An empirical study on integrating a small humanoid robot to support the therapy of children with Autism Spectrum Disorder and Intellectual Disability

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Abstract

Recent research showed the potential benefits of robot-assisted therapy in treating children with Autism Spectrum Disorder. These children often have some form of Intellectual Disability (ID) too, but this has mainly been neglected by previous robotics research. This article presents an empirical evaluation of robot-assisted imitation training integrated into the TEACCH program. The sample included six hospitalised children with different levels of ID, from mild to profound. We applied mixed-methods to assess their progress, during treatment and three months later. Results show increased Gross Motor Imitation skills in the children, except for those with profound ID and the therapists' positive attitude towards the humanoid robot. Furthermore, the therapists suggest how a robot could be used to autonomously collect and analyse the information obtained in the rehabilitation training for a continuous evaluation of the participants.

Keywords: Autism Spectrum Disorder, Intellectual Disability, Socially Assistive Robotics, TEACCH approach, Robot-Assisted Therapy.

1. Introduction

Intellectual Disability (ID) and Autism Spectrum Disorders (ASD) are the main neurodevelopmental disorders with a frequency of 2-3% in western countries (Bourke, De Klerk, Smith, & Leonard, 2016). The ID is expressed by significant limitations in both intellectual functioning and adaptive behaviour before the age of 18 and is commonly reflected by an IQ (Intelligent Quotient) below 70 (Ropers, 2010). Autism is a complex "spectrum disorder", which incorporates diverse disabilities, therefore, a multi-modal therapeutic intervention should be preferred to maximize the benefits of the treatment, in particular by adapting to the individual's patient needs (Dawson et al., 2010). ASD is often in comorbidity with some level of ID, with an estimated 70% of individuals with autism also having an ID (Oeseburg, Dijkstra, Groothoff, Reijneveld, & Jansen, 2011; Schwartz & Neri, 2012). This condition is commonly referred to as Low-Functioning Autism (LFA), whereas individuals are characterized by significant limitations in both intellectual functions and adaptive behaviour i.e. in problems with reasoning, learning or problem-solving as well as communication and social skills difficulties (American Psychiatric Association, 2013). This mixture makes therapeutic interventions more challenging and, therefore, technological aids could be useful to help therapy work (Goldsmith & LeBlanc, 2004).

Like for other conditions, technological solutions are proposed to help the education and therapy of children with ASD. In particular, researchers have found that some individuals with ASD likes the controllable autonomy of robots (Adams & Robinson, 2011) and that robots can generate a strong motivation and higher engagement in individuals who are unlikely or unwilling to interact socially with human therapists (Rabbitt, Kazdin, & Scassellati, 2014 for a review). Recent studies have positively presented robots as mediators between humans and individuals with ASD (Esteban et al., 2017). For instance, Duquette, Michaud, & Mercier (2008) showed improvements in affective behaviour and attention-sharing with co-participating human partners during an imitation task solicited by a robotic doll. Furthermore, the simplified social behaviour of robots may be especially beneficial for individuals with ASD who face difficulty in perceiving and expressing emotions, understanding gestures or facial expressions, because practising communication can be less intimidating with a robot than with a human (Alemi, Meghdari, Basiri, & Taheri, 2015; Kozima, Nakagawa, & Yasuda, 2005). When working with children with ASD, robots can be used to invoke interest and engagement (Robins, Dickerson, Stribling, & Dautenhahn, 2004) or as a diagnostic tool (Scassellati, 2007), that should always be included in the therapeutic plans.

Current social robotics projects increasingly show robots as an instrument for the enhancement of the care already in place, rather than a replacement of the human caregiver, showing numerous benefits of robot assistants in the treatment of children with ASD (Conti, Di Nuovo, Buono, & Di Nuovo, 2017; Robins et al., 2012; Wainer, Dautenhahn, Robins, & Amirabdollahian, 2013). The aim of using robots in clinical practice is to reduce therapists' workload by allowing the robot to take care of some parts of the intervention. This includes monitoring and recording the behaviour of the children, engaging them when they are disinterested, and adapting the appropriate levels of treatment. This allows the therapist to plan the required intervention for every child on an individual basis (Esteban et al., 2017).

As most of the studies focused on ASD individuals without ID or ignored to analyse comorbidities, using this approach could possibly highlight one of the current gaps between scientific research and clinical application (Diehl, Schmitt, Villano, & Crowell, 2012). While qualitative analysis is frequently considered in previous research (e.g. via analysis of video-recorded human-robot interaction), the quantitative analysis that can be made through the use of standardized psycho-diagnostic tools is often missing (Diehl et al., 2012; Kim, Paul, Shic, & Scassellati, 2012). This is because children with ASD and ID are more difficult to treat because they need constant support to carry out normal activities (Wong et al., 2015). Meanwhile, current robotic technology is still at an experimental stage and may require complex systems to be deployed (Cao et al., 2019). Therefore, explorative studies of new therapeutic approaches involving robotics are generally focusing on a small number of easier to manage cases, e.g. without comorbidities (see DiPietro, Kelemen, Liang,

& Sik-Lanyi, 2019 for a survey). These limitations have generated doubts and scepticism among the practitioners about the actual applicability of robotic-assisted therapy in standard treatment.

To address practitioners' concerns, this article presents a feasibility study that was designed and carried out with the support of specialized practitioners, who also provided feedback on the experience.

This feasibility study presents the design and the results of a robotic intervention, involving 6 children diagnosed with severe ASD and a level of ID from mild to profound, that aimed at supporting the children to learn about physical imitation in the "Treatment and Education of Autistic and related Communication handicapped CHildren" (TEACCH), one of the most common deficits observed in children with ASD (Edwards, 2014; Williams, Whiten, & Singh, 2004). This type of training needs more support in routine clinical practice, as it usually involves at least two therapists - one to show the task to imitate and the other to support the child. Unfortunately, rehabilitation centres are seldom able to conduct these types of training due to a lack of staff. This leaves an important and unbridgeable gap in the learning and rehabilitation of the child that may be addressed using robotics.

2. Material and Methods

In the intervention, we introduced just a small humanoid robot, which was programmed to autonomously prompt the children to imitate its movements, allowing the therapist to focus on supporting the child. The rehabilitation tasks were developed and personalized to the child's level according to a standardized psycho-diagnostic instrument designed for children with ASD: Verbal Behaviour Milestones Assessment and Placement Program (VB-MAPP) (Sundberg, 2008). This tool was used at the beginning as a first baseline (Ex-ante) to identify the tasks to be carried out by the robot, and as a second baseline (Ex-post) to quantitatively assess the results of the robot-assisted therapy, and finally in a follow-up phase, three months after the end of the treatment. The quantitative and qualitative data collected were analysed to verify the applicability of the robot-assisted therapy to lower ID levels as support for a psycho-diagnostic and training tool previously standardized and validated in the psychological field. The final part of this study, using a specific questionnaire, highlights the point of view of the therapists who have used a humanoid social robot for five months in their daily work with children with ASD and ID.

The study was carried out in a specialized healthcare and research institute, the IRCCS Oasi of Troina, where the training is programmed according to the TEACCH approach (Mesibov, Shea, & Schopler, 2004). The approach looks at the skills and strengths children already have, and it aims to build on these to promote development.

2.1. Participants

Six children (all males, age range=66-121 months, mean chronological age=104.3 months, *SD*=18.6) were recruited from patients diagnosed with ASD and ID. Specifically, one participant was diagnosed with mild ID level (diagnosis ICD-10: F70), one moderate ID level (F71), two with severe ID level (F72), and two with profound ID level (F73), as shown in Table 1.

All the participants at the time of the study were hospitalized and receiving treatment at the Oasi Research Institute-IRCCS (Italy), a specialized institution for the rehabilitation and care of patients with intellectual disabilities.

Table 1 Participants description: age in months, IQ, Age Equivalent, and ID level

Participant	Chronological Age	IQ	Age Equivalent	ID Level
P01	102	56	35	Mild
P02	66	53	26	Moderate
P03	116	38	31	Severe
P04	118	27	29	Severe
P05	103	22	22	Profound
P06	121	22	22	Profound

The criteria for selecting the participants were: (1) between 5 and 10 years of age; (2) no existing problems with aggressive behaviour or severe oppositional tendency; (3) no hearing, visual, or physical disabilities that would preclude participation in the treatment.

