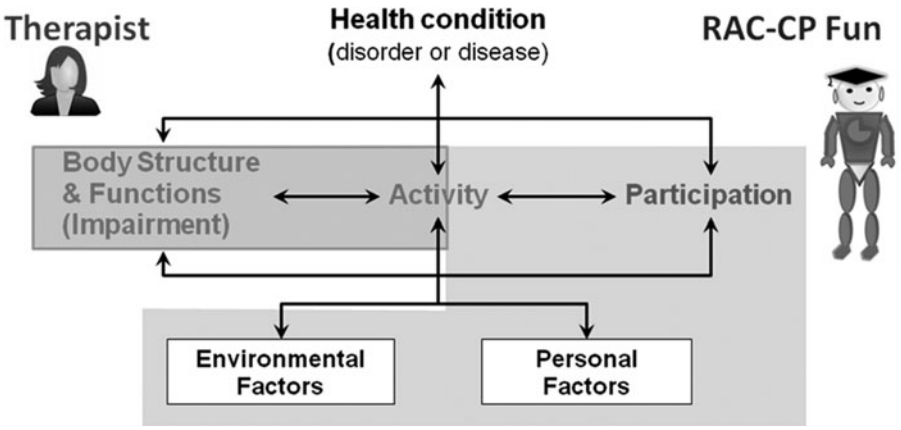


Fig. 1. RAC CP Fun functionality, based on the ICF Framework.

systems for training patients with CP by forced repetition and for reducing movement errors were found to be useful.[36] Social assistive robotics (SAR),[18] the class of robots that assist users primarily through social rather than physical interaction, have not been tested in treating CP.

The World Health Organization's International Classification of Functioning, Disability, and Health (ICF)[43] views functioning and disability as a complex interaction between the health condition of the individual and the contextual factors of the environment as well as personal factors. According to the ICF model, an important goal of rehabilitation services is to optimize children's participation at home, school, and in community life. In terms of ICF (Fig. 1), the conventional physiotherapy (therapist) mainly targets the body structure: the muscles, joints, etc. Through recent technological and clinical achievements, children's activity and participation (motor actions and games) are promoted through pleasurable game-like human-robot interactions. Thus there is a chance to improve the child's health through the two other components, i.e. increase in activity and participation of a child. SAR can involve a child into interaction with itself and with other children, contributing to the 'Participation' part of well being, while considering the personal and environmental factors and adjusting its behavior accordingly (Fig. 1).

The scientific world has made a significant leap in the last three decades in the field of motor control and learning, following discoveries related to brain plasticity and the ability to meaningfully improve motor functions. A motor learning approach, based on the principles of repetition, learning (Adaptation), appropriate feedback (Motivation), random practice and enriched environment (Conceptual Interference), may now be implemented by applying state-of-the-art technology, specifically SAR algorithms and approaches.

RAC CP Fun is a novel approach to the rehabilitation of children with CP. The aim of the project is to integrate novel algorithms for motor and social interactions between the robot and children with CP, into the very well-accepted ICF model. Moreover, the integration of RAC CP Fun into the ICF model can be extended to other disorders and physiotherapy techniques.

The objectives of RAC CP Fun include the following:

- development of learning algorithms for social interactions between a robot and children with CP, through interactive motor exercises;
- development and implementation of an integrative platform for detecting and measuring movement;
- verification and validation of a novel robotic platform for children with CP, along with a therapist during its use in a clinical setup.

Children with CP were selected as the target population, since they have restricted mobility, typically have previous experience using technology, and have a desire to participate in game-like interactions with a robot. The participation of a limited number of children, combined with low degrees of the participants' mobility, makes it possible to conduct an efficient vision-based scene analysis. The core issue of therapy for children with CP is motor training. The up-to-date 3D equipment used for measuring movement as well as modern methods and algorithms for movement analysis provide an excellent basis for efficient robot-child interaction and training. Moreover, previously

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Table I. Scenario: action, performance evaluation, and feedback.

