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Self-initiations in young children with autism during Pivotal Response Treatment with and without robot assistance

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Abstract

The aim of this study was to investigate the effect of Pivotal Response Treatment versus robot-assisted Pivotal Response Treatment on self-initiations of children with autism spectrum disorder and to explore the relation between self-initiations and collateral gains in general social-communicative skills. Forty-four participants with autism spectrum disorder aged 3–8 years (Pivotal Response Treatment: $n = 20$, Pivotal Response Treatment + robot: $n = 24$), who were recruited as part of a larger randomized controlled trial (number NL4487/NTR4712, https://www.trialregister.nl/trial/4487), were included. Self-initiations were blindly coded, assessing video probes of all parent–child sessions using an event-recording system. General social-communicative skills were assessed with the parent- and teacher-rated Social Responsiveness Scale during intervention and at 3-month follow-up. Results using linear mixed-effects models showed overall gains in self-initiations during both Pivotal Response Treatment intervention groups (estimate = 0.43(0.15), 95% confidence interval (CI): 0.13–0.73), with larger gains in functional self-initiations in children receiving robot-assisted Pivotal Response Treatment (estimate = −0.27(0.12), 95% confidence interval: −0.50 to −0.04). Growth in self-initiations was related to higher parent-rated social awareness at follow-up compared with baseline in the total sample ($r = -0.44$, $p = 0.011$). The clinical implications of these findings, as well as directions for future research in the utility of Pivotal Response Treatment and robot assistance in autism spectrum disorder intervention, are discussed.

Lay abstract

The initiation of social interaction is often defined as a core deficit of autism spectrum disorder. Optimizing these self-initiations is therefore a key component of Pivotal Response Treatment, an established intervention for children with autism spectrum disorder. However, little is known about the development of self-initiations during intervention and whether this development can be facilitated by robot assistance within Pivotal Response Treatment. The aim of this study was to (1) investigate the effect of Pivotal Response Treatment and robot-assisted Pivotal Response Treatment on self-initiations (functional and social) of young children with autism spectrum disorder over the course of intervention and (2) explore the relation between development in self-initiations and additional gains in general social-communicative skills. Forty-four children with autism spectrum disorder (aged 3–8 years) were included in this study. Self-initiations were assessed during parent–child interaction videos of therapy sessions and coded by raters

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who did not know which treatment (Pivotal Response Treatment or robot-assisted Pivotal Response Treatment) the child received. General social-communicative skills were assessed before start of the treatment, after 10 and 20 weeks of intervention and 3 months after the treatment was finalized. Results showed that self-initiations increased in both treatment groups, with the largest improvements in functional self-initiations in the group that received robot-assisted Pivotal Response Treatment. Increased self-initiations were related to higher parent-rated social awareness 3 months after finalizing the treatment.

Keywords

autism spectrum disorders, Pivotal Response Treatment, robot-assisted intervention, self-initiations

Deficits in social communication form one of the core features of autism spectrum disorder (ASD; American Psychiatric Association [APA], 2013) and have a profound negative impact on various domains of functioning such as school performance, friendship and relationships (Bauminger & Kasari, 2000; Koegel, Koegel, Shoshan, & McNerney, 1999). Self-initiations (i.e. the ability to spontaneously initiate a social interaction), such as question-asking and commenting, occur infrequently or are absent in children with ASD (Koegel et al., 2003). The results of a large-scale national survey of the Dutch Autism Society ($n = 4068$) demonstrated that diminished self-initiations in social contact are the most frequently reported maladaptive behaviours in children with ASD (Begeer et al., 2013). Furthermore, self-initiation is suggested to be a ‘pivotal’ (core) skill for the development of other social-communicative skills, as lower self-initiations are related to less naturally occurring opportunities for social communication (Koegel et al., 2003). This pervasive problem highlights the need for appropriate interventions promoting social communication for children with ASD.

Interventions integrating Applied Behaviour Analysis (ABA) and developmental principles have become the predominant approaches for treating the core symptoms of children with ASD (Ona et al., 2019; Ospina et al., 2008). These interventions involve a manualized approach that is balanced with individualized, naturalistic and motivational procedures, high involvement of family members and ongoing monitoring of progress (Fuller & Kaiser, 2019; Ospina et al., 2008; Rogers & Vismara, 2008). Pivotal Response Treatment (PRT), derived from ABA, incorporates all of these intervention components. This intervention is based on the assumption that targeting pivotal areas of impairment in ASD, such as self-initiations and motivation for social contact, will induce widespread gains in other areas of functioning and skills (Koegel, Koegel, Harrower, & Carter, 1999). PRT includes strategies to create learning opportunities for self-initiations, such as following the child’s interests, gaining the child’s attention, giving appropriate levels of help (prompting), providing immediate and contingent reinforcement in response to the child’s initiation or good attempt and interspersing maintenance and acquisition tasks (Koegel & Koegel, 2006, 2019). The involvement of parents is a key component to increase the generalization of learned skills into daily routines.