All participants had a previous diagnosis based on the DSM-5 criteria from a licensed clinical psychologist, which was further confirmed through the assessment and the consensus of experienced practitioners in the research group. The psychometric tests used for the diagnosis of ASD were: the Psycho-educational Profile, 3rd Edition (PEP-3: Schopler, Lansing, Reichler, & Marcus, 2004), Autism Diagnostic Interview-Revised (ADI-R: Lord, Rutter, & Le Couteur, 1994), and Childhood Autism Rating Scale-Second Edition (CARS-2: Schopler, Van Bourgondien, Wellman, & Love, 2010). These instruments confirmed the presence of severity scores from moderate (level 2) to profound (level 3) in both social communication and restricted interests and repetitive behaviours domains, according to the DSM-5 criteria. The participants' clinical details are shown in Appendix A.

The diagnosis of intellectual functioning was made using the Wechsler Intelligence Scale for Children (WISC: Wechsler, 2003) or the Leiter International Performance Scale-Revised (Roid & Miller, 2002) when more appropriate and reliable for the intellectual level.

For each child, Table 1 shows the Age Equivalent expressed in months, calculated as the average of the *Growth Scores* (GS) associated with the different Chronological Age groups. These are based using the benchmark performance of typically developed children in the test manual (Sundberg, 2008). All children started a clinical daily program of training at the same time, using the TEACCH approach (Mesibov et al., 2004) administered by highly specialized psychologists.

The study was conducted following the relevant guidelines and regulations for human participants. Ethical approval was obtained from the ethical councils of both the Oasi Research Institute of Troina and Sheffield Hallam University. All parents provided written consent before their children's participation. Participants were free to leave the experiment and had provided verbal assent before taking part in the tasks; tasks could be discontinued at any time to no disadvantage to the children, although a free pre-session was included to reduce the novelty effect and to check the children’s initial reactions.

2.2. Therapists’ role and prompts

In autism therapy with robots, a therapist is involved in the interaction between the child and the robot, which makes this a triadic form of interaction (Colton et al., 2009). The regular therapist, involved in everyday treatment, was always present as a "secure base" for the children (Bowlby, 2005). The therapist used *prompts* to encourage the production of new behaviour in the presence of a defined stimulus. During these sessions, the therapist’s *prompts* were systematically reduced so that the behaviour produced by the child became responsive to the stimulus and not to the *prompt* response. Learning theorists and autism researchers have long recognized the importance of reinforcement, extinction, and punishment on learning. The therapist provided verbal reinforcement (e.g. “good” and/or “right”, “wrong, look better”) with physical reinforcement (e.g. “give me five”) only in some cases. Moreover, the varieties of reinforcement used had been previously agreed with the clinicians and consisted of reinforcement variation. These reinforcements were different for each child and were connected directly and immediately to responses, behaviour, and the child's difficulties.

2.3. Setting and Materials

The experiment was carried out in the room where the children usually had their treatment sessions. The room was arranged as shown in Figure 1.

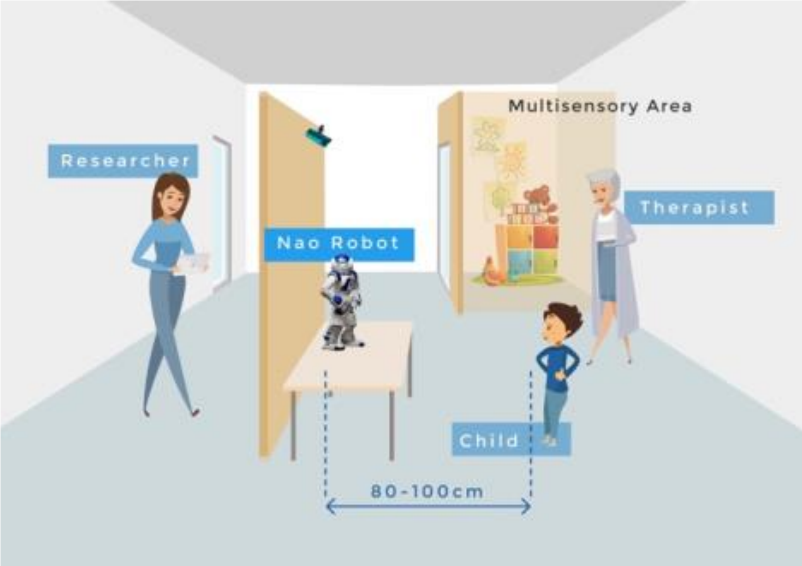


Fig. 1 Experimental setting

During a training session, the robot was positioned on a table, at about the same height as the child, initially at a distance of at least one meter. The child could move backwards or forwards to feel more comfortable. Taking into account the *Proximal development zone* (Vygotsky, 1978), we decided to involve the children with activities of a slightly higher level than their current competencies, but still simple enough to be comprehended.

The operator was hiding behind a panel, controlling the robot with the Wizard-of-Oz (WOZ) approach (Bainbridge, Hart, Kim, & Scassellati, 2011). The visual schedule tells a child where he should be and when he should be there. The robot-assisted therapy was included in the TEACCH program among the standard activities, with its own specific visual schedule (Fig. 2a and 2b). There was created a multisensory area on the side of the room where the child could rest between the task.

(a)

(b)

Fig. 2 (a) the visual schedule for the robot-assisted therapy; (b) a child returning the visual schedule after a daily session

2.3.1. The robotic-assisted therapy

The robot used for the experimental setting was the Softbank Robotics NAO (Appendix B), which is a small, toy-like humanoid robot, very popular for child-robot interaction studies (Coninx et al., 2016; Conti, Cirasa, Di Nuovo, & Di Nuovo, 2020; Conti, Trubia, Buono, Di Nuovo, & Di Nuovo, 2018). In the WOZ approach, the robot was interacting semi-autonomously with the children, i.e. the tasks were initiated by the operator when appropriate, then executed autonomously by the robot.

The robotic therapy was based on the Gross Motor Imitation (GMI) section of the VB-MAPP (Sundberg, 2008), which was administered as part of the baseline data collection to obtain information on the initial skills of the participants. Details on the VB-MAPP are in Appendix C.

The NAO robot was programmed to implement the VB-MAPP motor imitation tasks of level 1, which were then adapted and applied to match the specific level of each of the participants (Leyzberg, Spaulding, & Scassellati, 2014).

Before the start of the study (First Baseline), the psychologist administered the VB-MAPP in the standard form to each participant to assess his level to identify the starting level and to program the robot accordingly. The VB-MAPP protocol evaluates each milestone score by giving: 1 for the correct, fully executed task; 0.5 for a partial execution; 0 for error or no imitation.

2.3.2. Questionnaire for the evaluation of therapists' experience

To evaluate the therapists' attitude toward the use of technology, we decided to use a specialized questionnaire (Zubrycki & Granosik, 2016). This questionnaire consisted of two parts (see Table 3). The first part was composed of 31 statements, and the answers were given on a Likert scale to 5 values: strongly disagree, disagree, neutral, agree and strongly agree. Furthermore, in the second part of the questionnaire, the therapist was asked to grade the possible roles of the robotic tool from the most needed to the least needed. At the end of the training stage of the study, the questionnaire was given to all the therapists who had taken part in the experiment. The therapists filled out the questionnaire in their offices and during the compilation, the robot was not present. Questionnaires were distributed on paper and submitted anonymously. Participation in the study and responding to questions was voluntary; nonetheless, all the therapists filled in the questionnaire.

2.4. Design of the study

The simplest way to evaluate the effectiveness of a treatment is to verify the significance of the differences between the values of the variables under examination, before and after the treatment itself (pre-post intervention). In studies with few cases, as a research sample, it is preferable to consider not the groups of subjects but the observations of a certain behaviour, ability, characteristic, etc. in the same participant at different times of treatment (Barlow, Nock, & Hersen, 2009). In other words, the single case study analyses change in behaviours while providing a treatment to improve them, identifying an "evidence-based practice" for use in psychology (Blampied, 2013; Kazdin, 2010; Valsiner, 1986).