Action	Evaluation parameter	How to measure	Robot's feedback
Sit-to-stand transition	Time to initiation	Time from the verbal order to the displacement by at least 20 cm.	'Good, you started to move quickly!' or 'Come on, you can do it!'
	Time to complete	Time from the verbal order to a displacement by 30 cm and the end of movement.	'That was quick!' or 'Wow, you are doing it quickly now!'
Hands rising and holding	Quantative	Amount of successful attempts (see implementation in Table III)	'Cool, you are doing perfect'
	Quality	Deviation of the hand positions from the horizontal level. Symmetry	'Keeps your hands higher"or"Look at me, hold your hands as I do,' or 'Good, try to raise your left hand higher.'
	Duration	Time of the hand positions in the horizontal state	'Can you hold your hands longer the next time?'
Counting	Sound recognition	Sound detection	'I cannot hear you, count, louder!'
Stand-to-sit transition	Accuracy	Time of vertical displacement to the initial point.	'Be careful, you should sit and not fall!'

tested therapeutic setups proved that children interact well with a robot having a toy-like appearance. The RAC CP Fun scenarios include precise definitions of measurable parameters (e.g., reaction time, acceleration of particular body segments and range of motion). The exact type of feedback is defined for each specific motor behavior of a child with CP, his motor learning stage, pathology characteristics, and personal behavioral status (mood, motivation, attention, etc.).

An illustration of an RAC CP Fun scenario follows. The children sit in ordinary chairs. The RAC CP Fun sits down on a chair and says 'Look at me and do as I do'. Then it demonstrates the exercise: 'Stand up' (it stands up), 'raise your hands to the sides' (it performs), 'count to five' (it counts loudly), 'put your hands down' (it performs), 'and sit down' (it sits down). Then the robot moves to one of the children and says 'Would you like to play with me? Do it with me.' and performs the same actions again. The examples of child's performance evaluation are presented in Table I. The level of interaction is measured along the whole meeting, since the certain level of interaction is obligatory for effective use of the concept. The behavior of the robot is adapted, automatically or semi-automatically by therapist or operator, to children' interaction level changes.

The robot's feedback reactions (phrases) to the child are given according to the feedback algorithm that will be developed. According to this algorithm, feedback will be either positive or negative, quantitative or qualitative, given at every trial or not, etc. To create a pleasurable interaction, RAC CP FUN will sing songs and express emotions during the session.

Each child will perform the task several times. The robot will then say 'Thank you, it was pleasure to play with you. Now, I will see what your friend can do,' and will move to another child.

The RAC CP Fun modules were derived from the descriptions of the scenarios. A preliminary scheme of the modules and data flow is presented in Fig. 2. The Input module sets out the settings of the kindergarten staff and the robot's sensory data (video, audio, touch sensors) and Kinect data (measuring movement of the users). To analyze these data (Low-Level Perception module), the system applies the basic algorithms for vision processing and data analyses, such as skin detection,[44] edge detection,[45] and disparity computation[46]. Then, in the High Level Perception module, the system analyzes the scene (based on Berg *et al*.,[47]) tracks users' faces and monitors their eye contact

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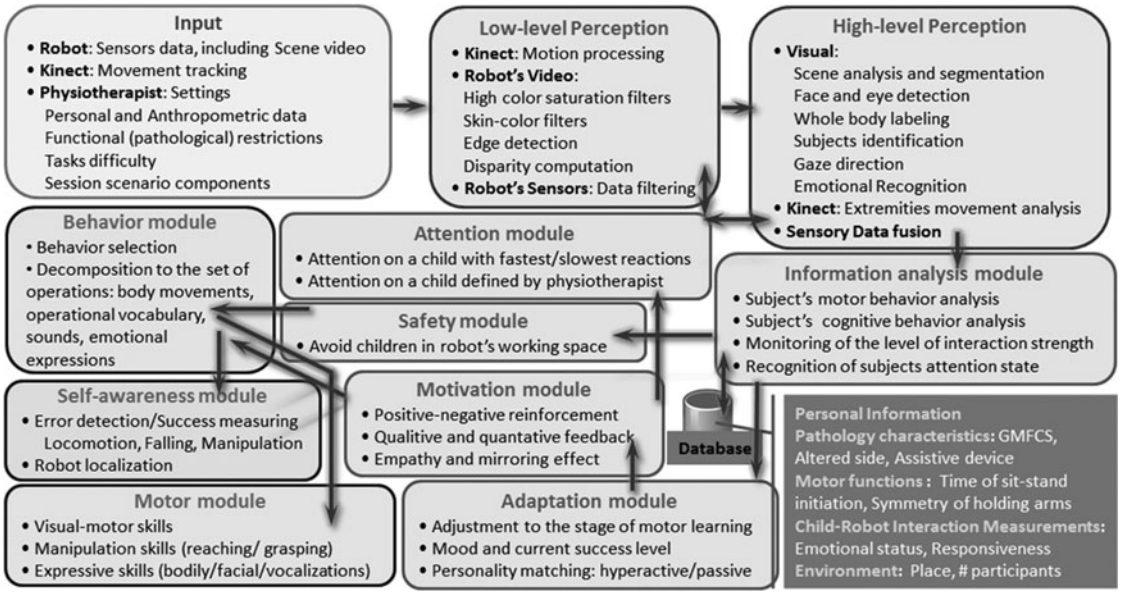


