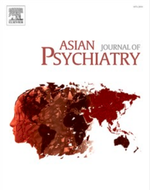
Asian Journal of Psychiatry 118 (2026) 104885

Contents lists available at ScienceDirect

Asian Journal of Psychiatry

journal homepage: www.elsevier.com/locate/ajp



Efficacy of a social robot-assisted training for socio-cognitive and cognitive functions in Parkinson’s disease: A comparison with an active control group.

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ARTICLE INFO

Keywords:
Cognitive and socio-cognitive training
Social robots
Theory of Mind (ToM)
Social competence
Parkinson’s disease
Elderly intervention

ABSTRACT

This study evaluated the efficacy of 12-week of Socially Assistive Robot (SAR) training program on socio-cognitive and cognitive functions in 11 individuals with early-stage Parkinson’s disease (PD) and 9 healthy older adults. Both groups underwent the same intervention with the Pepper robot. Pre- and post-assessments were analyzed using mixed-design repeated-measures ANOVAs. Results showed high adherence (90 %) and a significant main effect of *Time* on several outcomes, including global cognition, executive functions, and Theory of Mind (ToM) tasks (all $p < .05$), suggesting that both groups demonstrated significant improvements. These findings also suggest that a SAR-based intervention is feasible and effective. The main result of the study was the improvement in the skills trained during the intervention, observed in both groups. This pattern also indicate that SAR-based interventions may be beneficial not only for individuals with early-stage PD but also for healthy older adults, highlighting the potential preventive value of SAR-based training in supporting healthy cognitive and social aging.

1. Introduction

The ability to interact effectively and appropriately in social contexts, defined as social competence (Cavallini et al., 2013), represents a cornerstone of psychological well-being and quality of life. At the heart of this competence lies social cognition, a set of neurocognitive processes that allow individuals to recognize, interpret, and respond appropriately to social cues (Henry et al., 2016). A deficit in social cognition, therefore, significantly compromises social competence. Specifically, a failure in social cognition often manifests as a deterioration in Theory of Mind (ToM), which is the ability to attribute mental states – beliefs, intentions, and emotions – to oneself and others. An individual with an impaired ToM may misinterpret others’ intentions or fail to respond in socially congruent ways (Coundouris et al., 2020), leading to misunderstandings, awkward social exchanges, and eventual social withdrawal. Over time, these difficulties can reduce opportunities for meaningful social engagement, thereby increasing the risk of loneliness and social isolation (Cardona and Andrés, 2023).

Despite the importance of preserving these abilities, especially in aging and neurodegenerative populations, traditional interventions have historically relied on paper-and-pencil tasks. While useful, such approaches show clear limitations in capturing the dynamic and interactive nature of real-world social situations. In this context, a recent and promising line of research has captured the attention of the scientific community: the use of Social Assistive Robots (SARs) as a non-pharmacological approach to support not only general cognitive functioning but also the overall well-being of patients (Chen et al., 2024; Liao et al., 2023; Menozzi et al., 2025; Otaka et al., 2024). SARs, in fact, are

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https://doi.org/10.1016/j.ajp.2026.104885
Received 31 October 2025; Received in revised form 21 January 2026; Accepted 5 February 2026

not merely tools but interactive agents capable of simulating social interactions, providing a safe and controlled environment for training these complex socio-cognitive abilities.

The efficacy of social robots lies in their ability to act as genuine "social partners." Their anthropomorphic design and interactive features capture attention, sustain motivation, and reduce mind wandering during training sessions (Figliano et al., 2025). By providing a controlled, predictable, and emotionally safe environment, SARs allow participants to practice complex cognitive and social abilities without anxiety or performance pressure (Figliano et al., 2025). Social robots have demonstrated beneficial effects in stimulating autobiographical and episodic memory (Figliano et al., 2025), as well as enhancing communicative skills in patients, particularly those with Mild Cognitive Impairment (MCI) or Alzheimer's disease (Sugiyama and Nakamura, 2022; Tahan et al., 2024). The robot's capacity to display human-like behaviors - including eye contact, pseudo-emotional displays, and contingent responses - further enhance social presence, thereby facilitating learning and the generalization of acquired skills to daily life. However, despite growing evidence of their potential, a recent systematic literature review highlights a notable gap in the field: no SAR-based programs rely on structured, standardized, and validated training protocols specifically designed to stimulate cognitive and socio-cognitive outcomes in aging and neurodegenerative populations (Figliano et al., 2023).

Parkinson's Disease (PD), the second most common neurodegenerative disorder in the elderly population (Aarsland et al., 2017, 2021), is a progressive neurological disease characterized by an array of motor and non-motor symptoms. Among the non-motor symptoms, early forms of cognitive decline occur, including Mild Cognitive Impairment (MCI) (Baiano et al., 2020; American Psychiatric Association [APA], 2013). MCI affects a wide range of domains such as executive functions, memory, attention, and visuospatial abilities (Goldman and Sieg, 2020). Furthermore, social cognition appears to be impaired in this population, thereby affecting the social competence that enables individuals to interact effectively and appropriately within social contexts (Cavallini et al., 2013). Deficits in social cognition often involve impairments in both the cognitive and affective components of ToM (Bora et al., 2015), leading individuals to behave in socially incongruent ways (Coundouris et al., 2020). Over time, these difficulties can diminish opportunities for meaningful social interaction, thereby heightening the risk of loneliness and social isolation (Ahn et al., 2022).