A systematic review indicated the effectiveness of PRT in enhancing self-initiations and collateral improvements in language and communication skills such as increase in verbal utterances, social response and maintaining interactions (Verschuur et al., 2014). However, previous studies did not examine growth in self-initiations and gains in general social-communicative skills in direct relation to each other but rather reported results on both outcomes separately. Furthermore, most studies on PRT targeted self-initiations in general without distinguishing between subtypes of communicative intentions such as functional initiations (e.g. asking for objects, help, or information) and social initiations (e.g. requesting social information and commenting; Verschuur et al., 2019). However, outcomes in self-initiations may differ depending on the communicative intentions of the self-initiations that are under study. Studies using single-subject designs indicated that PRT may enhance self-initiations such as asking ‘what is it?’, ‘where is it?’ and ‘who is it?’ (Koegel et al., 2014) and asking for an object/activity (Vernon et al., 2012). Furthermore, mixed results were reported by studies that incorporated a more comprehensive definition of self-initiations, including — in addition to the questions as mentioned above — question-asking about the other’s opinion or previous experiences, commenting and starting to talk about a new subject (Huskens et al., 2012; Kuhn et al., 2008; Verschuur et al., 2019). Besides variation in definitions in self-initiations, PRT studies vary widely in treatment duration and intensity (ranging from 66 min to 60 h) and implementation strategies (Cadogan & McCrimmon, 2015; Ona et al., 2019; Verschuur et al., 2014). These differences between studies complicate the understanding of how self-initiations develop over the course of PRT, how this development is related to collateral improvements in social communication and which components may contribute to effectiveness of the intervention.

The use of robot assistance has been raised as a possible effective component of interventions for children with ASD (Dautenhahn & Werry, 2004; Diehl et al., 2012).

Robots are often appealing to children with ASD, because robot behaviour is predictable, consistent and easy to adjust in different levels of complexity (Gillesen et al., 2011; Scassellati, 2007). This potentially contributes to a more enjoyable and child-friendly learning environment in which children can practice self-initiations and interchange without social pressures (Diehl et al., 2012). Among children with ASD who received robot-assisted interventions, increases in self-initiations (Huskens et al., 2013) and general social-communicative skills (Boccanfuso et al., 2017) were observed. However, due to limitations in study design, no firm conclusions can be drawn on the additional value of robot assistance on the effectiveness of the intervention. In addition, many studies on robot assistance in ASD interventions are limited by methodological problems such as small sample sizes and a lack of control group (Diehl et al., 2012; Ismail et al., 2019). This highlights the need for rigorously designed studies on the effectiveness of robot assistance in established interventions such as PRT, investigating development in targeted behaviour (i.e. self-initiations) over the course of intervention and how this relates to collateral changes in untargeted, general social-communicative skills.

The current study aimed to address this need by (1) investigating the effect of PRT versus robot-assisted PRT on self-initiations of young children with ASD over the course of intervention in the Netherlands, distinguishing between functional and social self-initiations and (2) exploring the relation between growth in self-initiations and possible collateral gains in general social-communicative skills at the end of PRT intervention and at 3-month follow-up. We hypothesized that both PRT and robot-assisted PRT would be effective in increasing self-initiations and that growth in self-initiations would be related to gains in general social-communicative skills. Furthermore, we expected that children receiving robot-assisted PRT would show a larger growth in self-initiations and higher gains in general social-communicative skills compared to children receiving PRT.

Methods

Study design

This study was part of a larger three-armed randomized clinical trial (RCT) to the effectiveness of PRT, with and without the use of robot assistance, compared to treatment-as-usual (TAU) in the Netherlands (registered in Dutch National Trial Register, number NL4487/NTR4712; https://www.trialregister.nl/trial/4487). Random assignment to (1) PRT, (2) robot-assisted PRT or (3) TAU was performed with stratification by age, total intelligence quotient (TIQ), and site by an investigator not involved in data collection and outcome assessment. The study was approved by the Local Ethics Committee (Commissie Mensgebonden Onderzoek (CMO) Arnhem-Nijmegen, NL50509.091.14) and written consent was obtained from all families. The current in-depth study only used data from both PRT groups.

Participants

Participants were children with ASD referred for intervention at Karakter, an expert multi-site centre for child and adolescent psychiatry in the Netherlands. They were recruited with the following inclusion criteria: (1) a clinical diagnosis of ASD, according to the *Diagnostic and Statistical Manual of Mental Disorders* (4th ed., text revision; DSM-IV-TR) algorithm (APA, 2004); (2) age of 3–8 years; (3) a TIQ of 70 or higher; (4) ability to speak with one-word utterances at minimum; and (5) at least one Dutch-speaking parent. An exclusion criterion was having received PRT earlier. Comorbid psychiatric disorders of the child were allowed, but the primary diagnosis had to be ASD (and subsequently the primary intervention was focused on ASD). Before the start of the intervention period of PRT (with and without robot assistance), dosages of medication had to be stable. However, participants were not excluded if dosages changed during the intervention due to the intention-to-treat (ITT) approach.