Fig. 2. The primary experimental architecture of RAC CP Fun.

with the robot (based on Pol *et al.*,[48]) and analyzes facial and bodily expressions of emotion.[49–50] In the Information Analysis module the system uses data from motion-capture equipment (Kinect camera) to monitor children's motor behavior.[51] Also measured will be a number of parameters used to monitor the subject's cognitive behavior, such as subjects' response times to the robot's questions, number of answers, strength of interaction with the robot (see 'Measuring Child-Robot Interaction' below), duration of sustained attention). All of this information is entered in the database. To reinforce the children's learning (Motivation module,[52]) the robot can shift its attention to different children (Attention module), for example according to the teacher's setting. Moreover, RAC CP Fun is capable of adapting the robot's behavior to a child's personality, stage of cognitive learning, and current mood[50] (Adaptation module).

The system then selects the current behavior (Behavior module), which is implemented by the Motor module. To create closed-loop control of the RAC CP Fun robot, we will provide it with the ability to monitor its performance and measure its successes and errors.

The current study used humanoid robot Nao (Aldebaran Robotics), which suites the needs of RAC CP Fun, though other humanoid robotic platforms can be implemented for the approach. Some of the concept elements (behavior, scenario, measurements, and feedback elements) have been implemented and tested in the current study.

Nao has 25 degrees of freedom, and is equipped with an inertial sensor, two cameras and many other sensors, including sonar, which allows it to comprehend its environment with stability and precision. Nao is based on a Linux platform and scripted with Urbi, an easy-to-learn programming language, with the option of a graphic interface for beginners or code commands for experts.

3. Methods

3.1. Robotic appearance and experimental platform

Our previous results[53] showed that the appearance of the robot Nao (Aldebaran Robotics), used as a platform in the presented study, had a positive impact on the child-robot interaction. Nao[54] is a small, 58-cm tall robot that looks like a toy and is perceived as a smart, non-threatening educational tool[55] that induces positive interaction with children of pre-school age (Fig. 3). RAC CP Fun speaks in a child-like voice (commonly associated with kindergarten staff), expresses emotions (through verbal and non-verbal communication), and uses the proper vocabulary. The robot has 25 degrees of freedom, which allows it to perform the designated motor tasks. The following experimental procedure was first designed by a specialist in development psychology, as well as a physiologist and a specialist in human-robot interactions. The design documents specify the robot movements, speech, expression of

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Fig. 3. Children playing with the robot. (A) – FMP, one-to-many team decomposition; (B) – MIP; one-to-one team decomposition.

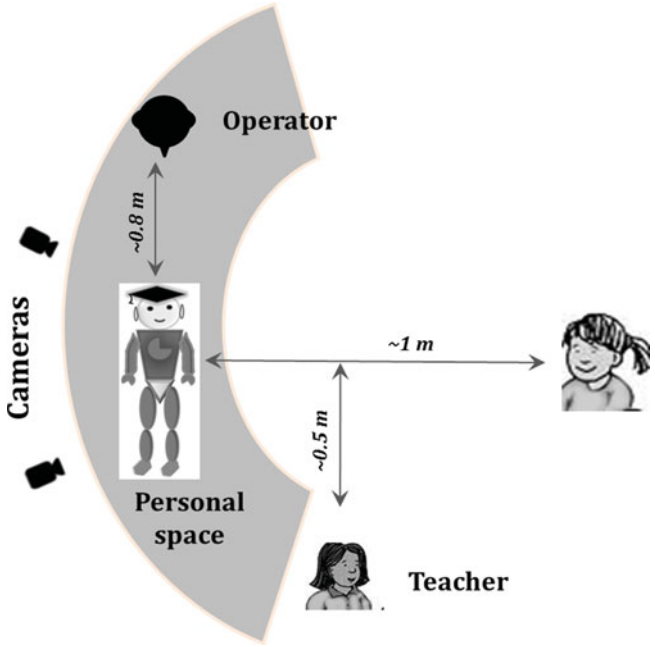


Fig. 4. (Colour online) Experimental setup. The shadowed area indicates the child's personal space.

emotions, and program flow. A programmer coded this design using the Python language and Nao's graphical user interface. The robot was operated by a technician, who sat nearby the robot (Fig. 4) and determined the flow of the procedures (Fig. 5), depending on the child's success of performance.