While traditional paper-and-pencil tasks have shown modest but promising efficacy in people with PD for domains like attention, memory, and executive function (Gattoni et al., 2025), the use of robot-mediated cognitive training in this population is still in its early stages. For these reasons , individuals with early-stage PD represent an ideal clinical model for the investigation of the efficacy of robot-mediated training.

Building on these premises, the principal aim of the present study is to implement and evaluate the efficacy of a cognitive and socio-cognitive training program delivered by the social robot Pepper. The training program mediated by the robot has been developed to create an interactive environment with the aim of enhancing engagement, enriching social cues, and ultimately strengthening social competence, ToM, and cognitive abilities. This study builds upon a preliminary investigation (Figliano et al., 2025), which served as a pilot phase to fine-tune the experimental protocol and optimize the interaction flow with Pepper.

1.1. Objectives

The primary objective of this study was to evaluate the efficacy of a social robot-assisted training program to stimulate socio-cognitive and cognitive abilities in older adults with early-stage PD, with a healthy older adult sample serving as an active comparison group. We explored a potential "catch-up effect," defined as the magnitude of change over time, rather than absolute performance levels (Luu et al., 2011). Specifically, we hypothesized that PD participants would show greater pre-post improvement than the Control group. This hypothesis was tested by examining the significance of the Time x Group interaction in our statistical analyses.

Secondary objectives were to: 1) assess differential improvements in core socio-cognitive functions (ToM, perspective-taking) and general cognitive domains (e.g., executive functions, memory, and attention); and 2) confirm high adherence and acceptability of the intervention.

2. Methods

2.1. Participants

Participants were recruited from an initial pool of 24 individuals, divided into two groups: the PD group (experimental group) and the Control group. Inclusion criteria for the PD group required a formal neurological diagnosis of early-stage Parkinson's disease. General exclusion criteria, applied at screening for all participants, included a diagnosis of dementia, major psychiatric disorders (e.g., major depression), and unstable pharmacological treatment for mood disorders. Clinical histories were collected for all participants: for the PD group, neurological records were used to confirm the diagnosis, while for both groups clinical histories were used to verify compliance with the exclusion criteria. During the anamnesis collection, PD participants reported mild cognitive difficulties, including memory impairment, reduced concentration, early lexical access issues, and, in some cases, symptoms of anxiety or depression, as diagnosed by the medical team. During the intervention period, four participants from the PD group were withdrawn from the study. The reasons for withdrawal are as follows: a cerebrovascular event (ischemia) prior to the start of the training ($n = 1$), pharmacological instability ($n = 1$), and failure to meet the minimum adherence criterion of completing at least 60 % of the training sessions ($n = 2$). There was no dropout in the Control group. See the flow diagram (Fig. 1) for dropout details.

The final sample consisted of 20 participants. The PD group included 11 individuals who had received a neurological diagnosis of early-stage Parkinson's disease (PD group: mean age = 70.3 years, *SD* = 6.13; 30 % women). The Control group included 9 healthy older adults (Control group: mean age = 60.11 years, *SD* = 5.88; all women). Sociodemographic characteristics of the sample are reported in Table 1.

The study was conducted in accordance with the ethical standards of the local Ethics Committee of the Università Cattolica del Sacro Cuore (CERPS; ethical approval no. 89/24, 08/05/2024). All participants provided written informed consent before their inclusion in the study.

2.2. Procedure and training program

The training program, conducted between January 2025 and April 2025, consisted of twelve individual weekly sessions, each lasting approximately 20 min. The program comprised six socio-cognitive training sessions alternated with six cognitive training sessions. Each session began with a familiarization phase, during which Pepper greeted the participant and introduced the activity, to establish a collaborative and engaging work environment.

Each socio-cognitive session followed the protocol by d'Arma et al. (2023). Participants were presented with short illustrated social stories on Pepper's tablet depicting everyday situations involving two or more characters. These stories encouraged reasoning about mental states, such as beliefs, intentions, emotions, and perspectives. After listening to each story, the participant answered a series of multiple-choice questions or open-ended questions, each targeting a distinct socio-cognitive component (e.g., identifying what a character knows or how they feel in a given situation, or predicting their behavior based on their beliefs or goals). The open-ended questions were used to encourage verbalization and reflection on the reasoning process.