The single case design involves observation of a single case prior (A), during (B), and following (A) an intervention. The post-intervention phase or second baseline (A) indicates whether the effects of the intervention (B) remain when the intervention is no longer in place, or if the removal of the intervention (the NAO robot in our study) results in a return to baseline (A) behaviours. Moreover, in this case, we will also use A' to indicate the baseline with the robot.

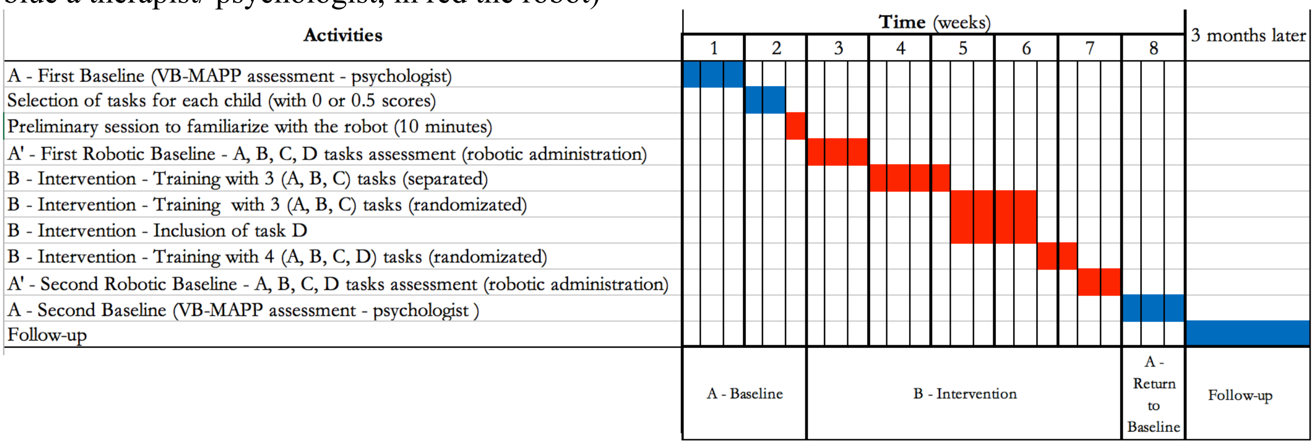
The benefit of a single-case experimental design is to allow a more intensive investigation of the single participant. This approach is the preliminary way to establish generality because researchers can use the single case to identify first the relevant controlling variables for the phenomenon under study, before generalizing the results (Sidman, 1960). For studies that employ a single-subject design, it is typical to analyse the data using a combination of visual analysis techniques and descriptive statistics (Gall, Gall, & Borg, 2007).

Generality and external validity are then established inductively, moving from a single case to ever-larger collections of single-case experiments (Guala, 2003; Hogarth, 2005). In other words, “to find out what people do in general, we must first discover what each person does in particular, then determine what, if anything, these particulars have in common...” (Thorngate, 1986, p.75).

2.5. Procedure

The investigation was carried out over five months. During the first two months, the preparation and training with the children were conducted, then after three months the follow-up session with the therapist took place. To avoid interfering modification of the target variable, no other intervention directly related to imitation was administered during the trial. All the activities are shown, in detail, in Table 2.

Table 2 Timeline of the activities carried out by children. Colour identifies who led the activity (in blue a therapist/ psychologist, in red the robot)



2.5.1. Phase A – First Baseline (Ex-ante evaluation with the therapist)

During the first week, the therapeutic team administered the VB-MAPP psycho-diagnostic and training instrument, reporting the results obtained on the GMI tasks. This was a prerequisite for defining the baseline (A) named Ex-ante. The VB-MAPP Ex-ante was administered by a qualified psychologist, without the robot present. At the same time, the clinical team contacted and discussed the study with the families of the selected children and distributed the informed consent form to them so that they could read the contents in detail, in their own environment, and at their own pace.

After administering the VB-MAPP, the psychologist selected three GMI tasks specifically for each child (Task A, Task B, and Task C) including ones that they were not likely to be able to do or perform properly, i.e. that received a milestone score of 0 or 0.5. In this way, children were associated with their “personal baggage" of tasks on which the training was focused. During this period, the clinical team collected the informed consent signed by the parents and their authorization to participate in the study their availability to be contacted regarding further requests or problems. Meanwhile, we programmed the NAO robot to administer the VB-MAPP imitation tasks of level 1. The robot-assisted tasks were individually designed after preliminary evaluation and development with the therapeutic team.

In the second week, the experimental procedure included a preliminary session to familiarize the children with the robot, so as to decrease the novelty effect, where the robot was presented to all the children individually in a non-therapeutic setting for 10 minutes. During this session, the robot was turned on in front of the children, spoke in a low voice tone, dancing, and moved into the room. We also used this session to see the children's reaction to the robot, which was positive for all of them; therefore, they were included in the continuation of the study.

2.5.2. Phase B - Intervention

The intervention training started after one week and included a total of fourteen encounters with the robot over one month, averaging three sessions per week.

For the first six training sessions, i.e. two weeks, there were three activities, one for each task (A, B, C). At the beginning of each activity, the robot prompted the children to imitate a task, e.g. arms out in front (Fig. 3). Each activity included the repetition of a GMI procedure six times. This was for each task for a total of 18 procedures (6 times for 3 tasks). The procedure started with the robot verbally presenting the behaviour to perform using simple and clear language. Then, it asked the child to imitate its movements. Each activity lasted approximately 6-8 minutes for each child including 1-minute breaks to let the children rest in the nearby multisensory area.

Fig. 3 Example of training with robot-assisted

The robot was programmed to address children by their name to make the intervention more personalized (Leyzberg et al., 2014). A video was recorded by the video camera integrated within the NAO robot, and another hidden video camera was placed in the room, behind the robot. We randomized the training activities for each session to avoid order effects in their responses. An example of task randomization is shown in Figure 4. This randomized condition is fundamental to avoid the child realizing that certain motor skills could be used in repeated patterns within the same sequence (Landa, 2007). Moreover, randomization also allows countering and working on a time delay (Yoder & Stone, 2006).

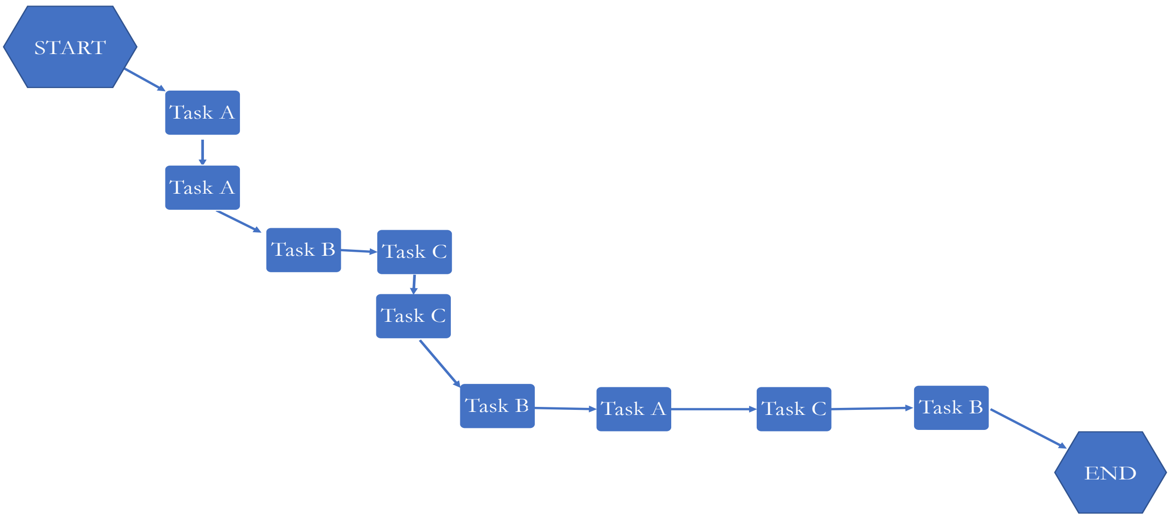


Fig. 4 Example of randomization with three tasks (A, B, C)

In the fifth week, we added a further task (Task D) for each child that showed significant progress. In this case, an example of a sequence was shown in Figure 5.