3.2. Subjects

The experiments were performed in a kindergarten, which is a natural environment for children (Fig. 3). The experimental room was the classroom where the educational staff typically conducted classes for small groups of children.

Sixteen typically developed children participated in the study. After two of them left at the initial stage of the experiments, only the data of remaining children ($n = 14$) were used for analysis: (6 boys, 8 girls, mean age 3.3 ± 0.3 years) and 11 children with CP (9 boys, 2 girls, mean age 5.7 ± 0.6 years) (Table II). The functional abilities of the children with CP ranged from level I to level IV, using the gross motor function classification system (GMFCS).[56]

The children participated in two sessions: a first meeting procedure (FMP) followed by a motor involvement procedure (MIP).

During the FMP a group of children sat 1 m in front of the robot, in the child's social space (Fig. 4). A kindergarten teacher was present in the room and sat 0.5 m from an imaginary line connecting the robot and the child. Two camcorders, located behind the robot, video-recorded the experiment. The robot's operator was also present in the room and sat 0.8 m to the side of the robot.

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Table II. Experimental groups of subjects. TD – typically developed children; CP – children with cerebral palsy.

Group	Boys	Girls	Total
TD	6	8	14
CP	9	2	11
Total	15	10	25

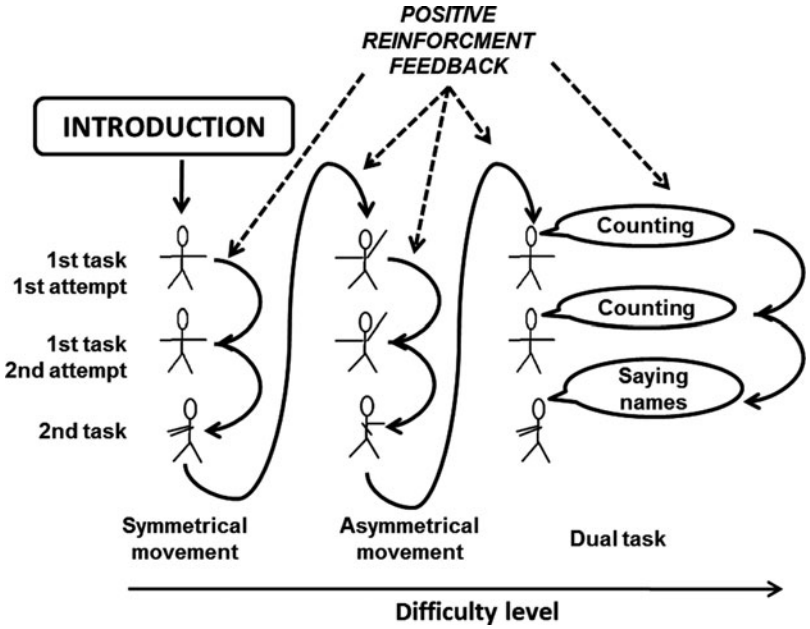


Fig. 5. The scheme of the detailed motor involvement protocol.

3.3. Experimental procedures

The experimental setup and protocols were approved by the local institutional ethics committee. The parents of the participating children signed an informed consent form. The kindergarten staff not only participated in designing the procedure, but also approved its final implementation.

Following short desensitization, two procedures were performed with the children on two separate meetings. The first aimed to introduce the robot to the children, to initiate the interaction between them, and to provide the children the basic explanation on the robot's nature and behavior. The second procedure aimed to enforce the interaction and to test the ability of SAR to involve the children in the performance of motor exercises, assuming the future possibility of encouraging their physical therapy routine.

Desensitization: The children with CP underwent a desensitization procedure (DP) for the robot developed by us. The necessity for DP was revealed during experiments with typically developed children described below, when some children exhibited fear of the robot. Variants of Wolpe's original desensitization procedure[57] are usually required with phobic children. A graded series of real-life exposures to the feared animal is formulated, ranging from least anxiety-provoking to the most anxiety provoking ('real-life desensitization'). These exposures should be planned thoroughly so that there is little likelihood of a traumatic experience and resultant intensification of the fear problem.[58] The procedure began when an extinguished robot sat on the floor. The kindergarten teacher presented the robot to the children and asked who would like to play with it. If there were children that were afraid of the robot, she hugged them and proposed that they try to play with the robot. Children that refused, went out of the room. The teacher informed the children that the robot will now start to move. The robot was turned on, it woke up, stood up, said 'Hello', and then sat down. The teacher, following the reactions of the children, said to them if they were very afraid, they should leave the room. She proposed to others to stay and try to 'play' with the robot. Then the FMP began.

