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Social Assistive Robotics (SARs) to promote and support Theory of Mind and Cognitive skills in healthy and pathological ageing

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Executive Summary

The ageing population and the increasing incidence of cognitive decline, such as Mild Cognitive Impairment (MCI) and Parkinson's disease (PD), have created a need for non-pharmacological interventions aimed at supporting the cognitive and socio-cognitive abilities of older people. This thesis aims to develop, analyse and evaluate structured cognitive and socio-cognitive training protocols mediated by Social Assistive Robotics (SARs), with the objectives of supporting Theory of Mind (ToM) and cognitive functions, thereby contributing both to the preservation of residual abilities and to the promotion of healthy ageing.

The work presented in this thesis includes three complementary studies relating to the main theme.

The first study is a systematic review conducted in accordance with the PRISMA guidelines, which analysed 19 studies focusing on the use of Social Assistive Robotics (SARs) in people diagnosed with Mild Cognitive Impairment. The analysis highlighted a high level of acceptance of both humanoid and zoomorphic robots, as well as potential positive effects on memory, executive functions, emotional well-being and social participation. However, significant limitations were identified, including heterogeneity of the samples, non-standardised protocols, the lack of control groups and the absence of consistent neuropsychological assessments.

In the second study, a preliminary qualitative study assessed the acceptability of the Pepper robot and the feasibility of a structured training programme offered to a sample of nine older adults with mild to moderate dementia. Analysis of interviews and video recordings revealed emotional engagement, increased attention, greater independence during the exercises, and an effective triadic relationship between the robot, the researcher and the participant. The training also encouraged reminiscence, motivation and active participation among those involved.

In the third study, a controlled experimental trial, a structured 12-week programme was tested on 11 people with Parkinson's disease (PD) and 9 healthy older adults. Socio-cognitive assessments carried out before and after the intervention revealed high adherence (90%) and significant improvements in global cognitive function, executive function, verbal memory and Theory of Mind (ToM). No differences in the rate of improvement emerged between the PD group and the control group, indicating that cognitive and socio-cognitive plasticity is preserved even in the early stages of PD.

Overall, the three studies agree in showing that SARs are promising, scalable and well-accepted tools capable of supporting cognitive and socio-cognitive abilities in both healthy ageing and pathological conditions. However, the thesis highlights the necessity of more standardised protocols, larger sample sizes, integrated assessments and greater robotic autonomy to optimise the effectiveness of interventions.

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Chapter 1

General Introduction

A significant issue today, which receives increasing attention from various scientific disciplines, is ageing. Ageing is a physiological process involving biological, psychological and social changes, with very different outcomes among individuals. The World Health Organisation estimates that the number of people over 65 worldwide is increasing quickly. This fact requires the development of strategies to improve the quality of life of older people and support healthy ageing (iris.who.int).

Referring to healthy ageing is not limited to indicating a condition characterised by the absence of disease, but rather a condition defined by the maintenance of physical, cognitive and social functionality. In addition to the main determinants of lifestyle, which include regular physical activity, a balanced diet, social support, continuous learning and a positive attitude, mental health and social participation are increasingly recognised as key factors (Abud et al., 2022; Lin et al., 2022).

The other is pathological ageing, which is defined by the development of chronic and neurodegenerative conditions, such as mild cognitive impairment (MCI), dementia, Alzheimer's disease and Parkinson's disease. Unlike physiological ageing, pathological ageing is characterised by a decline in cognitive and behavioural functions. The differences between normal and pathological ageing are the focus of many studies, which highlight how loss of independence and symptoms like aggression or social withdrawal are typical of pathological forms (Fernández-Rubio et al., 2025).

Nowadays, dementia is one of the main global health challenges, impacting over 55 million people, with a higher prevalence in low- and middle-income countries. Approximately 10 million new cases are diagnosed each year, making dementia the seventh leading cause of death and one of the main sources of disability among the elderly population (World Health Organisation, 2023).

The first signs of cognitive decline, such as Mild Cognitive Impairment (MCI), frequently precede the onset of neurodegenerative diseases such as Alzheimer's and Parkinson's, compromising functions such as memory, attention, language and executive function (American Psychiatric Association, 2013; Castelli et al., 2016; Saredakis et al., 2019). Furthermore, MCI could negatively affect Theory of Mind (ToM), i.e. the ability to understand one's own and others' mental states (Premack & Woodruff, 1978), a function tending to worsen with advancing age and cognitive decline (Knopman et al., 2014; Moreau et al., 2015; Rossetto et al., 2020; Winblad et al., 2004).

Pathological ageing impacts not only the person to be directly affected, but also has deep implications for the entire family unit and for the national healthcare system.

Relatives often take on a caring role, providing daily assistance to their loved ones. This responsibility involves a considerable emotional, physical and financial burden. Such a burden may lead to stress, social isolation, financial difficulties and, in the most serious cases, burnout (www.cdc.gov).

Pathological ageing also leads to an exponential increase in demand for health and social care services. These increasing demands determine an exponential increase in the demand for health, pension and social services, affecting public budgets and the sustainability of the national health system. Furthermore, the management of patients with dementia and those who are not self-sufficient requires continuity of care, integration between health and social services, and the development of adequate residential and community facilities (www.salute.gov.it).