Procedures

Parents of potential participants were approached by clinicians of Karakter. If parents were interested, information letters of the study were provided. Parents gave written informed consent when they agreed with the participation of their child. If children met the inclusion criteria, participants were randomized. In each condition, parents received psycho-education on ASD before the treatment, individually or in a group. PRT and robot-assisted PRT consisted of 20 weekly sessions in which self-initiations were targeted using the motivational techniques of PRT (Koegel, 2014; Koegel & Koegel, 2012). Treatment was delivered by certified PRT therapists trained up until level III, with a reached fidelity score of over 80%. A total of 13 PRT therapists participated in this study. In both treatment groups, implementation of learning opportunities during PRT sessions was in line with the used PRT manual (Koegel & Koegel, 2012), and parent training, intensity and duration of the intervention were similar across both groups. Of the PRT sessions in both treatment groups, 14 were parent–child sessions, 4 were parent-only sessions and in 2 sessions the child's teacher was involved. Each session had a duration of 45 min, except for one teacher session including a 90 min school/daycare visit. Parent–child sessions were recorded on video for later analysis.

PRT. In the PRT condition, parent–child sessions consisted of practicing PRT strategies during parent–child play. The therapist modelled the techniques and subsequently coached the parents in applying the techniques during interaction with their child. During the parent-only sessions, the progress of the child was discussed as well as the use of PRT techniques by parents. The child's teacher was involved by being briefed about PRT and how to practice it at school/day care.

Robot-assisted PRT (PRT + robot). In the robot-assisted PRT condition, the programmable humanoid robot NAO was used in the parent–child sessions. This robot can move its arms, legs and head and thus have expressive gestures. The TiViPE programming environment was used for developing the game scenarios for robot–child interaction (Barakova et al., 2013). Two interfaces were developed, one for creating the interactive robot behaviours and one text-to-speech module for additional intervention during the interaction. The game scenarios were pre-programmed in a flexible way, so the robot could act according to the child's choice or following child's initiation or response (see Supplementary Material S1 for details). These game scenarios for robot–child interaction were controlled by the PRT therapist and used in the first 15–20 min of each session for practicing the target behaviour of the child. Parents were seated close to the child and were asked to observe how the PRT techniques were practised by the therapist using the robot. Specifically, the therapist modelled the techniques to the parent by controlling the robot.

Game scenarios for robot–child interaction were developed based on motivational techniques of PRT and a three-step contingency was used: (1) the therapist controlled the robot in providing an antecedent stimulus, (2) the therapist controlled the robot in prompting the child in showing target behaviour and (3) the therapist controlled the robot in reinforcing the (attempt to) target behaviour naturally and contingently. Nine different game scenarios were created with seven levels of complexity each. After the robot-assisted part of the session, parents were coached by the therapist in practicing the techniques during interactions with their child. The content of the parent sessions and sessions with the involvement of the child's teacher were similar to the PRT condition.

Fidelity of PRT implementation. Fidelity of PRT Implementation of parents at the end of the intervention was measured using the partial interval recording procedure as described in the study of Verschuur et al. (2020), in which fidelity criteria are based on a sequence of correctly implemented PRT components, instead of coding each PRT component separately. Video probes of 10 minutes of the last two recorded parent–child sessions were coded by a trained research assistant, blinded to group assignment. A mean of these two was calculated to determine the total percentage of fidelity for each parent. Of the video probes, 20% was coded by a naïve second rater resulting in excellent agreement (intraclass correlation coefficient = 0.97).

Measures

Demographics and participant/parent characteristics. Demographics and participant/parent characteristics (i.e. age, gender, total intelligent quotient (TIQ), psychiatric comorbidity, medication use, psychopathology parents, educational level of parents) were retrieved from electronic medical records. If TIQ was not assessed within 2 years before start of the study, it was estimated by either the Wechsler Intelligence Scale for Children (Kort et al., 2005), Wechsler Preschool and Primary Scale of Intelligence (Hendriksen & Hurks, 2009) or Mullen Scales of Early Learning (Mullen, 1995), depending on age. Participant ASD symptom severity at baseline was retrieved from calibrated severity scores (CSS; Gotham et al., 2009) of the Dutch version of the Autism Diagnostic Observation Schedule (De Bildt et al., 2013).

Self-initiations. The development of self-initiations of the participant was assessed using videotaped parent–child play interactions of all parent–child PRT sessions. An event-recoding scheme was developed to code the number of self-initiations, in which only initiations considered as verbal, spontaneous (i.e. without prompting) and appropriate within the context were scored. Play sounds, undirected verbal utterances and echolalia were not scored. In order to distinguish different communicative intentions, self-initiations were coded as either *functional* (related to parent–child play context; requesting for object/activity, help, information and protesting) or *social* (early social conversational skills; asking for social information, opinion, commenting). In Supplementary Material S2, examples of these subtypes of self-initiations are listed. Total self-initiations were determined by summing the spontaneous functional and social self-initiations. Six minutes video probes of each parent–child session were used for coding, in which the starting point of the video probe was defined as the moment the child had chosen a game to play. Two raters (master level students), naïve to group allocation, were trained in PRT principles and the coding scheme by the first authors of this study (MdK and IvdB), both certified PRT level III therapists. After training, both MdK and IvdB served as second raters on 20% of the videos, resulting in excellent interrater reliability (intraclass correlation coefficient = 0.92, 0.90 and 0.87 for total self-initiations, functional self-initiations and social self-initiations, respectively). Self-initiations change scores were computed between baseline and endpoint for total, functional and social self-initiations. Baseline scores were based on the mean amount of self-initiations in the first two parent–child sessions and endpoint scores were based on the mean amount of self-initiations in the last two parent–child sessions.