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First Meeting Procedure (FMP): The robot stood up, introduced itself to the children, and sang a well-known Israeli song, 'Hello, everybody.' RAC CP Fun initiated personal contact by moving into the children's personal space and briefly conversed with them. Nao explained its mission (to play with the children) and proposed a game of 'Simon Says.' In the course of the game, Nao provided positive feedback to the children and explained to them that the robot was unable to understand everything because it is a robot. RAC CP Fun repeatedly stated to the children that it is a robot, to prevent children from becoming emotionally attached to it as much as possible, and to distinguish it from humans. To explain potential changes in its appearance and behavior in future encounters, Nao told the children that it sometimes becomes ill and then it has be taken to a 'robot doctor.' The robot also explained to the children that it cannot play with them for an extended period of time, because it needs to 'eat,' i.e., to be charged often. To demonstrate what happened when the robot do not have electrical power, the robot fall down. Finally, Nao said goodbye to the children and the session ended. he child, turned around and exited the room.

Motor Involvement Procedure (MIP): During this procedure, the child faced the robot, seated at a distance of 1 m from it, which was in the child's social space (Fig. 1(B), 4). A kindergarten teacher was present in the room and sat 0.5 m from an imaginary line connecting the robot and the child. Two camcorders located behind the robot video-recorded the experiment. The robot's operator was also present in the room and sat 0.8 m to the side of the robot.

The MIP took place one week after the children's first meeting with the robot for the FMP. The kindergarten teacher invited each child to participate individually in a game with the robot. If the child agreed, the teacher allowed the robotic agent to initiate the session in a small-groups classroom. The interaction protocol consisted of an introduction, motor actions and parting (Fig. 5).

The session started with Nao in a sitting position. Nao woke up, made a yawning sound, and stood up. To make the child feel comfortable, the robot sang the 'Hello, everybody' song, which was familiar to the children from the FMP. The robot stated that it likes to exercise, and invited the child to join it. RAC CP Fun sang the Hebrew version of the song, 'Head, Shoulders, Knees, and Toes,' while demonstrating the movements.

Movement tasks were of gradually increasing difficulty, from symmetrical movements, through asymmetrical movements, to dual tasks (Fig. 5). Each level of difficulty included two exercises: (a) symmetrical exercises (i.e., 'Raise both arms to the sides' and 'Raise both arms upward'); (b) asymmetrical exercises: (i.e., ' Raise one arm to the side and the second arm up' and 'Raise one arm forward and the second to the side'); and (c) dual task exercises (i.e., 'Raise both arms to the side while counting to five' and 'Hold your arms out and say the names of the children you like to play with'). Asymmetrical movements and dual movements are considered more difficult than symmetrical movements since their performance requires a child's development of a bimanual coordination.[59] Nao asked the child to perform a movement. If the child did not succeed, the robot asked the child to try to perform the same movement again. If the child's second attempt was also unsuccessful, the child was instructed to try another movement. The procedure ended if the child was unable to successfully perform the second movement. If the child succeeded, the robot asked the child to perform a motor task having the next difficulty level. Each motor performance by a child was reinforced by the robot through positive verbal feedback. Finally, the robot thanked the child for participating, provided positive feedback (e.g. 'Cool, you are doing perfect'), sat down and sang a song.

3.4. Measuring child-robot interactions

Two parameters were chosen to test whether the successful interaction of the children with the robot can be achieved. These parameters cover the emotional side of the interaction, ability of RAC CP Fun to attract and keep the attention of the children during the interaction, and the ability of the robot to involve the children into the protocol of obeying robot's requests.

Interaction Level (IL): To evaluate the quality of child-robot interaction, we used the child-robot interaction measurement index.[64,65] This index combines eye contact and emotional expressions, such as voice, face, and body expressions. Considering the age of our subjects, a post-hoc analysis of video footage of interaction sessions is the only feasible method of data collection and analysis.

Cronbach's alpha, the coefficient that determines the internal consistency was calculated in order to test the reliability of the IL measurements.