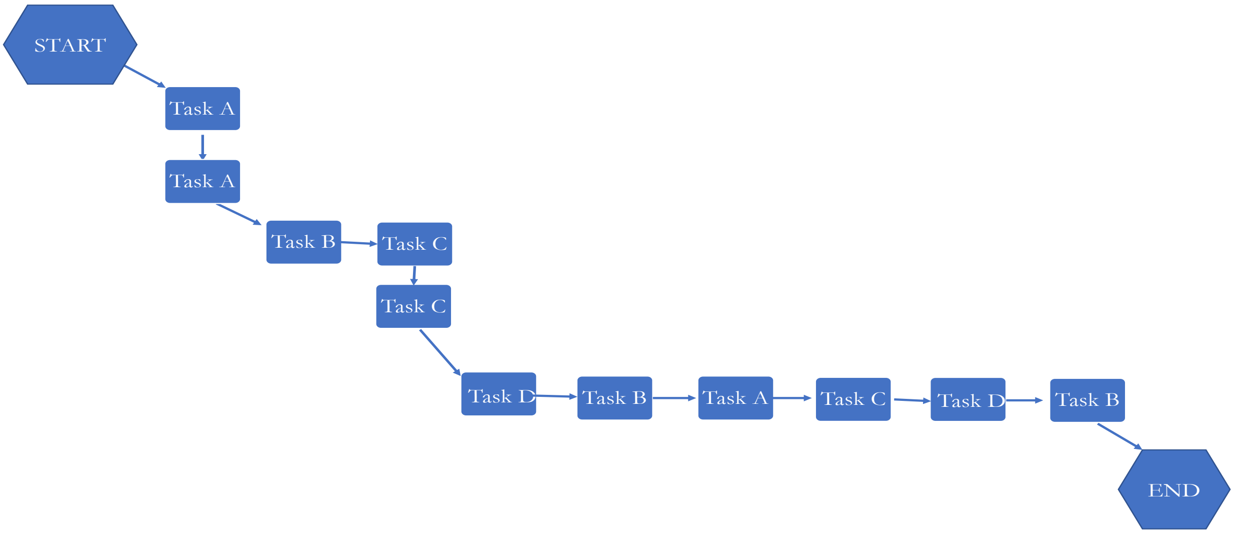


Fig. 5 Example of randomization with four tasks (A, B, C, D) – from week 5 for the children successful with A, B, C

To avoid frustrating children with profound ID (P05 and P06), the clinicians suggested the training should include only three tasks.

2.5.3. Phase A – Second Baseline (Ex-post evaluation with the therapist)

The study main objective was to verify the generalization of the imitation skills in other contexts and with a human being. This was because, the literature suggests that generalization skills are among the most evident problems in patients with ASD (Wong et al., 2015).

Therefore, we performed another evaluation in which the therapist acted as a model to be imitated. In this evaluation, the therapist performed the 33 tasks of the VB-MAPP, including those used in the training with the robot (Fig. 6). The imitation tasks were proposed by the therapist before singly to facilitate learning and subsequently in a grouped and randomized way to solidify learning. A meter behind the child, another therapist was positioned ready to intervene if needed. The Ex-post evaluation was performed by a licensed clinical psychologist following the VB-MAPP manual.

Fig. 6 Therapist imitation

2.5.4. Phase A' - Robotic Baseline (evaluation with the robot)

We indicate with A’, the baselines when we used the robot to lead the administration of the task. In this case, the therapist did not use the *prompts*.

2.5.5. Follow-up evaluation (3 months later)

The study is concluded by a follow-up evaluation carried out three months after the conclusion of the training by the psychologist and therapists of the IRCSS. The follow-up phase is essential to evaluate if the benefits have been maintained in the absence of intervention or after a long time from its suspension. The same clinical psychologist who had previously assessed the A phases performed the evaluation again in the follow-up session.

2.6. Quantitative Measures for the Evaluation of Video Recorded by the Robot

To analyse the behaviour of the child during the interaction, we used: *eye gaze, imitation, near* (to the robot), and seeking *feedback* from the therapist, i.e. direct interaction with the therapist (Conti, Di Nuovo, Buono, Trubia, & Di Nuovo, 2015). While the eye gaze evaluation has been extensively studied (see Di Nuovo, Conti, Trubia, Buono, & Di Nuovo, 2018), in this work we focused on imitation. The imitation criterion measured the percentage of time the child was actively imitating the robot’s movements when prompted. This was a good performance indicator.

In order to measure the children's tasks during the sessions, the interactions were recorded using the NAO webcam. The authors extracted 31,726 frames (i.e. 2 frames per second) from 204 videos recorded by the robot during the therapy sessions. Video length varied according to the number of tasks performed and was dynamically adapted to the child's condition for each session.

Subsequently, all video episodes of the tasks were coded separately by two researchers, with the use of a record sheet divided into seconds and were separately compiled. The inter-coder agreement score was 0.94, producing a reliability (measured by Cohen's kappa) of 0.85. Any discrepancies were resolved via discussion.

3. Results

In this section, we will present a mixed-method study for each child. We report the qualitative results obtained in the GMI tasks of VB-MAPP with the human therapist, and the quantitative results obtained from the analysis of the recordings of the training with the NAO robot.

Overall, the training was successful with P01, P02, P03 and P04, learning to perform the tasks correctly and improving their overall imitation skills significantly. This was shown by both the VB-MAPP scores and the quantitative video analysis that demonstrated that all these children increased the time spent imitating the robot. The two children (P05 and P06) with profound ID were not successful in their learning, with the video analysis showing as little as a 5% increase in their imitation time.

In the following report, the letters indicate the Tasks, while the qualitative scores 0, 0.5, and 1 are associated with, respectively, incorrect, attempted, and correct execution. We present, in detail, two graphs for each child where one shows the results of the qualitative scores of the 33 GMI tasks of the VB-MAPP (in Ex-ante, Ex-post and Follow-up) administered by the psychologist. While the other graph presents the quantitative video analysis, i.e. the average percentage of time spent by the child in performing the imitation tasks, being near the robot, and seeking feedback from the therapist. The analysis includes the first baseline session (s0), second baseline session (s13) and all training sessions with the robot (s1 to s12). To clarify, the assessment of the 33 VB-MAPP imitation tasks was always performed with the child imitating a human therapist, while, for the quantitative assessment, the researchers analysed the videos recorded during the robot-assisted training, i.e. the child imitated the robot.

Participant 1 (P01). Figure 7 shows a strong increase in the number of GMI tasks of the VB-MAPP performed correctly (score=1), from 7 to 25. Indeed, there is also a decrease from 17 to 7 for the partially executed tasks (score=0.5), while, in the follow-up, there is only 1 task that was not performed or was wrong (score=0) from the 9 from the ex-ante evaluation.

Figure 8 shows how all the proposed imitative tasks increased in their score. This is also evident in the randomizations to A+B +C (s8, s9) and A+B+C+D tasks (s10, s11, s12). Interestingly, in the first sessions, the child showed the need to be closer to the robot, while, after s4 this was no longer evident, and his focus became the imitation. The child also showed an initial need for proximity with the therapist, which decreased over time. However, the need for human feedback increased again during the last sessions, when the therapist no longer supported him with direct prompts, we see that the child is looking for the therapist. This was probably due to the child's need for approval, considering "the difficulties in the social-communicative area and the presence of oppositional/provocative attitudes" as described in the psychological evaluation.