General social-communicative skills. Collateral gains in general social-communicative skills were assessed with the Social

Responsiveness Scale (SRS; Constantino & Gruber, 2005; Roeyers et al., 2011) child version and preschool version. The 65-item digitalized questionnaires, rated on a 4-point scale, were completed by both the participant's parent(s) and teacher/daycare attendant at baseline, intermediate assessment (week 10), endpoint (week 20) and follow-up (week 32) as part of the larger randomized controlled trial. In the current in-depth study, we only investigated change in general social-communicative skills at endpoint and follow-up. The SRS consist of the following subscales: Social Awareness, Social Cognition, Social Communication, Social Motivation and Restricted Interests and Repetitive Behaviour. Scores for each subscale and total raw scores were computed, with higher scores representing lower general social-communicative skills. SRS change scores were computed for the total score and subscales between baseline and endpoint and between baseline and follow-up.

Statistical analyses

Between-group analyses using one-way analysis of variance (ANOVA; or a non-parametric equivalent) for continuous measures and chi-square analysis for categorical measures were conducted to examine whether descriptive characteristics, baseline self-initiations and total SRS scores, and hours of treatment differed between the groups. Outliers were identified with the use of boxplots and, when necessary, adjusted to quartile (Q)1 − 1.5 × interquartile range (IQR) and Q3 + 1.5 × IQR to obtain a normal distribution. For all analyses, α was set on 0.05 (two-tailed).

The development of self-initiations over time for both groups (PRT and PRT + robot) was assessed with linear mixed-effects models, using the lmer function of the lme4 package (Bates et al., 2015) in R (version 3.4.0; R Core Team [Pinheiro et al., 2017]). Separate analyses were performed for total self-initiations, functional self-initiations and social self-initiations. Data on self-initiations were available on 14 measurement occasions (i.e. 14 parent–child PRT sessions, distributed over 20 weeks of intervention). Because of heterogeneity among participants in intercepts (number of self-initiations in session 1) and slope (change over time; see Supplementary Figure S3), a per-participant random adjustment to the fixed intercept and the slope of time were included in the model besides the fixed effects for time (weeks), group (PRT vs PRT + robot) and the interaction effects between time and group. Confidence intervals (95% CI) were derived from the function *confint* in R (R Core Team [Pinheiro et al., 2017]), with CI that do not include zero indicating significant estimates.

Change over time in general social-communicative skills was assessed with paired-samples t-tests. Furthermore, to examine between-group differences (PRT vs PRT + robot) in the change in general social-communicative skills, independent sample t-tests were conducted on SRS change scores. Correlational analyses on the total sample were conducted to explore the relationship between change in self-initiations (total, functional and social) and change in general social-communicative skills after PRT intervention in general (baseline vs endpoint and baseline vs follow-up).

Results

Study population

Fifty-two participants were assigned to either the PRT group or the PRT + robot group. Two participants allocated to the PRT group did not start with the intervention nor received a baseline assessment because of the need to switch to another intervention for comorbid problems. As a result, 50 participants started with the treatment to which they were assigned. Of these participants, 6 were excluded from the analyses as they had video recordings of less than 4 PRT sessions, due to early termination of the intervention or due to technical problems with the recording of video data. This resulted in a total of 44 participants who were included in this study, with 20 participants in the PRT group and 24 participants in the PRT + robot group. Of the included participants, 91% scored above the ASD cut-off of the Autism Diagnostic Observation Schedule, Second Edition (ADOS-2), with 2 participants (4.5%) scoring 1 point below and 2 participants (4.5%) scoring 2 points below the cut-off. Participants scoring below the ASD cut-off were equally distributed across groups (Fisher's exact test: $p = 1.000$).

Table 1 shows descriptive statistics, baseline scores and hours of treatment for both groups, with the results of between-group analyses. As expected due to randomization, no significant differences existed between the groups. The mean number of PRT sessions was 17 and 18 in the PRT and PRT + robot group, respectively, and did not significantly differ between the groups ($t(42) = 0.96$, $p = 0.345$). None of the parents in both PRT groups showed adherence to the 80% fidelity of PRT implementation criterion at the end of treatment and this differed significantly between groups (PRT: 36.3%; PRT + robot: 19.8%, $t(31) = 2.19$, $p = 0.037$).