Measuring the Execution of Motor/Cognitive Tasks in FMP: In the course of the interactive session, the children are asked to perform motor and cognitive tasks. If the child completes the motor task

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Table III. Coding scheme for evaluating the induced motor performance.

Code	Performance
0	did not perform
1	attempt to perform – 2nd attempt
2	incomplete performance – 2nd attempt
3	attempt to perform – 1st attempt
4	complete performance – 2nd attempt
5	incomplete performance – 1st attempt
6	complete performance – 1st attempt

or gives a complete answer to the question, the child's performance (Ex) is recorded as 2, partial performance is recorded as 1, and no response is recorded as 0. On tasks comprising more than one movement or question, P is computed as the mean of all component scores.

Performance of Motor Tasks (P): During the course of the experiment the robot asked the children to perform motor tasks having three gradually increasing difficulty levels. At each level of difficulty, children were instructed to perform two tasks. In case of an unsuccessful or incomplete performance, the child was asked to attempt to perform the movement again. The coding is provided in Table III.

3.5. Data analysis

IL and P for each child were collected. Coding of IL and P measurements were performed by two research assistances (who did not know the researcher hypothesis).

FMP: Repeated measures ANOVA of the procedure stages was performed with IL as the main factor and two between-subjects factors: the group of subjects (Table II) and gender (boy, girl). The significance P at different procedure stages was evaluated similarly by repeated measures ANOVA.

MIP: We analyzed IL and P by performing two MANOVA tests with two between-subjects factors: the procedure stages and the children's status (typically developed versus. CP).

4. Results

During the FMP with 16 typically developed children, two of them exhibited signs of the fear when the robot first started to move and they ran from the room. These children did not continue participating and their parameters and data were not included. The remaining children ($n = 14$) completed the protocol of the procedure.

Following the experience with the typically developed children, we implemented the DP prior to the FMP with children with CP. Two children hesitated during the DP regarding whether to stay; however, they decided to stay, and they, similar to all the other children, enjoyed 'playing' with the robot. Nobody left the room and nobody was fearful. All the children enjoyed both the FMP and MIP encounters with the robot and interacted well with it.

IL was positive during the whole FMP, with the exception of the stage 'Robot Falls Down'. IL measurements revealed a significant difference between the procedure stages (Greenhouse-Geisser correction, $F(7, 23) = 15.43$, $p < .0001$). Cronbach's alpha for IL was 0.78.

The results (mean $\pm$ SE) of children-robot IL are presented in Fig. 6. A significant difference was observed between the IL of children with CP (14.09 ± 1.87) and typically developed children (6.87 ± 1.65), ($F(1, 23) = 8.33$ $p = 0.008$). A pairwise comparison revealed significant differences between the stage 'Motor Game' and the stages 'Hello', 'Explanation', and 'Parting'. The IL at the stage 'Robot Falls Down' was significantly smaller than that of the remaining stages of the procedure.

The performance levels measured during the cognitive stage ('Conversation') and during the motor task ('Motor Game') of the FMP did not reveal significant differences (Fig. 6).

The analysis of the results of MIP (Fig. 7) revealed a significantly higher IL of children with CP than the IL of typically developed children ($P = 0.019$; $F(1, 72) = 5.72$), whereas the children with CP exhibited a lower motor performance than that of typically developed children ($P < 0.001$; $F(1, 69) = 19.58$).

A comparison by stages of the MIP showed a significant difference in IL at the introduction stage only, more than four times higher in children with CP than in healthy children ($P = 0.019$; $F(1,21) = 15.16$). The motor performance of typically developed children was significantly higher with the