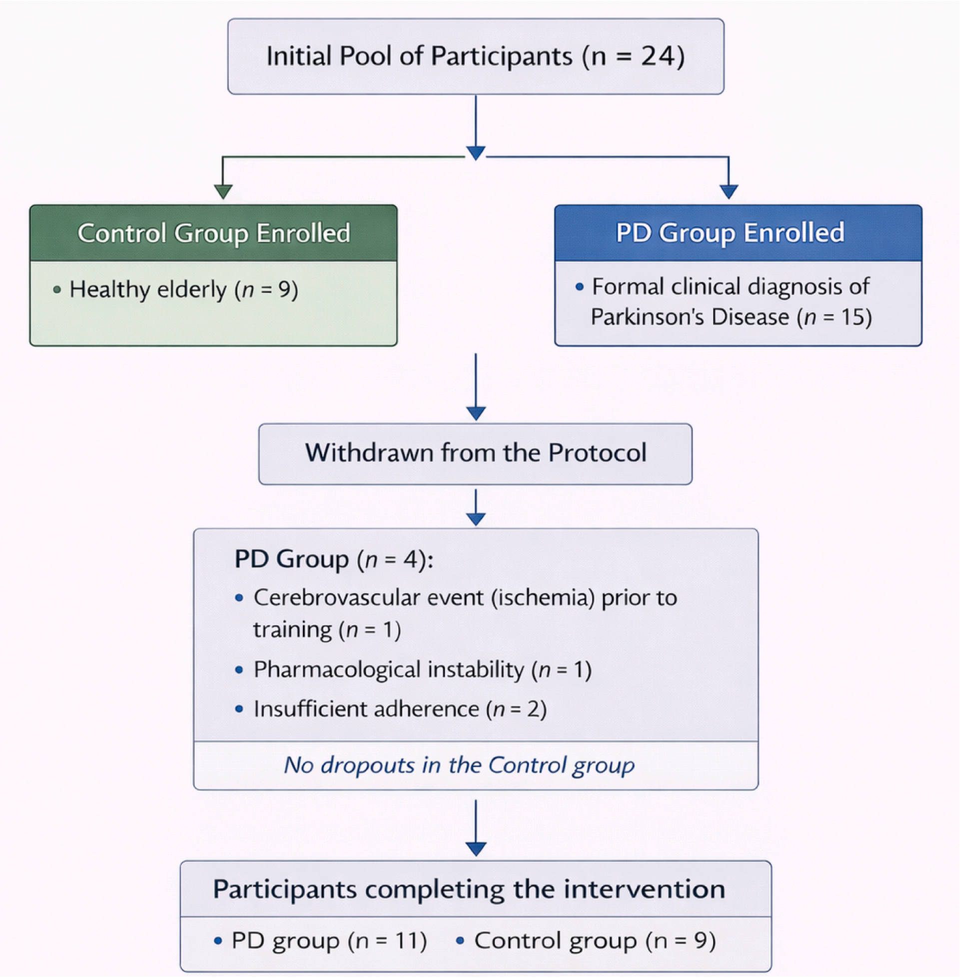

Fig. 1. Flow diagram of participant recruitment and retention. The final sample consisted of 11 PD participants and 9 controls.

Table 1
Sociodemographic characteristics of the sample divided into PD and Control groups.

Sociodemographic characteristics	**PD Group** *N* = 11	**Control Group** *N* = 9
Age, mean ± SD	70.3 ± 6.13	60.11 ± 5.88
Gender	N (%)	N (%)
Male	8 (72.73 %)	0 (0 %)
Female	3 (27.27 %)	9 (100 %)
Educational level	N (%)	N (%)
Middle school or below	2 (18.18 %)	-
High school	3 (27.27 %)	4 (44.44 %)
Graduate school	3 (27.27 %)	2 (22.22 %)
Postgraduate school	3 (27.27 %)	3 (33.33 %)
Employment status prior to retirement	N (%)	N (%)
Unskilled worker or manual laborer	4 (36.36 %)	2 (22.22 %)
Artisan or skilled worker	4 (36.36 %)	2 (22.22 %)
Retailer or specialized technician	-	2 (22.22)
Technical and professional occupation	1 (9.09 %)	3 (33.33 %)
Highly qualified professional role	2 (18.18 %)	-

During cognitive sessions, participants undertook exercises designed to target memory, attention, language, and executive functions, drawing upon validated training protocols (Cattelani and Corsini, 2012; Wilson, 2002). These tasks included recalling a previously presented story and maintaining items in working memory. Examples of these tasks include verbal memory activities (e.g., recalling short narratives), attentional tasks requiring sustained focus or selective attention, and lexical retrieval exercises. As in the socio-cognitive sessions, stimuli were presented via Pepper's tablet and responses were provided by selecting from multiple-choice options or providing brief verbal answers.

For each response, Pepper provided immediate feedback, reinforcing correct answers verbally, while incorrect responses prompted the robot to repeat the question or provide simplified cues. After two consecutive incorrect responses, the therapist intervened to support comprehension without directly providing the correct answer. This feedback structure ensured that participants actively engaged in inferential reasoning while maintaining a safe, non-judgmental learning environment.

The interaction was organized in a triadic format (robot-therapist-participant; Fig. 2): while Pepper managed the flow of the activity and adaptive feedback, the therapist intervened when necessary to clarify instructions or support comprehension. Each story ended with a brief open-ended reflection, encouraging participants to relate the scenario to real-life experiences or to provide a summary of the story they had just listened to.

All training materials were delivered via the *Robotic Platform for Social Interaction* (Piattaforma Robotica per l'Interazione Sociale; PRIS), a web-based tool developed in collaboration with Intesa Sanpaolo's Innovation Center. The PRIS platform enabled a modular and replicable content structure, ensuring the standardization of the intervention.