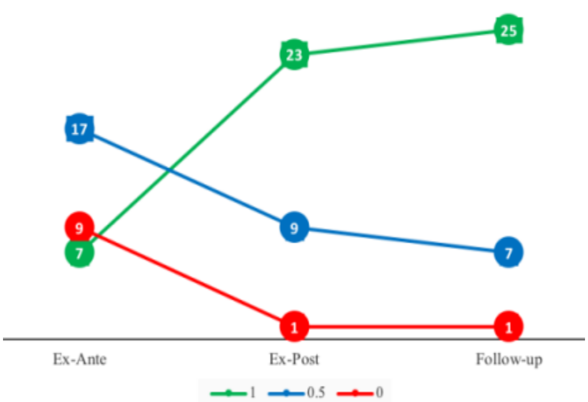


Fig. 7 Result of the VB-MAPP imitation tasks assessment (Ex-ante, Ex-post, and

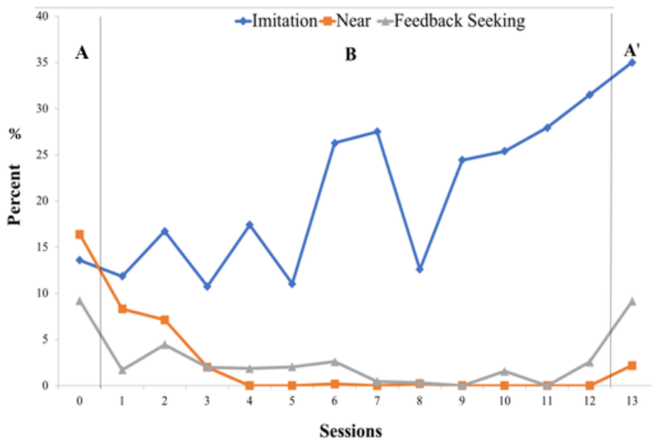


Fig. 8 Average percentage of time spent by the child (P01) in imitation, near the robot, and

Follow-up) for the child (P01) administered by the psychologist. The green line indicates the number of fully executed tasks, the blue line the number of partially executed tasks, the red line the number of tasks not executed or wrong

seeking feedback from the therapist

Participant 2 (P02). Figure 9 shows the results of the Baseline session, where the child wasn't able to imitate any of the 33 GMI tasks of the VB-MAPP; only one was incorrectly attempted. After the training with NAO robot, there was a significant decrease of wrong tasks from 32 to 15 (score =0 in the follow-up session), an increase from 1 to 5 for the inexact tasks (score=0.5), and an increase from 0 to 13 for the imitative tasks performed exactly (score=1).

Figure 10 shows that the imitation time incremented for all tasks. However, a decrease in imitative activity is shown in s8 and s10, when the protocol included the randomization of the third and fourth tasks. During s6 the child was closer to the robot, probably because "he showed interest in the environment, carries out exploratory conduits", as specified by the psychological evaluation.

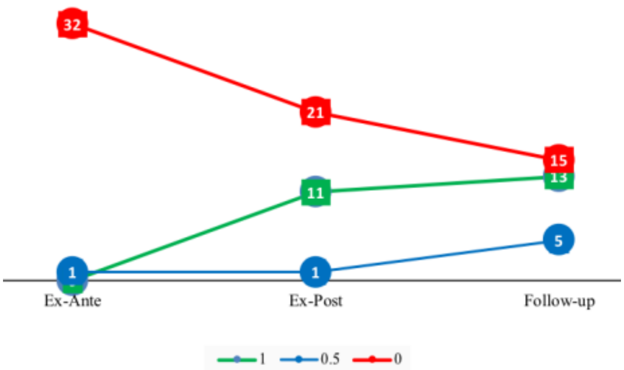


Fig. 9 Result of the VB-MAPP imitation tasks assessment (Ex-ante, Ex-post, and Follow-up) for the child (P02) administered by the psychologist. The green line indicates the number of fully executed tasks, the blue line the number of partially executed tasks, the red line the number of tasks not executed or wrong

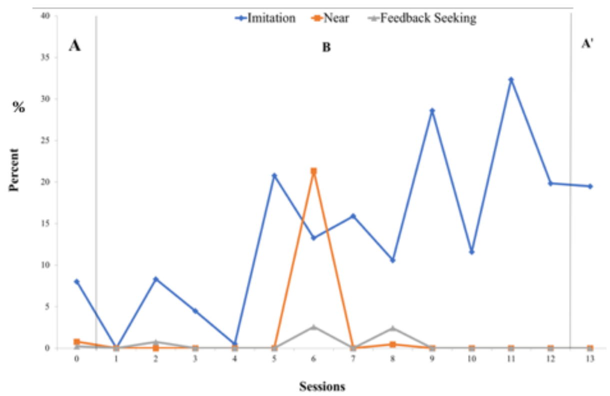


Fig. 10 The average percentage of time spent by the child (P02) in imitation, near the robot, and seeking feedback from the therapist

Participant 3 (P03). Figure 11 shows a decrease for all 33 GMI tasks, from 10 to 3 for the tasks not executed (score=0). Scores also decreased from 15 to 5 in the Ex-ante session for the follow-up session for the imitative tasks performed incorrectly (score=0.5), while the exact tasks (score=1) increased significantly from 7, before the training with NAO robot, to 25 in the follow-up session. Figure 12 shows how all the tasks selected for the child increased the score, even during the randomization phase to A+B+C (s9) and A+B+C+D tasks (s10, s11, s12). During the first randomization (s8) a decrease in imitation occurred, probably due to the complexity of the activities. From s8 there is a continuous increase which ends with the best result obtained in the post-intervention session. Also, in this session seeking feedback from the therapist increased, although the task was conducted without the therapist's *prompts*. We think that there was a greater visual demand on the part of the child, due to the search for approval during the task, independently. We consider that the child could experience a greater need for visual support, due to the autonomy with which he was performing the activity.

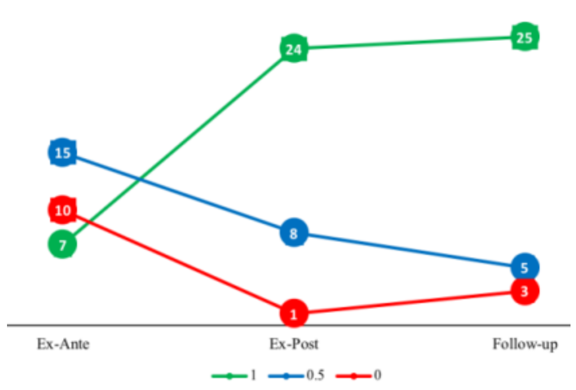


Fig. 11 Result of the VB-MAPP imitation tasks assessment (Ex-ante, Ex-post, and Follow-up) for the child (P03) administered by the psychologist. The green line indicates the number of fully executed tasks, the blue line the number of partially executed tasks, the red line the number of tasks not executed or wrong

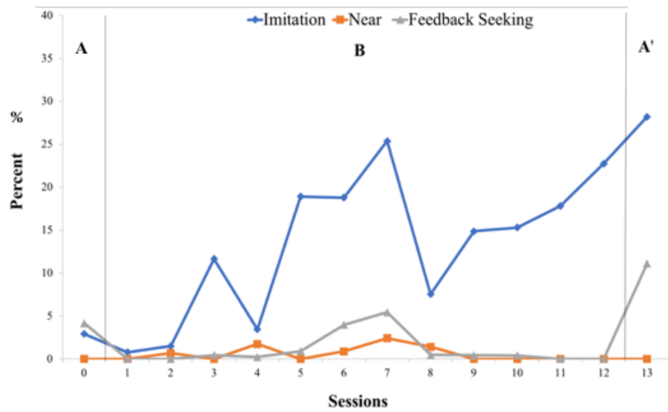


Fig. 12 Average percentage of time spent by the child (P03) in imitation, near the robot and seeking feedback from the therapist

We should note that the child showed anxiety during the baseline and the first two sessions (s2, s3). For this reason, we decreased, just for the child, the volume of the robot's sounds and speech (from 100% to 70%) from the third session (s3) following recommendations from the clinicians. Indeed, the result has improved since that session.

Participant 4 (P04). Figure 13 shows a decrease from 31 to 25 of the absent tasks. While an increment from 2 in Ex-ante to 5 (Ex-post), and 2 (Follow-up) of the imitative tasks performed incorrectly (v=0.5) was shown. Furthermore, the exact tasks (v=1) increased from 0 to 6 during the follow-up session.

In this case, all four of the imitative tasks selected for the child showed increased scores during the robot training (Figure 14). We noted an imitation decrease in s10 when the randomization was applied (A+B+C+D), and therefore the task was more complicated.