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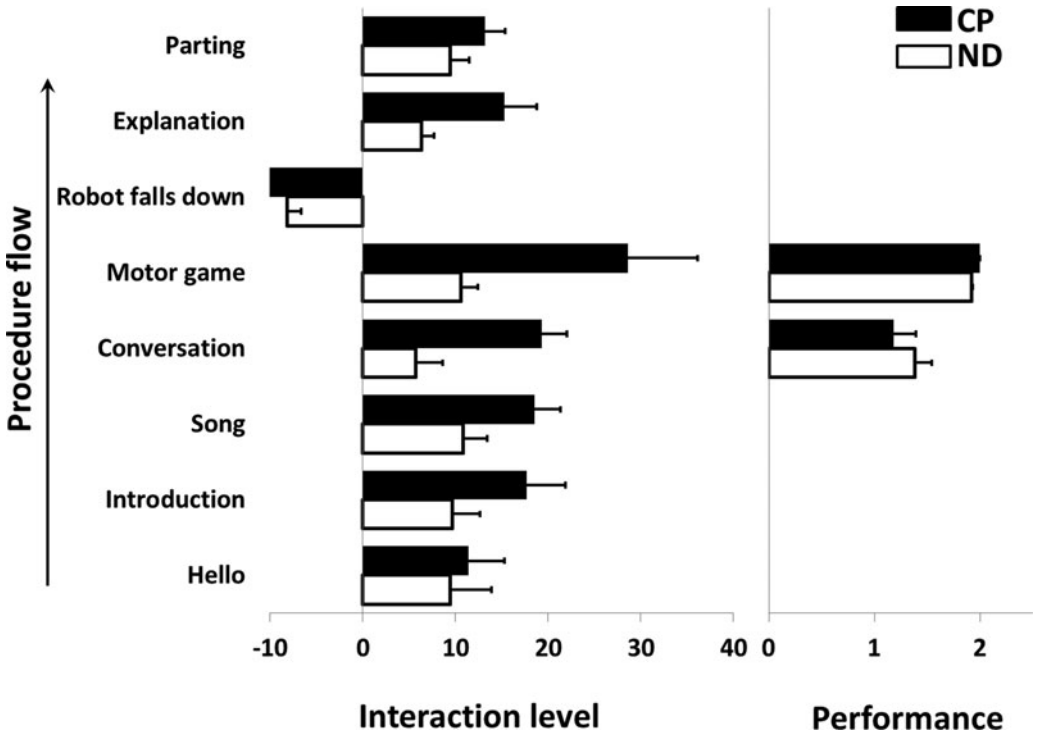


Fig. 6. Results of the FMP (Mean ± Standard Error, significant levels indicated in the section 'Results'). Black bars – children with CP; white bars – TD children.

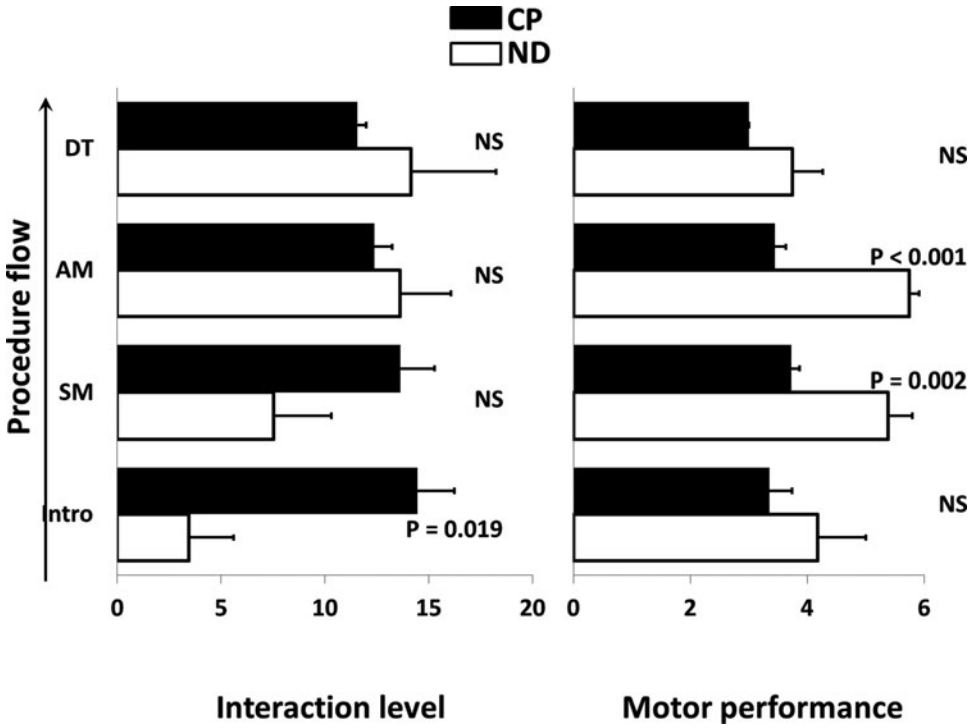


Fig. 7. Results of the MIP (Mean ± Standard Error, significant levels indicated in the section 'Results'). Black bars – children with CP; white bars – TD children.

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easier motor tasks: symmetrical task ($P = 0.02$; F (1, 18) = 13.31) and asymmetrical task ($P < 0.001$; F (1, 18) = 98.14). No differences in P of TD and CP children were observed at the introductory stage or at the most difficult motor exercise level of dual tasks.