2.3. *Measures*

To evaluate the training program's effects, a battery of neuropsychological and socio-cognitive assessments was administered at baseline (T0) and post-training (T1). The measures included the following:

Cognitive measures:

Fig. 2. The triadic approach: participant's interaction with Pepper robot is facilitated by the experimenter.

- *Mini-Mental State Examination* (MMSE) was administered as a screening assessment of global cognitive level, providing an overview of the participant's general cognitive abilities (cut-off: <22; Magni et al., 1996).
- *Frontal Assessment Battery* (FAB) for executive functioning (Appollonio et al., 2005).
- Immediate and delayed verbal recall tasks to assess episodic memory (Carlesimo et al., 1996, 2002).
- *Attentional Matrices Test* (Sala et al., 1992) and *Trail Making Test-A* to evaluate attention and processing speed (Siciliano et al., 2019).
- *Digit Span* (forward) to assess short-term memory (Monaco et al., 2013).

Neuropsychological test scores were interpreted using normative data corrected for age, sex, and education, and all analyses were conducted using these adjusted scores (Appollonio et al., 2005; Carlesimo et al., 1996; Magni et al., 1996; Monaco et al., 2013; Sala et al., 1992; Siciliano et al., 2019).

Socio-cognitive measures:

- *False-Belief Tasks*, including the *Unexpected Transfer task*, the *Look Prediction task*, and the *Say Prediction task (*Liverta Sempio, Angeli., 2005*;* Wimmer, 1983*)*. The test question was scored as 1 (correct) or 0 (incorrect) if Control questions were answered correctly.
- *Strange Stories Test* (Happé, 1994; Liverta Sempio, Angeli., 2005) to assess the interpretation of complex social situations (e.g., irony, implicit meaning), coded according to the original scheme (Happé, 1994)
- *Reading the Mind in the Eyes Test* (short version) to assess the ability to infer mental and emotional states from the eye region (Chander et al., 2020).

2.4. Data analysis

Statistical analyses were performed using IBM SPSS Statistics (Version 29.0). Descriptive statistics were computed for all measures, and the normality of the data distribution was assessed using the Shapiro-Wilk test.

Baseline (T0) differences between the PD and Control groups were examined using independent-samples *t*-tests on all outcome measures. Furthermore, group differences in the socio-cognitive measures were were further examined using univariate analyses of covariance (ANCOVAs), with age included as a covariate to control for its potential confounding effect.

The effects of the intervention were evaluated using mixed-design repeated-measures ANOVAs with *Time* (pre- vs. post-training) as a within-subject factor and *Group* (PD vs. Control) as a between-subject factor. Greenhouse-Geisser corrections were applied where the assumption of sphericity was violated. The significance level (alpha) was set at $p < .05$ for all analyses. Cognitive measures were analyzed using adjusted normative scores corrected for age, sex, and education (e.g., MMSE; Magni et al., 1996).

Our primary hypothesis, therefore, was centered on a potential "catch-up effect." Statistically, this hypothesis was tested by the Time x Group interaction in the mixed-design ANOVAs. A significant interaction would indicate that the trajectory of change from pre- to post-training differs between the groups, providing robust evidence for a differential training effect and supporting the notion of a catch-up phenomenon.

3. Results

3.1. Adherence and feasibility

Adherence to the intervention was high, with an average completion rate of 90 % across all scheduled sessions. Both the cognitive and socio-cognitive training components achieved an 87 % completion rate. This high completion rate supports the feasibility and acceptability of the robot-assisted program.

3.2. Baseline comparisons

At baseline (T0), independent-samples *t*-tests revealed no significant differences between the PD and Control groups across all pre-training (T0) cognitive measures. Specifically, performance was comparable in global cognition (MMSE: $t(17) = 1.53$, $p = .15$), executive functions (FAB: $t(17) = .71$, $p = .49$), attention (TMT-A: $t(17) = 1.21$, $p = .24$), and working memory (Digit Span: $t(17) = 1.15$, $p = .27$). Similarly, no significant group differences emerged for verbal fluency, recall tasks, or numerical matrices (all $p > .05$). This confirms a comparable cognitive baseline between groups (see Table 2 for means and standard deviations).

Conversely, a significant baseline difference was observed in overall ToM performance, $t(17) = 2.93$, $p = .009$. Specifically, the Control group demonstrated higher scores when compared to the PD group, suggesting the presence of socio-cognitive impairments at the initial stage (see Table 3 for means and standard deviations). An ANCOVA with clinical condition (PD *vs.* Control) as the between-subjects factor and age as a covariate revealed a significant main effect of clinical condition, $F(1, 17) = 6.42$, $p = .022$, partial $\eta 2 = .29$, whereas age did not

Table 2
Means and standard deviations of cognitive measures at baseline (T0) for the Parkinson's disease (PD) and Control groups. Neuropsychological scores are age- and education-corrected according to normative data.

	Clinical condition	*Mean*	*Std. Deviation*
MMSE	Control	26.90	1.59
	PD	26.25	2.88
FAB	Control	14.39	2.38
	PD	13.74	1.77
TMT-A	Control	41.33	10.51
	PD	45.70	17.31
Attentional Matrices Test	Control	38.06	6.68
	PD	34.26	6.32
Fluences Phonemic	Control	26.55	7.86
	PD	33.40	12.47
Fluences Semantic	Control	48.02	6.76
	PD	42.98	5.93
DIGIT-Span	Control	5.60	1.11
	PD	6.01	1.2
Immediate recall	Control	5.72	2.08
	PD	4.0	2.32

Table 3
Means and standard deviations of socio-cognitive measures at baseline (T0) for the Parkinson's disease (PD) and Control groups.