Development of self-initiations over time

Figure 1 shows the linear growth in total self-initiations over time for both groups. There were no significant baseline differences between groups. Mixed-model analysis showed a significant main effect of time, Estimate = 0.43(0.15), 95% CI: 0.13–0.73. For the interaction effect between time and group, a marginal trend towards significance was found, Estimate = −0.19 (0.10), 95% CI: −0.38 to 0.02.

For functional self-initiations, a significant main effect of time was found, Estimate = 0.44(0.18), 95% CI: 0.09–0.79, as well as a significant interaction effect between time and group, Estimate = −0.27(0.12), 95% CI: −0.50 to

Table 1. Descriptive Characteristics, Baseline Scores and Hours of Treatment in Both Groups.

	Mean (SD)/ *N* (%)				*F* (df)/ X^2(df)		*p*
	PRT		PRT+robot				
	(*n* = 20)		(*n* = 24)				
Age in years	6.59	(1.67)	6.11	(1.28)	1.16	(1,42)	.287
Gender					0.02	(1)	.880
Male	17	(85.00)	20	(83.33)			
Female	3	(15.00)	4	(16.67)			
TIQ	105.85	(15.42)	99.96	(11.81)	2.01	(1,41)	.164
ASD symptom severity	6.35	(2.18)	6.04	(1.52)	0.30	(1,42)	.585
Psychiatric comorbidity [a]	9	(45.00)	7	(29.17)	1.18	(1)	.277
Medication use [a]	5	(25.00)	5	(20.83)	0.11	(1)	.743
Stimulants	4	(20.00)	3	(12.50)			
Stimulants + antipsychotics	1	(5.00)	0	(0.00)			
Antipsychotics	0	(0.00)	2	(8.33)			
Psychopathology mother [a]	8	(40.00)	7	(29.17)	0.57	(1)	.450
Psychopathology father [a]	3	(15.00)	5	(20.83)	0.25	(1)	.617
Education mother					0.13	(2)	.937
Low	4	(20.00)	6	(25.00)			
Average	8	(40.00)	9	(37.50)			
High	7	(35.00)	9	(37.50)			
Missing	1	(5.00)		N/A			
Education father					0.18	(2)	.673
Low	5	(25.00)	6	(25.00)			
Average	6	(30.00)	5	(20.83)			
High	6	(30.00)	10	(41.67)			
Missing	3	(15.00)	3	(12.50)			
Baseline self-initiations (Mean of session 1 and 2)							
Total	17.58	(6.50)	14.96	(5.63)	2.50	(1,42)	.122
Functional	16.95	(6.51)	14.04	(4.96)	2.83	(1,42)	.100
Social	0.63	(1.05)	0.65	(0.92)	–0.18[b]		.939
Baseline SRS total score							
Parent-rated	90.80	(18.60)	84.03	(23.03)	1.12	(1,42)	.296
Teacher-rated	84.74	(26.65)	78.25	(23.66)	0.70	(1,40)	.208
Hours of treatment (week 0-20)	15.43	(4.06)	16.49	(5.71)	0.49	(1,42)	.487

Note: [a] Percentage of presence, [b] represents z-score resulting from Mann-Whitney test. df = degrees of freedom; *F* = test statistic resulting from analysis of variance; *N* = number of participants, *p* = p-value (two-tailed), PRT = group of participants who received Pivotal Response Treatment; PRT+robot = group of participants who received robot-assisted Pivotal Response Treatment; SD = standard deviation; TIQ = total intelligence quotient; X^2 = test statistic resulting from chi-square analysis.

−0.04. Post hoc mixed model analyses per group showed a linear growth over time in the PRT + robot group, Estimate = 0.17(0.07), 95% CI: 0.03–0.31, but not in the PRT group, Estimate = −0.10(0.10), 95% CI: −0.31 to 0.11.

For social self-initiations a significant main effect of time was found, Estimate = 0.09(0.05), 95% CI: 0.01–0.18, but no significant interaction effect between time and group, Estimate = −0.01(0.03), 95% CI: −0.07 to −0.05.

Change in general social-communicative skills and relation with self-initiations

In Table 2, the mean and *SD* scores on self-initiations (total, functional, social), parent-rated and teacher-rated SRS total and subscale scores are presented for both groups separately and for the whole sample. The total score of the parent-rated SRS decreased significantly from baseline to endpoint ($t(42) = 5.68$, $p < 0.001$) and from baseline to follow-up ($t(43) = 5.02$, $p < 0.001$) in the total sample. The total score of the teacher-rated SRS also decreased significantly from baseline to endpoint ($t(38) = 2.78$, $p = 0.009$), but not from baseline to follow-up ($t(37) = 1.64$, $p = 0.110$).