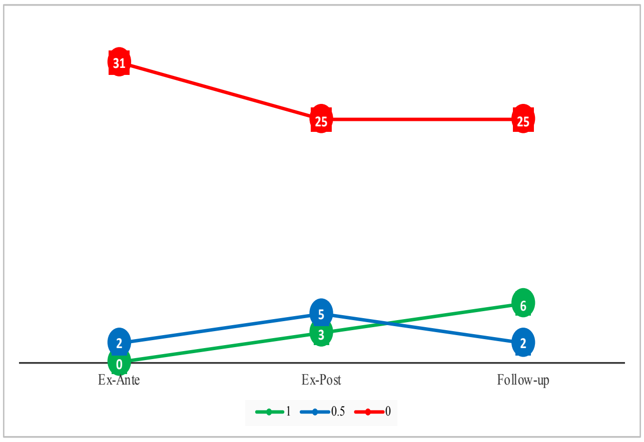


Fig. 13 Result of the VB-MAPP imitation tasks assessment (Ex-ante, Ex-post, and Follow-up) for the child (P04) administered by the psychologist. The green line indicates the number of fully executed tasks, the blue line the number of partially executed tasks, the red line the number of tasks not executed or wrong

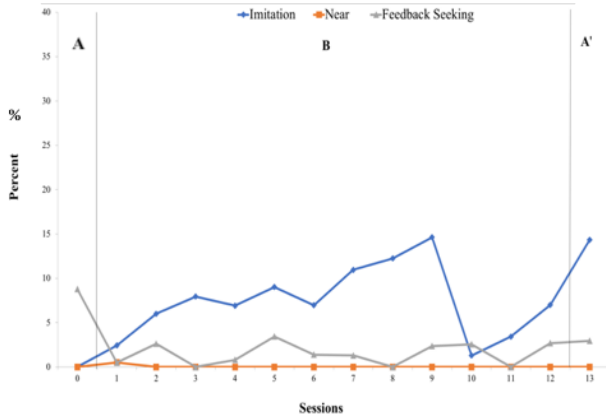


Fig. 14 Average percentage of time spent by the child (P04) in imitation, near the robot and seeking feedback from the therapist

Participant 5 (P05). Figure 15 shows the general results obtained by the psychologist from the administration in the standard form of all 33 GMI tasks of VB-MAPP. For this child, incorrect imitative tasks (score=0) decreased in the baseline section from 33 to 31 in the follow-up. Furthermore, the tasks performed incorrectly (score=0.5) increased from 0 to 2, while no activities with 1 score had been performed.

During the robot training sessions, the child slightly increased the imitation (s5-s7). Moreover, when the randomization was applied (s12) this resulted in a slight increase (Fig. 16).

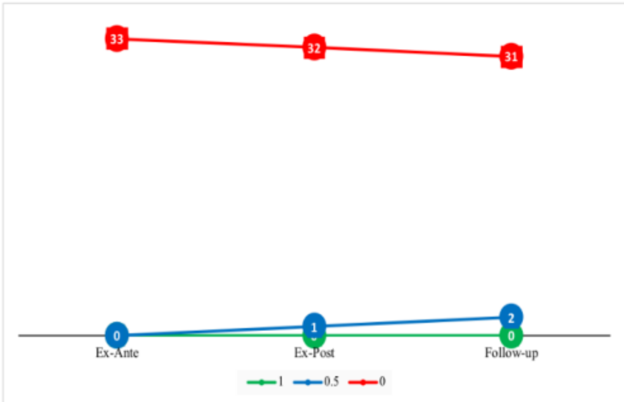


Fig. 15 Result of the VB-MAPP imitation tasks assessment (Ex-ante, Ex-post, and Follow-up) for the child (P05) administered by the psychologist. The green line indicates the number of fully executed tasks, the blue line the number of partially executed tasks, the red line the number of tasks not executed or wrong

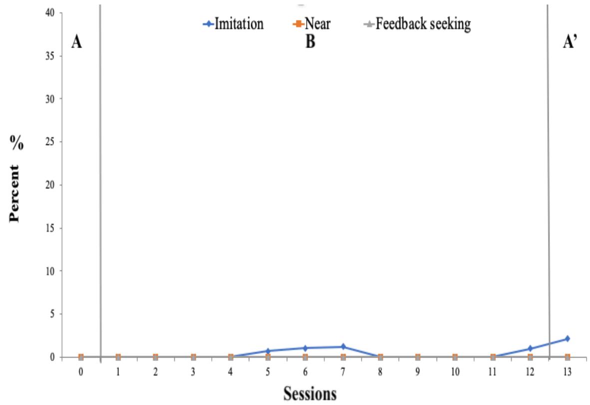


Fig. 16 The average percentage of time spent by the child (P05) in imitation, near the robot and seeking feedback from the therapist

Participant 6 (P06). Figure 17 shows the child's inability to perform all 33 GMI tasks of VB-MAPP. These are completely absent (no.33) in the baseline, with a score of 0 to 31 in the follow-up session, and tasks performed incorrectly (score=0.5) with 0 in ex-ante rising to 2 after training with robot. In this case, none of the selected tasks showed an improvement either when the tasks were proposed separately, or when they were joint and randomized proposals (A+B+C). Instead, increased feedback was sought from the therapist (Fig. 18).

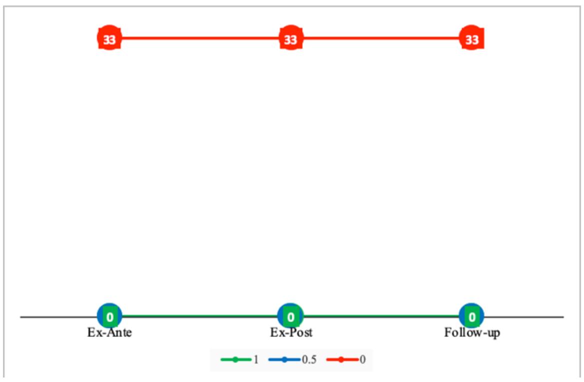


Fig. 17 Result of the VB-MAPP imitation tasks assessment (Ex-ante, Ex-post, and Follow-up) for the child (P06) administered by the

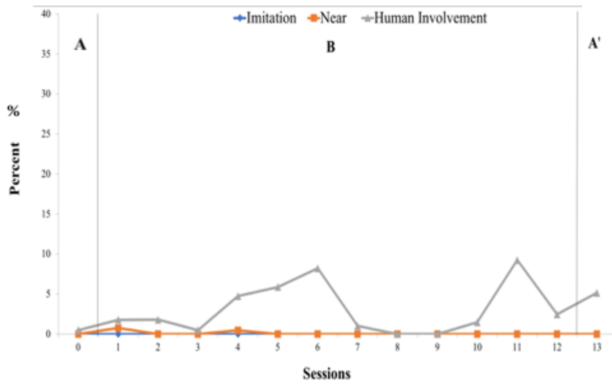


Fig. 18 The average percentage of time spent by the child (P06) in imitation, near the robot and seeking feedback from the therapist

psychologist. The green line indicates the number of fully executed tasks, the blue line the number of partially executed tasks, the red line the number of tasks not executed or wrong

3.1. Evaluation of the therapists' opinion

Table 3 presents the therapists' answers to our questionnaire. The Table shows descriptive statistics (Median and Mode) and the frequency of each level of response.

Table 3 Sentences used in attitude towards robots' survey (Zubrycki & Granosik, 2016), and responses on Likert scale (1-strongly disagree, 2-disagree, 3-neutral, 4-agree, and 5-strongly agree)

	Questionnaire	1 2 3 4 5	Median	Mode
1	A robot could improve value of my work		3	Neutral 4/6
2	A robot could make my work more varied		3.5	Agree 3/6
3	A robot could help me with repeatable tasks		4	Agree 6/6
4	A robot could help me systematise my work		4	Agree 6/6
5	A robot could give me way to self-growth		2.5	Neutral 3/6
6	A robot could improve my focus on the most important parts of my job		4	Agree 5/6
7	Use of a robot could lessen conflicting parts of my job		3	Agree 3/6
8	A robot could give me feedback		3.5	Agree 5/6
9	A robot could help me with setting my work goals		2.5	Disagree 3/6
10	A robot could help with setting the range of my responsibilities		2	Disagree 5/6
11	A robot may become an important device in my work		4	Agree 6/6
12	By using a robot, my value in workplace will increase		3	Neutral 6/6
13	A robot will lessen my workload		4	Agree 5/6
14	A robot will lessen my overtime		3	Neutral 5/6
15	By using a robot, I will have more control over my work		2	Disagree 4/6
16	Use of robots could improve my control over how my work tasks are done		4	Agree 5/6
17	A robot could give me objective reports about my work		3	Neutral 3/6
18	A robot could describe therapy process		3	Agree 3/6
19	A robot could motivate me in my work		3	Disagree 4/6
20	A robot could help me with physically strenuous work		4.5	Agree 5/6
21	A robot could help me work more ergonomically		4	Agree 6/6
22	A robot could help me check my emotions		1.5	Disagree 4/6
23	A robot could accompany me in work		4	Agree 5/6
24	Using robots could give me more support from supervisors		4	Agree 4/6
25	Through use of robots my work would be more objectively evaluated		3	Neutral 5/6
26	A robot could help me with aggressive behaviour of my clients		2	Disagree 4/6
27	A robot could help me use more my abilities more		3	Neutral 4/6
28	A robot could bring more creative solutions to problems in my work		3	Agree 3/6
29	Use of robots could lead to my self-improvement		3	Neutral 4/6
30	Use of robots could lead to improvement of my work-life balance		3	Neutral 4/6
31	A robot could give me more time for breaks		3	Neutral 4/6