	Clinical condition	*Mean*	*Std. Deviation*
TOM tot	Control	4.11*	.78
	PD	2.90*	.99
SS	Control	5.67	1.22
	PD	5.30	2.11
ET	Control	11.67	2.87
	PD	11.40	2.46

* significance level at $p < .05$.

significantly contribute to the model, F(1, 17)= 2.05, $p = .17$. Pairwise comparisons (Bonferroni corrected) indicated higher ToM scores in the Control group ($M = 4.74$; $SE = .29$) compared to the PD group ($M = 3.73$; $SE = .28$), confirming the presence of socio-cognitive impairments in the PD group at baseline.

3.3. *Training program outcomes*

The effects of the intervention were analyzed using mixed-design repeated-measures ANOVAs. No significant Time x Group interactions were found for any measure (all $p > .05$), suggesting no evidence of differential change between groups over time. We therefore examined the main effects of *Time* to describe overall pre-post change across the sample.

3.4. *Cognitive outcomes*

The analysis of cognitive outcomes revealed a significant main effect of *Time*, indicating improvement from T0 to T1 across both groups. Specifically, we found significant improvements in global cognition (MMSE), F(1, 18)= 20.99, $p < .05$, partial-η2 = .55, δ= .99, and executive functioning (FAB), F(1, 18)= 25.93, $p = .004$, partial-η2 = .40, δ= .89. Verbal memory also showed a main effect of *Time* F(1, 18)= 8.83, $p = .009$, partial-η2 = .34, δ= .80. For instance, while improvement in delayed recall was observed in both groups, the benefit in immediate recall was statistically significant only for the PD group. Post-hoc comparisons are detailed in Table 4.

No statistically significant changes ($p > .05$) were found for attention (Attentional Matrices Test and Trail Making Test-A) and working memory (Digit span).

Mean scores for each cognitive domain before and after the intervention are displayed in Fig. 3 (PD group) and Fig. 4 (Control group).

3.5. *Socio-cognitive outcomes*

Consistent with the training's objectives, analyses revealed significant improvements in socio-cognitive functioning. Specifically, a significant main effect of *Time* was found for the False Belief tasks, F(1, 18)= 12.73, $p < .002$, partial-η2 = .43, δ= .92, and the Strange Stories Test, F(1, 18)= 18.84, $p < .001$, partial-η2 = .53, δ= .98. As detailed in Table 5, post-hoc comparisons confirmed that both the PD and Control groups showed significant post-training improvements on these measures. These findings suggest an enhanced ability to infer and represent others' beliefs and intentions and a better comprehension of irony, indirect speech, and other subtle social cues. An ANCOVA conducted at T1, with clinical condition as the between-subjects factor and age entered as a covariate, revealed a significant main effect of clinical condition, F(1, 18)= 6.85, $p = .018$, partial η^2= .29. Bonferroni-adjusted pairwise comparisons confirmed that this difference remained statistically significant ($Mdiff = 1.08$; $p = .018$).

Table 4
Cognitive training effects on cognitive domains: post-Hoc comparisons between T0 and T1.

Cognitive domains (Measures)	Control Group		PD Group	
	T0 Mdiff *(SE)*	T1 Mdiff *(SE)*	T0 Mdiff *(SE)*	T1 Mdiff *(SE)*
Global Cognition (MMSE)	26.91 *(.79)*	29.1 *(.77)*	26.25 *(.75)*	27.59 *(.73)*
Executive Function (FAB)	14.36 *(.69)*	16.22 *(.68)*	13.75 *(.66)*	15.23 *(.65)*
Verbal Memory (Total Effect)				
… Immediate Recall			4.0 *(.70)*	6.07 *(.62)*
… Delay Recall	6.72 *(.41)*	7.96 *(.32)*	6.28 *(.39)*	7.46 *(.30)*

Changes on the Reading the Mind in the Eyes Test (ET) did not reach statistical significance ($p > .05$); in contrast, performance on ET remained stable, indicating the preservation of affective ToM abilities over time.

As shown in Figs. 5 and 6, these results suggest the training effectively enhanced cognitive ToM (False Beliefs and Strange Stories), while affective ToM abilities were preserved over time.

4. Discussion

The present study evaluated the pre-post changes associated with a robot-mediated training program in older adults with early-stage PD compared to a healthy Control group. The findings were threefold. First, the high level of adherence supports the acceptability of the robot-mediated training format - a relevant outcome considering the difficulties that elderly individuals and clinical populations often face in maintaining engagement over time (Mendorf et al., 2025). This result may be due both to the presence of the Pepper robot and to the structure of the socio-cognitive and cognitive training program. On one side, the effectiveness of the intervention likely stems from Pepper's anthropomorphic features and interactive design (Bemelmans et al., 2012; Marchetti et al., 2022; Tanioka, 2019), which fostered emotional engagement and sustained attention. On the other side, the training program was designed to enhance motivation and focus through a customized and structured feedback system that helped maintain attention and provided a safe environment for trial and error, gradually increasing participants' autonomy (Figliano et al., 2025). As shown in our previous study, the triadic structure of the sessions, involving participant, robot, and therapist, created a socially meaningful and reassuring environment, facilitating engagement and comfort during training activities (Figliano et al., 2025).