The change on the parent-rated SRS from baseline to follow-up (but not from baseline to endpoint) was significantly larger ($t(42) = -2.65$, $p = 0.011$) in the PRT + robot group compared with the PRT group. When examining between-group differences on the subscales of the parent-rated SRS, a larger decrease was found in the PRT + robot

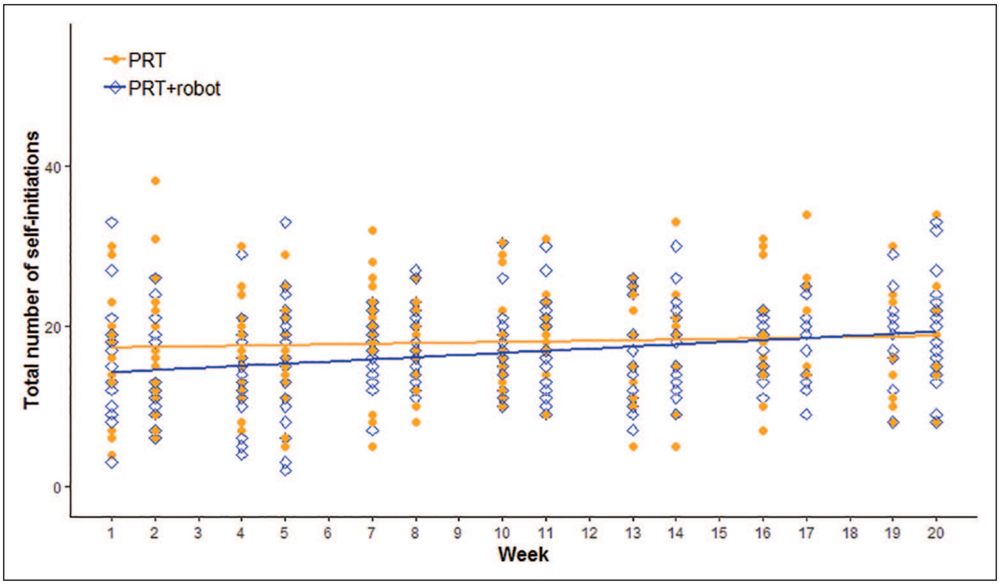

Figure 1. Linear growth of total number of self-initiations over time for PRT and PRT + robot.

group on the Social Communication score from baseline to endpoint ($t(41)=-2.24$, $p=0.030$) and baseline to follow-up ($t(42)=-2.88$, $p=0.006$). Furthermore, a larger decrease from baseline to follow-up (but not from baseline to endpoint) was found in the PRT + robot group on the Social Motivation ($t(42)=-2.11$, $p=0.041$) and Restricted Interests and Repetitive Behaviour ($t(42)=-2.50$, $p=0.016$) subscales. No significant between-group differences were found for the change scores on the Social Awareness and Social Cognition subscales of the parent-rated SRS and on the total score and subscales of the teacher-rated SRS.

The relation between change in self-initiations (total, functional, social) and change in general social-communicative skills after PRT was examined for the whole sample. Only the change score from baseline to follow-up on the Social Awareness subscale of the parent-rated SRS was significantly related to the change score on total self-initiations ($r=-0.44$, $p=0.011$) and functional self-initiations ($r=-0.42$, $p=0.016$), but not to social self-initiations ($r=-0.09$, $p=0.638$). No significant correlations were found between change in self-initiations (total, functional, social) and the other parent-rated SRS scales. There were also no significant correlations between change in self-initiations (total, functional, social) and any of the teacher-rated SRS scales.

Discussion

The aim of this study was to investigate the efficacy of PRT versus robot-assisted PRT on increasing functional and social self-initiations of young children with ASD over the course of the intervention and to explore the relation with collateral gains in general social-communicative skills at the end of the intervention and at 3-month follow-up. This study is the first in examining the effect of robot assistance during PRT on the development of self-initiations, using mixed-effect models to account for individual differences in baseline self-initiations and changes over time. We expected growth in self-initiations in both groups and hypothesized that growth in self-initiations would be related to gains in general social-communicative skills. Moreover, we hypothesized that children receiving robot-assisted PRT would show a larger growth in self-initiations and higher gains in general social-communicative skills compared to children receiving PRT.

The results indicated growth in total self-initiations over the course of a 20-week intervention for both the PRT and robot-assisted PRT group. Regarding the subtypes of communicative intention of self-initiations, children in the robot-assisted PRT group showed a larger growth in functional self-initiations, compared to the PRT group. There were no group differences in growth in social self-initiations. Furthermore, the results showed that both PRT and robot-assisted PRT interventions were effective in improving general social-communication skills, with larger improvements for the robot-assisted PRT group. However, we did not find significant correlations between change in self-initiations and change in most of the scales for general social-communicative skills; we only found an association between change in self-initiations and parent-rated social awareness.

The higher gains in both self-initiations and general social-communicative skills in the robot-assisted PRT group may be explained by the intrinsic interest in robotics of many children with ASD, which may be related to higher motivation for treatment (Scassellati, 2007). Motivation is considered a pivotal area in treatment (Koegel et al., 2001)

Table 2. Outcome statistics on self-initiations and general social-communicative skills across timepoints.