5. Discussion

The SAR approach has been tested for rehabilitation purposes before RAC CP Fun was initiated. Implementation of SAR was attempted in interventions for children with autism spectrum disorders in order to encourage them to initiate and sustain social interactions with a parent, therapist, sibling, or peer.[58] SAR systems designed to improve therapeutic compliance through verbal, non-contact coaching and encouragement have been tested with post-stroke rehabilitation patients.[79,80] Some studies have demonstrated the benefits of the robot's physical embodiment in human-robot social interactions, e.g., therapeutic interactions of elderly participants suffering from Alzheimer's disease with SAR-promoted cognitive stimulation through a music game.[81] SARs have been shown to provide empathy and unconditional positive support,[82] thereby increasing motivation,[83] an important determinant of training outcomes. Summarizing the prove of efficient implementation of SAR approach in various conditions and the lack of studies with SAR in cerebral palsy, the presented here RAC CP Fun concept was developed.

The aim of RAC CP Fun, and the main contribution of this paper, is to implement rehabilitation and treatment approaches for children with CP, which have been extensively explored in the last two decades (see, for example, Bar-Haim *et al*.,[84] Shadmehr *et al*.[85]) and that are based on repetition of training, appropriate feedback, stages of learning, random practice to enhance problem solving, and enriched environment. Motor learning coaching treatment results in significantly greater retention of gross motor function and transfer of mobility rehabilitation approaches.[10] These methods emphasize function in a natural environment; however, they have not used other key elements of motor learning such as the organization of practice, timing, adaptive training, and various types of feedback,[89] which are considered in the algorithms of RAC CP Fun. These algorithms are also based on Fitts and Posner's classic learning stages.[90]

The initial meeting of a child with a robot is a critical stage that may determine the ensuing interactions between a child and a robot and the therapeutic outcomes of such an interaction. This paper describes how children with CP meet the robot for the first time and it compares their reaction to that of typically developed children. This is a large-scale (25 participants) study involving pre-school CP and typically developed children in a natural kindergarten environment. The 'Desensitization procedure' performed with children with CP helped those children who needed it to overcome their fear of the robot.

The positive level of IL throughout the experiment (except the stage when the robot falls down) demonstrated that the children enjoyed the robot's presence. They mostly expressed positive emotions and interacted with the robot. Even when the robot fell down, the IL returned to positive at later stages of the experiment. The robot, being in the personal space of the children, did not provoke any negative reactions. Motor and cognitive task performance reflected compliance with the robot's instructions, demonstrating that the children accepted the robot's authority.

The quantitative evaluation of the performance of MIP elements by children did not consider the quality and completeness of the performance (Table III). For this reason, no significant differences between P of TD and CP children were revealed. As planned in the concept design (Table I), more precise evaluation of P will be implemented.

The higher IL levels of children with CP in comparison with TD children during the FMP and the MIP suggest that the robot influenced more the motivation of the children with CP than the TD children. This may be caused by less variable and routine of the children with CP, which is augmented more by their meeting with the robot, than those of TD children.

The lower P value of children with CP during the MIP denotes their lower ability status and not their decreased motivation.

6. Conclusions

Socially assistive robotic technology is still in its infancy, but the results of our experiment indicate that assistive robotic platforms can be successfully used in the near future in hospitals and homes, as well as in training and therapeutic programs that monitor and encourage pre-school children.

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The main contribution of this paper is to demonstrate that the concept of RAC CP Fun presented here may serve as a useful tool to assist physical therapists by motivating patients of pre-school age, structuring the training sessions, and in the future providing diagnostic features during its use.

Another important contribution of this paper is the proof of feasibility of RAC CP Fun approach. Here we demonstrated the feasibility of RAC CP Fun to interact with children of pre-school age, to augment the motivation of children with CP, and to involve these children in motor exercises.

RAC CP Fun extends the state of the art in two main scientific domains that facilitate the process of learning and gaining new functions: (1) the development of novel algorithms that optimize SAR-CP interactions and (2) the development of an optimal environment in which to practice, gain, and consolidate motor functions. Both of these are part of the basic methodology that guides the process of rehabilitating children with CP.

Future development of algorithms should evaluate the child's personality, the level of cognition, and motor capabilities when using RAC CP Fun in order to develop a personal task-oriented training program and to elicit emotional arousal by incorporating SAR-CP interactions. All together, RAC CP Fun will target all components known today in neuroscience to facilitate motor learning in order to gain efficient motor functions.

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