Secondly, the training program was effective on the key cognitive and socio-cognitive outcomes, as showed by the main effect of *Time*. Specifically, increases in MMSE and FAB post-training scores indicate an improvement in global cognitive abilities and executive functions. This was presumably attributable to enhanced attentional regulation and problem-solving strategies (Cerasa et al., 2014; Naismith et al., 2013). The improvement in immediate recall observed in the PD group indicates the acquisition of more effective memory strategies promoted by the structured and repetitive nature of the exercises (Cerasa et al., 2014). Similarly, the significant increase in delayed recall in both groups suggests an overall enhancement in verbal memory retention, likely reflecting the development and consistent application of mnemonic strategies acquired during the structured exercises, which emphasized repetition, attentional focus, and active engagement in memory-related tasks (Giehl, Ophey, Hammes, et al., 2020; Giehl, Ophey, Reker, et al., 2020).

Although attention and working memory did not show statistically significant change, their stability is noteworthy, as these functions are typically prone to decline in aging and in PD (Biundo et al., 2025; Di Rosa et al., 2017): the general trend of higher post-training means suggests that these functions remained stable over time. The absence of any performance drop, therefore, represents an encouraging outcome, pointing to a protective effect of the intervention on key cognitive processes that sustain autonomy and daily functioning even in healthy

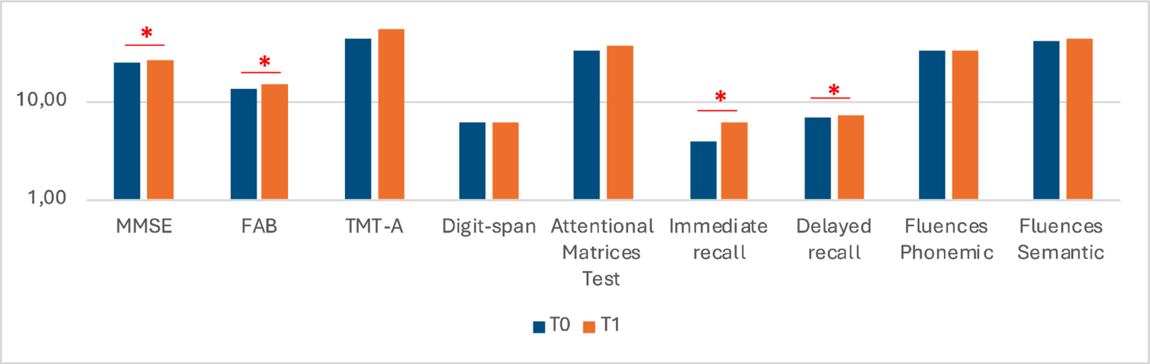

Fig. 3. Cognitive performance of the Parkinson's disease (PD) group before (T0) and after (T1) the training. Asterisks denote significant pre–post differences ($p < .05$).

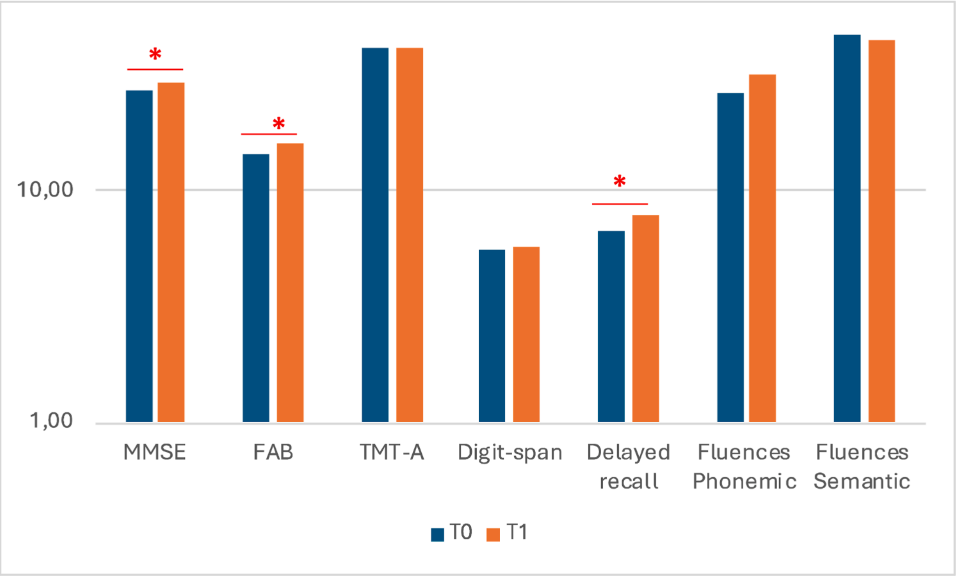

Fig. 4. Cognitive performance of the Control group before (T0) and after (T1) the training. Asterisks denote significant pre–post differences ($p < .05$).