Outcome	Baseline						Endpoint						Follow-up					
	Total		PRT		PRT + robot		Total		PRT		PRT + robot		Total		PRT		PRT + robot	
	Mean	(*SD*)	Mean	(*SD*)	Mean	(*SD*)	Mean	(*SD*)	Mean	(*SD*)	Mean	(*SD*)	Mean	(*SD*)	Mean	(*SD*)	Mean	(*SD*)
Self-initiations	*n* = 44		*n* = 20		*n* = 24		*n* = 32		*n* = 11		*n* = 21							
Total	16.00	(6.14)	17.58	(6.50)	14.69	(5.63)	18.66	(5.79)	16.59	(7.71)	19.74	(4.80)	–	–	–	–		–
Functional	15.36	(5.83)	16.95	(6.51)	14.04	(4.96)	16.27	(4.97)	14.50	(5.09)	17.19	(4.77)	–	–	–	–		–
Social	0.64	(0.97)	0.63	(1.05)	0.65	(0.92)	2.39	(2.60)	2.09	(3.51)	2.55	(2.05)	–	–	–	–		–
SRS parents	*n* = 44		*n* = 20		*n* = 24		*n* = 43		*n* = 19		*n* = 24		*n* = 42		*n* = 20		*n* = 22	
Total score	87.11	(21.17)	90.80	(18.60)	84.03	(23.03)	74.82	(21.05)	81.91	(20.63)	69.21	(20.04)	72.88	(27.00)	84.28	(24.30)	63.38	(25.84)
Social communication	30.39	(7.85)	31.70	(6.94)	29.29	(8.53)	25.77	(8.67)	29.32	(9.23)	22.96	(7.21)	25.28	(10.33)	30.20	(9.94)	21.42	(9.01)
Social awareness	12.32	(2.92)	12.65	(2.39)	12.04	(3.33)	10.98	(2.85)	11.31	(3.30)	10.71	(2.49)	10.61	(3.39)	11.30	(3.13)	10.04	(3.56)
Social motivation	14.45	(4.42)	15.75	(3.93)	13.38	(4.60)	12.05	(4.84)	13.89	(5.28)	10.58	(3.98)	11.68	(5.87)	14.30	(5.64)	9.50	(5.20)
Social cognition	16.89	(5.44)	17.10	(5.10)	16.71	(5.81)	15.23	(5.46)	16.00	(5.87)	14.63	(5.17)	15.03	(5.87)	16.35	(5.96)	13.92	(5.68)
Restricted interests and repetitive behaviour	12.93	(4.94)	13.60	(5.19)	12.38	(4.77)	11.23	(5.00)	12.37	(5.69)	10.33	(4.30)	10.43	(5.76)	12.75	(5.85)	8.50	(5.01)
SRS teachers	*n* = 42		*n* = 20		*n* = 22		*n* = 41		*n* = 19		*n* = 22		*n* = 40		*n* = 19		*n* = 21	
Total score	81.34	(25.03)	84.74	(26.65)	78.25	(23.66)	72.09	(23.90)	80.25	(25.15)	65.05	(20.83)	74.33	(25.70)	78.16	(24.69)	70.87	(26.70)
Social communication	29.67	(10.37)	31.70	(9.63)	27.82	(10.89)	26.17	(11.15)	31.26	(11.68)	21.77	(8.72)	27.28	(10.83)	30.32	(10.15)	24.53	(10.93)
Social awareness	10.76	(3.48)	11.00	(3.52)	10.55	(3.51)	9.85	(3.48)	10.47	(3.44)	9.32	(3.50)	9.70	(3.50)	9.84	(3.72)	8.57	(3.37)
Social motivation	13.88	(5.03)	14.10	(5.48)	13.68	(4.70)	11.88	(5.25)	12.95	(5.90)	10.95	(4.55)	12.33	(5.42)	12.68	(4.75)	12.00	(6.06)
Social cognition	15.50	(4.97)	15.80	(4.56)	15.23	(5.42)	14.17	(4.85)	15.32	(4.96)	13.18	(4.64)	14.73	(5.49)	14.89	(4.33)	14.57	(6.46)
Restricted interests and repetitive behaviour	11.40	(5.87)	12.20	(6.79)	10.68	(4.94)	10.85	(5.84)	12.05	(6.71)	9.82	(4.89)	10.15	(5.74)	10.42	(6.49)	9.90	(5.11)

PRT: Pivotal Response Treatment; *SD*: standard deviation; SRS: Social Responsiveness Scale.

and contributes to a higher learning curve of the child (Koegel & Koegel, 2019). Furthermore, the robot was a consistent factor in treatment, because it was always added in the first 15 min of the parent–child sessions and there was high similarity in robot behaviour across sessions. Since children with ASD show higher intolerance of uncertainty and this is related to higher levels of anxiety in these children (Neil et al., 2016), predictability may have lowered their anxiety and positively affected their learning curve.