The therapists saw the robot as something that could be an important resource at work by 100% of the therapists, and 83.3% agreed that the robot could help them to focus on important aspects of work. Further analysis shows that therapists agreed (66.7%) and strongly agreed (33.3%) that the use of robots could make their work more systematic, while they also agreed that robots could help them with repeatable tasks (100%). Therapists agreed (100%) that robots could improve their workplace ergonomics, while 83.3% felt the robots could lessen their physical workload. However, when asked if a robot could help with the aggressive behaviour of patients, 66.7% disagreed.

Therapists agreed (83.3%) that the use of robots could lessen their workload but were neutral (83.3%) that robots could lessen their overtime. The 56.6% of the therapists agreed that the use of robots could give them more support from their supervisors. Also, the therapists were neutral (83.3%) about robots helping to make their work be evaluated more objectively, and 83.3% felt that robots could not help set their range of responsibilities.

Table 4 shows the mean rank of preferred robot functionalities where 1= the most desirable role, and 5= the least desirable role).

Table 4 Mean rank value for robots' functions (1—the most desirable role, 5—the least desirable role)

Child's behaviour analyser	1.1
Recordkeeper and reporting device	2.4
Therapeutic robot	3.1
Emotional support/emotional mirror	3.5
Team player	4.2
Helper in critical/dangerous situations	4.3

Therapists felt the most desirable role for the robot would be in a support for analysing the child's behaviour. This was followed by roles as a record keeper and reporting device (2.4). The robot was also evaluated as a therapeutic tool (3.1) of emotional support (3.5). Therapists also evaluated the robot in the role of a team player and helper in critical/dangerous situations as the least desirable role (4.2 and 4.3).

4. Discussion and Conclusions

In this feasibility study, we presented a feasibility study on integrating robotic technologies within current daily therapeutic protocols, e.g. TEACCH, to support the therapist when treating children with autism and comorbid intellectual disability. Overall, the analyses of the results showed a successful integration of a robot assistant into the standard treatment of autistic children with mild, moderate and severe intellectual disability. In fact, after the training with the robot, these children were able to adequately perform new Gross Motor Imitation (GMI) tasks with the human therapist, i.e. to generalize in human-human interaction and to maintain the skills after three months. Furthermore, it is essential to emphasize that the children not only learned the tasks that had been part of their personal "baggage" but also improved their performance of other tasks that had not been part of the robot training. Indeed, the scores increased for their imitative level and they acquired the capability to perform new tasks. The 3 or 4 tasks, which were supported by the robot training, also allowed each child to activate and generalize his imitative learning and apply it to the other remaining tasks.

As a further investigation, shown in Figure 19, we decided to verify the progress with a peer, i.e. a child with ASD (diagnosis ICD-10: F84.0, male, chronological age=124 months) who was not included in this study. However, the child was included in a separate study (Conti, Trubia, Buono, Di Nuovo, & Di Nuovo, 2019), showing excellent imitative skills and could act as a model in the peer group. This may be useful in reducing the anxiety that adults generally cause with ASD children (Kim, Szatmari, Bryson, Streiner, & Wilson, 2000).


Fig. 19 Peer imitation

However, the two children with a profound intellectual disability did not benefit from robot-assisted therapy as they were not able to fully perform any new task. This is connected to their conditions as both children had been diagnosed with profound intellectual disability and had difficulties in comprehending the stimuli. These children were less engaged than the other participants; in this regard, their behaviour with the robot was comparable to their behaviour with human beings. This result is also supported by the studies of Pioggia et al. (2007), where the participants who derived less benefit from the robot-assisted therapy were the ones with a more severe form of autism and with the lowest IQ. There is a need to find more advanced solutions and approaches for persons with profound intellectual disability. These cases require more care and, thus, the robot-assisted therapy may be very much welcomed by the therapeutic team, who can reduce their workload by allowing parts of the treatment to be taken over by a robot.

A strength of this feasibility study, most of the children kept a high interest during the five months of the intervention, showing a sustained adherence to the treatment. This confirms the results of our previous study (Conti et al., 2015) and encourages the development of effective protocols where the robot becomes a mediator between the child with autism and intellectual disability and humans.

In practical terms, the success of the training with the robot shows that the intervention may be carried out by only one therapist when usually, this requires two. Human therapists remain an essential part of the treatment system. In fact, one human is needed to show the task to imitate and another to provide physical support to the child, because of their intellectual conditions. Indeed, the majority of therapists involved recognize that the robot can reduce their workload while maintaining the efficacy of the intervention.

The overall results of this study indicate the underlying potential of the application of social robots in this field. Further research might investigate the use of an automatic method for assessing the response of different types of patients during the interaction with the robots based on the video and audio recordings, as shown for instance by Di Nuovo et al., (2018). It is well known that, with the same nosographic diagnosis, every condition is unique and therefore should be treated in a personalized way (Dawson et al., 2010). This is supported by experimental results in other contexts that indicate that the personalization of intervention can significantly improve the utility of an educational or assistive human-robot interaction (Leyzberg et al., 2014).

The current investigation was limited by the relatively low number of participants and the absence of a control group, which is very difficult to obtain for these cases, which caused us to choose a single-case approach, which we felt would be more suitable and reliable for a feasibility study. A large randomized controlled trial could provide definitive evidence. Also, we designed the protocol to be administered with a humanoid robot where its specific design could be the cause of the effect. Due to the scope of this study, we only administered one section of VB-MAPP. Future research could consider developing and evaluating other sections and levels of the VB-MAPP (e.g. imitation with objects, fine motor imitation).

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Author Contributions DC and GT curated the data, formally analysed the data, provided the methodology, validated the data, and wrote the original draft of the manuscript. DC and AD investigated the data and provided the resources. AD administrated the project. SB, SD, and AD supervised the study. DC visualized the data. All authors wrote, reviewed, and edited the manuscript.

Compliance with Ethical Standards

Conflict of Interest Statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Ethical Approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional research committee (Oasi Research Institute of Troina 2017/01/17/CE-IRCCS-OASI/4 and Sheffield Hallam University No. Z6559086) and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

Informed Consent Informed consent was obtained from all individual participants included in the study.

Appendices

Appendix A - Participants Clinical Details

Participant 1 (P01). Autism Spectrum Disorder (ICD-10: F84.0), supported level 2 in comorbidity with mild intellectual disability (ICD-10: 70) and compromise of the associated language (simple sentence). The psychological evaluation revealed difficulties in the social-communicative area and the presence of oppositional/provocative attitudes. These unstructured situations impact on the child's relationship with peers. He initially presented negativity and the tendency to run and not to listen to the caregiver. If stimulated, the child was able to adhere to the set rules and the therapist's requests, especially in a structured environment. From a cognitive point of view, for the prerequisites for learning, the child remained seated at the worktable but needed supervision. Attention was often undermined by verbal stereotypes, and if ignored tended to decrease considerably. From the perceptual point of view, the child was able to make associations and discriminations of images, by shape and colour, and associations of numerical symbols. Moreover, there was also a sense of chaos and impulsiveness in the execution of the activities, with a tendency to proceed by trial and error. The use of objects wasn’t always functional and sometimes appeared stereotypical. The child's interest in objects was short. In the area of communication, verbal production consists of a simple sentence. The child used morpho-syntaxes and contents that were not always coherent. Qualitative speech anomalies were observed as deferred echolalia and altered prosody. With motor skills, the child displayed stereotypical with his hands (e.g. mixing objects, which tended to pile up, fixing the movement). There were basic motor patterns and the child was autonomous in his movements. However, the movements were undermined by the lack of attention to the task. Fine motor skills had mild hypotonia, especially in the modulation of gestures that required pressure and selective movements of the fingers. The child still found difficulty in executing a movement on command (e.g. running at different speeds and stopping at the stop), while he was more able to maintain the slow-fast pace.