Table 5
Socio-cognitive training effects on socio-cognitive domains: post-Hoc comparisons between T0 and T1.

Socio-cognitive domains (measures)	Control Group		PD Group	
	T0 Mdiff *(SE)*	T1 Mdiff *(SE)*	T0 Mdiff *(SE)*	T1 Mdiff *(SE)*
Cognitive ToM (False Beliefs)	4.11 *(.30)*	4.77 *(.30)*	2.90 *(.29)*	3.70 *(.28)*
Cognitive ToM (Strange Stories)	5.67 *(.58)*	7.22 *(.32)*	5.30 *(.55)*	7.40 *(.31)*

aging population (Tanaka, 2025; Valdés et al., 2017).

Socio-cognitive outcomes were equally promising. Participants in both groups exhibited significant improvements in the understanding of others' mental states, as reflected by higher scores in the *False Belief tasks* and the *Strange Stories Test* in the post-training evaluation. These results are consistent with the focus of the socio-cognitive training, which targeted ToM-related abilities specifically through story-based exercises that required participants to take the perspective of different characters and reason about their knowledge, emotions, and mental states. Although the affective component of ToM, measured by the brief version of the Reading the Mind in the Eyes Test (Baron-Cohen, 1997; Chander et al., 2020), did not show significant improvement, the slight increase in scores is a positive outcome, given that emotional inference abilities tend to deteriorate with age and disease progression (Enrici et al., 2015; Rossetto et al., 2020). This result suggests that socio-cognitive training may help to maintain affective ToM abilities.

Finally, we did not find a significant Time x Group interaction. While we hypothesized a catch-up effect, i.e., a greater magnitude of improvement on key domains in the PD group, we found no evidence of differential change over time. However, given the improvements observed in the PD group, we can conclude that individuals in the early stages of PD retain responsiveness to a structured socio-cognitive program.

Taken together, these results can likely be attributed to the structured, repetitive, and feedback-based nature of the training (Figliano et al., 2025), as such approaches are known to enhance neuroplasticity and the consolidation of learning strategies in older adults (Bouça-Machado et al., 2020; Hertzog et al., 2008; Nguyen et al., 2019; Park and Reuter-Lorenz, 2009). Pepper's consistent prompts and error-correction mechanisms helped participants sustain focus and develop compensatory strategies. The socially engaging context provided by Pepper, which offered consistent feedback and a human-like social presence (Khosla et al., 2021; Nyamathi et al., 2024), likely amplified these effects by maintaining motivation and emotional involvement for both the clinical and control groups, thus explaining the

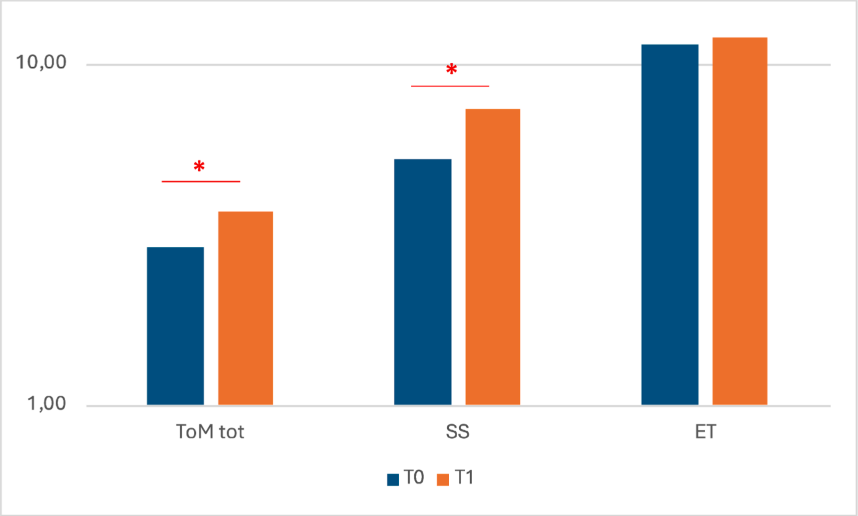

Fig. 5. Socio-cognitive performance of the PD group before (T0) and after (T1) the training. Asterisks denote significant pre–post differences ($p < .05$).

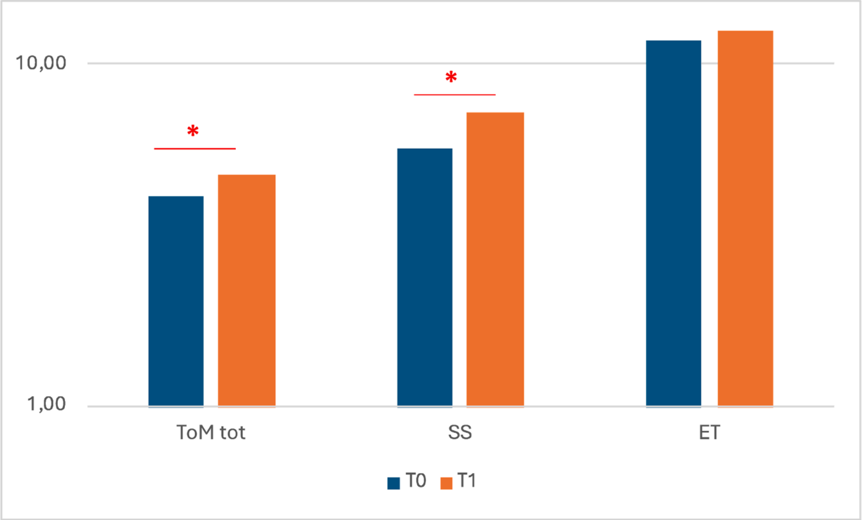

Fig. 6. Socio-cognitive performance of the Control group before (T0) and after (T1) the training. Asterisks denote significant pre–post differences ($p < .05$).

robust main effect of *Time* across groups.