However, in this intervention, the enhancing effect of robot assistance was found for functional self-initiations and not for social self-initiations (i.e. early social conversational skills). A possible explanation is that within the game scenarios for robot–child interaction, a higher focus may have been placed on eliciting self-initiations related to the direct play context (i.e. the game that the child played with the robot). Also, the reinforcements provided by the robot showed a short delay, which was particularly the case for reinforcement of social self-initiations as these were mainly provided by a text-to-speech module (i.e. typing of the reinforcement sentence caused a delay) and were not pre-programmed. This may also have limited generalization of these types of self-initiations to the parent–child interaction.

Our results are in line with studies that reported increases in self-initiations (Huskens et al., 2013) and general social-communicative skills (Boccanfuso et al., 2017) among children receiving a robot-assisted intervention. Contrary to earlier studies that showed design limitations, our study allowed the comparison of a group that received robot-assisted intervention with a group that did not receive robot-assistance in their intervention. Furthermore, this study involved (1) further differentiation of self-initiations based on communicative intention, (2) a higher number of intervention sessions, (3) higher differentiation in levels of prompting and (4) a larger library of game scenarios for robot–child interaction with varying levels of complexity.

Although we found improvements in self-initiations over the course of PRT and also gains in general social-communicative skills after PRT, improvements in self-initiations were not related to gains in most aspects of general social-communicative skills of children with ASD. As the underlying assumption of PRT is that targeting the pivotal skill of self-initiation contributes to collateral gains in other functioning areas (Koegel & Koegel, 2006, 2019), we expected stronger relations between self-initiation and SRS change scores. On one hand, the differences in measurement (observation vs questionnaire) and rater (trained observer vs parent/teacher) between self-initiations and general social-communicative skills may have complicated the possibility to find strong associations. Moreover, it is possible that the SRS scores may not reflect the collateral gains as mentioned in the underlying assumption of PRT. On the other hand, while previous studies mainly focused on self-initiations as a pivotal skill (Verschuur et al., 2014), other pivotal skills such as motivation, self-management, multiple cues and empathy are proposed (Koegel et al., 2016) but their relation to other, more general and untargeted skills has hardly been studied. In light of a variety of components that may be related to treatment efficacy (Fuller & Kaiser, 2019; Ospina et al., 2008; Rogers & Vismara, 2008), it is important to further study the underlying working mechanisms that contribute to the effectiveness of PRT and to optimize outcome measures.

Furthermore, we only found associations between self-initiation change scores and parent-rated scales of the SRS, though not for the teacher-rated scales SRS. The fact that the majority of PRT sessions were focused on training parents (teachers were involved in only two sessions), may have resulted in lower generalizability of skills to the school setting.

Although this study showed considerable strengths in design compared to earlier studies, some limitations should be considered. Our relatively high sample size still resulted in insufficient power to examine child, parent, and/or intervention-related modifiers of intervention efficacy. Moreover, we did not account for multiple testing in this subsample of an exploratory RCT, which may induce bias. Also, because we only included 3- to 8-year-old children with ASD, it is unclear whether the findings of this study on the additional value of robot-assistance generalize to other age groups. Besides, one may assume that the development of social self-initiations is associated with age since these types of self-initiations refer to early social-conversational skills. Furthermore, this study only incorporated the assessment of self-initiations during the intervention sessions, which limits insight in the generalization of self-initiations to other settings. In addition, only the SRS questionnaire rated by parents and teachers was used, to measure collateral gains of targeting self-initiations during PRT. Additional measurements of a broader range of child's functioning are warranted to evaluate widespread improvements in children with ASD. Independent blinded assessments on collateral gains would further strengthen the validity of results. In the larger RCT from which the data for this study were drawn, additional blinded measurements were included (van den Berk-Smeekens et al., 2020). Parental fidelity of PRT implementation was low in our study, due to (1) the high emphasis of daily implementation of PRT techniques at home (not recorded on video for scoring), rather than intensively during a video-recorded 10-min parent–child interaction and (2) the use of a different (and more stringent) fidelity coding system, in which a correct sequence of PRT skills are highly emphasized (Verschuur et al., 2020). Although in both groups parental fidelity of PRT implementation did not reach 80%, the fidelity rate in the robot-assisted PRT group was significant lower than in the PRT group. It could be that the manner of modelling of PRT techniques (i.e. directly by PRT therapist or via a robot) may have influence on parental fidelity of implementation. However, it is remarkable that despite of group differences in fidelity rate, largest treatment gains were observed in the robot-assisted PRT group. Different intervention manuals stress the importance of fidelity of implementation (Koegel & Koegel, 2006, 2012), but whether and how this modifies treatment effects should be subject of future study.

In conclusion, our results suggest that robot assistance within an established intervention, namely PRT for ASD, may be a valuable treatment component, particularly when targeting functional self-initiations. However, increases in self-initiations were not robustly associated with gains in more general social-communicative skills. These results highlight the importance of further investigation of possible components and working mechanisms that contribute to efficacy of PRT in optimizing both targeted and general social-communicative skills. While robot-assistance may serve as such a component, more rigorous studies are needed to further tailor interventions to individual needs of children with ASD.

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Supplemental material

Supplemental material for this article is available online.

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