Participant 2 (P02). Autism Spectrum Disorder (ICD-10: F84.0), supported level 3, absence of language in comorbidity with moderate intellectual disability (ICD-10: 71), and focal epilepsy (ICD-10: G40.209). The child showed elusive eye contact regarding the mutual social relationship and participated in the interaction for a short time with games he liked. The child was very intolerant to frustrations and his mood was often irritable and showed interest in the environment when carrying out exploratory conduits. Compared to his peer group, there wasn’t adequate interest and he tended to isolate himself. Moreover, unusual and repetitive behaviours relating to unusual sensory reactions were observed (e.g. exploring objects with peripheral vision), or orally exploring the object and trying to block out the (not very intense) sounds; furthermore, he was swinging his head. His fine motor skills showed little force in the motor action, especially in carrying out tasks that required pressure. Cognitively, his visual perception allowed him to put two colours together and recognize some commonly used objects. Finally, his verbal expression was limited to some sounds.

Participant 3 (P03). Autism Spectrum Disorder (ICD-10: F84.0), supported level 3, impairment of language and severe intellectual disability (ICD-10: F72). For socio-emotional reciprocity, the child had a reduced sharing of interests and expression of emotions. The search for interacting with another seemed instrumental in satisfying his needs. The child tended to stand aside, not always accepting bodily contact or physical closeness, approached his peers and looked at them, but it was difficult to involve him in two play activities and was only able to carry out parallel sports activities or share the objects with the mediation of an adult. The child did not use any gestures for non-verbal communication behaviours usually used in social interaction, and eye contact was elusive. Facial mimicry rarely varied and only for expressions of some emotions. Spontaneous activity was completely absent. The child showed no interest in the material or toys, and when over-excited, presented stereotyped movements of the upper limbs associated, sometimes, with vocalizations with a particular intonation. On the psychomotor development, the child showed clumsiness and poor coordination of rough movements, while his fine motor skills demonstrated simultaneous use of the hands and unstructured prehension.
Regarding his communication, verbal language was limited to the emission of some vocalizations without clear communicative intentionality. The cognitive area was characterized by performance not in line with the expected capabilities for his age, with strengths in the motor areas and significant deficits in the language areas.

Participant 4 (P04). Autism Spectrum Disorder (ICD-10: F84.0), supported level 3, in comorbidity with severe intellectual disability (ICD-10: F72), and absence of verbal language. The child had a reduced capacity for initiative for affective-relational skills. Sometimes he sought the other to satisfy a primary need or emotional containment, but in cases where he was the one being approached, he could not escape contact. With his peers, the child tended to approach them using inappropriate behaviour. Overall, the child showed motor restlessness, significant difficulties functionally organizing themselves, and moved without purpose. There were provocative behaviours (e.g. pushing, throwing objects, etc.) an unmotivated smile, oppositionism, motor stereotypes and stereotypical use of objects. Furthermore, the child had no capacity for symbolic imitation. From the cognitive point of view, the child was able to identify and correctly insert geometric shapes and not in a joined table. For oculo-manual coordination, he was able to put tacks in the frame and could scribble and correctly fit a 4-piece puzzle. The prehension was of tridigital type. For the prerequisites to learning, there was discontinuous attention and a lack of motivation to the task. The use of the material wasn't very functional while remaining seated at the worktable, the child needed continuous stimulation to carry out the activities. Sometimes he refused by activating oppositional-provocative behaviours, gross motor skills were poor; harmony of movements was observed, but with a lack of organization and planning of motor activity. The child displayed motor impairment, especially in dynamic activities involving the coordinated use of various body parts.

Participant 5 (P05). Autism Spectrum Disorder (ICD-10: F84.0), severity level 3 with language impairment in comorbidity with profound intellectual disability (ICD-10: F73). Regarding the area of mutual social relations, the child approached the adult mainly when he needed to be content or wanted to satisfy his needs, while he didn't show any interest towards the peers. Modulated facial mimic was observed except for the expression of anger, and pleasure through a smile. Eye contact was poor and not socially modulated. There were deficits in shared attention, emotion, and joint intention, and didn't use gestures or pointing, to share attention. The verbal language was absent and stereotypical sounds were observed, while the use of other communication methods was not detected.

Behaviour patterns included motor stereotypes such as turning on himself. The child was only able to wait for a short time, showing low levels of tolerance to frustration. Also, in an unstructured environment, spontaneous activity was chaotic, stereotyped and limited to a selective interest for some objects. In over-excited situations, he displayed hand flapping, hopping and spinning on himself. With his motor skills, the basic schemes appeared unscathed, but he failed to perform activities on request. While walking was done on his tiptoes, his fine motor skills displayed little interest in the objects he grasped with pluri-digital grip.

Participant 6 (P06). Autism Spectrum Disorder (ICD-10: F84.0), supported level 3, in comorbidity with profound intellectual disability (ICD-10: F73), and absence of verbal language. The psychological evaluation showed excessive motor restlessness associated with motor stereotypies and hetero-aggression attitudes towards peers. The child showed significant impairments in social communication and social interaction with others, with greatly reduced behaviours and interests and the presence of repetitive activities. These problems greatly affected adaptive functioning. In the area of mutual social relations, his relationship remained restricted to the family nucleus and reference figures, and he couldn't communicate his needs except through his gaze.

The mood tone seemed labile with a tendency to irritability and poor control of the impulses. His verbal production consisted of individual vocalizations while he did understand some simple and concrete deliveries, which contained a single order. His exploration of the environment appeared to be characterized by chaos and a lack of interest in the materials. In these frustrating conditions, the child was biting his hands, squeezing and closing his eyes. He was rubbing his nose with his fingers, and sometimes flapped his hands, all accompanied by the emission of screams. Moreover, if the child was left free, he tended to prefer isolation.

No symbolic game ideas were observed, nor was any functional use of the object. The child needed total physical guidance to perform simple motor paths. His movements were disharmonic and dysmetric. His fine motor skills displayed poor praxis ability. Prehension was mostly tridigital, with poor eye-hand coordination and the simultaneous use of both hands.

Appendix B - The NAO Robot

NAO is 57.4 cm high, weighs 4.3 kg and can produce very expressive gestures with 25 Degrees of Freedom (DoF) (4 joints for each arm; 2 for each hand; 5 for each leg; 2 for the head and one to control the hips) (Softbank Aldebaran Robotics, 2018). NAO can detect faces and mimic eye contact moving the head appropriately, and also can change the colour of the LEDs in its eyes' contour to simulate emotions and capture a lot of information about the environment using sensors and microphones. The NAO robot is programmed with a graphical programming tool, named *Choregraphe* (Pot, Monceaux, Gelin, & Maisonnier, 2009).

Appendix C - Verbal Behaviour Milestones Assessment and Placement Program (VB-MAPP)

The VB-MAPP has five components including a milestones assessment, barriers assessment, transition assessment, task analysis and skills tracking, and placement and individualized education program goals (Sundberg, 2008). Each of the skills in the VB-MAPP is developmentally appropriate, measurable, and is a comprehensive and balanced assessment of language skills. The assessment is used to evaluate performance on Skinner's verbal operands across several tasks (Skinner, 1957). The milestones assessment contemplates skills that are balanced and sequenced using three different levels (1=0-18 months, 2=18-30 months, and 3=30-48 months), based on the attainment of developmental milestones by typically developing children. For this study, only level 1 of the assessment on the GMI abilities was administered. This level includes the evaluation of early *mand,* tact, listener, social, visual-perceptual and match-to-sample, independent play, motor imitation, and echoic skills, as well as spontaneous vocal behaviour (Sundberg, 2008). As with all tools and protocols, the results of the *VB-MAPP* can only be meaningful if the assessment is conducted by professionals who are expert in its administration.

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