In conclusion, the interactive and relational nature of the training may have contributed to sustained engagement throughout the sessions. This study highlights that a structured, robot-mediated intervention based on validated protocols is associated with measurable pre-post improvements on cognitive and socio-cognitive domains in older adults. The improvements on key cognitive and socio-cognitive domains in PD and Control groups indicates that they both benefited from the training, a particularly noteworthy finding, as it suggests that socially assistive robot interventions may be effective not only in compensating mild cognitive fragility but also in maintaining and strengthening cognitive and socio-cognitive abilities in typical aging.

5. Conclusions and limitations

In conclusion, this study demonstrates that a structured, robot-assisted training program is a feasible and highly effective intervention for enhancing cognitive and socio-cognitive abilities in older adults, including those with PD. The central finding was the pre-post improvements on the key cognitive and socio-cognitive domains observed in both the PD and Control groups. Participants exhibited significant improvements in global cognition, executive functioning, verbal memory, and ToM abilities. These findings suggest that individuals with early-stage PD benefited from the program, showing significant improvements in the abilities and competencies trained during the training. Importantly, significant improvements shown also by the Control group highlight that such training programs may also serve a preventive and cognitively stimulating function in healthy ageing.

Beyond its empirical findings, this study represents a first effort to address a critical gap in the literature by developing and testing a robot-mediated training program grounded in validated protocols and structured sessions. The high adherence rate underscores the motivational and relational benefits of the triadic patient-robot-therapist interaction. Collectively, these results lay the groundwork for the development of scalable, non-pharmacological interventions that integrate social robotics to enhance cognitive health, social engagement, and quality of life in aging populations.

Finally, although open-ended questions were used to encourage verbalization and reflection on the reasoning process, these were not collected using a standardized qualitative protocol. Future work should incorporate systematic recording and a predefined coding framework to complement the quantitative outcomes.

Despite these encouraging findings, several limitations must be acknowledged. A key limitation is the composition of the sample, particularly regarding age and sex. Future studies should recruit larger samples with closer matching for age and sex. However, this limitation does not apply to cognitive outcomes, since all neuropsychological test scores were interpreted using age-, sex-, and education-corrected normative data.

Second, the absence of a long-term follow-up limits conclusions about the durability of the observed benefits over time.

A further limitation is the absence of a passive (no-treatment) or placebo control group. This design, therefore, does not allow for definitive disentangling of the robot-mediated training from potential non-specific effects, such as the social contact with the therapist, novelty effects, or Hawthorne effects. However, this design was a deliberate choice guided by significant ethical and clinical considerations. Withholding a potentially beneficial intervention from a clinical population actively seeking engagement was considered ethically problematic. Furthermore, the unpredictable progression of PD makes a wait-list design unreliable for capturing stable baseline-to-intervention changes. The healthy Control group should therefore be interpreted as an active comparison benchmark, useful for assessing differential change rather than absolute efficacy against no intervention.

Author contribution

DM, AM, CDD, and FM conceptualized and designed the study. DM, FM, LM, and GF secured ethical approval. MN, IB, MD, and LR developed the PRIS platform and provided technical support. LM prepared materials and conducted the quantitative analysis. LM, GF and TR collected data and conducted the training sessions. LM, GF and TR drafted the original manuscript. All authors reviewed and provided feedback on early versions and approved the final manuscript.

Ethical statement

The study was conducted in accordance with the ethical standards of the local Ethics Committee of the Università Cattolica del Sacro Cuore (CERPS; ethical approval no. 89/24, 08/05/2024). All participants provided written informed consent before their inclusion in the study.

Funding

This research has been funded by Intesa Sanpaolo Innovation Center.

Declaration of Competing Interest

The authors declared that there is no conflict of interest.

Acknowledgments

The authors thank to Dr. Andrea Deplano, Director of Istituto De Rodolfi, Azienda Speciale Multiservizi Vigevano (PV), for welcoming the research team during the experimental phase of the study. They also would like to express deepest gratitude to the staff of the Istituto De Rodolfi - particularly Davide Trubbia and Jean-Claude Kouakou - for their essential support in organizing the study materials and preparing the experimental settings. Their contribution was fundamental to the smooth execution of the research activities. The authors are also sincerely grateful to Piera Lodigiani from the *Associazione Pavese Parkinsoniani ODV* and to Sara Comelli and Elena Galuppo from the *Fondazione Caritas Vigevano* for their valuable assistance during the recruitment phase.

Finally, the authors sincerely thank all participants for their time, dedication, and enthusiastic engagement in the project.

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