Theory of Mind (ToM) and Social Cognition

Theory of Mind (ToM)

Theory of Mind (ToM) describes the ability to understand other people's behaviour based on their mental states like intentions, motivations and beliefs, which could be different from one’s. This process of ‘*mentalization*’ is necessary to predict what others may do next and acting as a socially aware person. According to Perner & Wimmer (1985), Premack & Woodruff (1978) and Wellman et al. (2001), ToM is based on the awareness that people have their own mental states, different from those of the observer. Frith & Frith (2007) emphasise how this ability allows individuals to act efficiently in social interactions.

There are two main parts of ToM, which are described as follows: the “*affective*” component, which is the ability to understand other people's emotions, and the “*cognitive*” component, that is the ability to make inferences about other people's thoughts, beliefs and intentions (Shamay-Tsoory and Aharon-Peretz, 2007); the optimal development and functioning of ToM is crucial for adequate interactions with others. Such components, while working in a complementary manner, activate partial overlapping but functionally different neural circuits. The “*cognitive*” component, related to the capacity for mentalization, involves areas that include the medial prefrontal cortex and the superior temporal sulcus; the “*emotional*” component, which is the basis of empathy, activates circuits including insula and anterior cingulate (Perrotta, G. et al., 2020; Shamay-Tsoory and Aharon-Peretz, 2007; Siegal, M., et al., 2002).

Social cognition (SC)

The concept of social cognition refers to the mental processes underlying the ability to perceive, understand and process information from the social environment in order to attribute meaning to the thoughts, feelings and behaviours of others. The development of this ability is essential and plays a crucial role throughout an individual's life (Slaughter & Perez-Zapata, 2014).

Fiske & Taylor (2013) describe social cognition such as the way people process and conceptualise information about themselves, others and social events.

Social cognition involves several important cognitive processes:

- **Forming impressions:** the ability to construct mental representations of others based on available social information.
- **Social categorisation**: the process of classifying individuals into groups based on common characteristics.
- **Causal attribution:** the tendency to explain others' behaviour by attributing internal causes (intentions, emotions) or external causes (situations, context).
- **Understanding others' emotions and intentions:** the ability to infer others' mental states and motivations, which is fundamental to theory of mind.
- **Emotional regulation:** controlling and modulating one's emotions in response to social interactions.
- **Knowledge of social norms:** learning and applying the rules that govern group life.

Typical development of ToM and Social cognition

Theory of mind and social cognition follow specific developmental stages, allowing individuals to improve the ability to understand others' intentions and refine their social and emotional skills throughout their life cycle, which enables them to adapt to social situations and contexts at different stages of life. Language, social interaction and environmental stimulation are essential for the development of these skills.

From early childhood, in the first years of life, children acquire theory of mind skills through dyadic-interaction with their primary caregiver; during these months, their gaze focuses mainly on certain elements of the face: eyes and mouth.

Furthermore, by the end of their first year of life, children show episodes of triadic-shared-attention (child-adult-object), which is fundamental for the development of communication and social cognition (Tomasello, 1995; Striano & Reid, 2006; Mendoza-Garcia, A., 2023).

During the second year of life, can be observed the development of "*pretend play*", requiring the child to be aware that others could pretend (Tomasello, 1995; Garfield et al., 2001).

The third year of life involves improving and understanding that sensory perception is necessary to figure out what is inside a box whose contents are unknown (Wellman et al. 2001; Garfield et al. 2001). At the age of four, children become able to perform "*false belief*" tasks, indicating that they comprehend another person may have incorrect beliefs about reality ("*Sally and Anne Test*" - Baron-Cohen et al., 1985; Wellman et al., 2001).

At school age, from 6 to 9 years old, the development of more complex constructs occurs, such as emotions, irony, double bluffing and "*faux pas*" (*Faux Pas Test* - Baron-Cohen et al., 1999; *Strange Stories* - Happé, 1994; Baron-Cohen, 2008).

Adolescence and adulthood are characterised by a refinement of ToM and social cognition skills, and an improved understanding of mental states, implicit intentions and complex emotions (*Reading the Mind in the Eyes Test* - Baron-Cohen et al., 2001; Blakemore, 2008).

Throughout the aging process, in the absences of acquired pathologies, abilities related to ToM and social cognition could undergo a physiological decline, which would manifest itself primarily in the cognitive components of ToM (such as the inference of beliefs and intentions), while affective components seem to be more preserved (Henry, J. D., et al., 2013). This decline is linked to a concurrent reduction in the performance of executive functions (Charlton, R. A., et al., 2009; Cho et al., 2019), which govern the processing speed of information and working memory. In addition, environmental variables could also have an impact, such as a reduction in stimulations depending on lifestyle, and the radical changes which occur at the time of retirement.

However, the signs of such decline are often compensated in part by the enabling of some compensatory neural circuits activated with the aim of maintaining social skills (Castelli, I., et al., 2010) and by individual variability linked to the level of education and cognitive reserve, to experiences lived and scripts learned and consolidated as a result of these experiences, as well as to lifestyle (Henry, J. D., et al., 2013).

Atypical development of ToM and Social cognition

Some conditions could affect how theory of mind and social cognition skills develop, with the typical path being interrupted, changed or altered by various factors.

There are two main reasons why these skills may not develop as expected: neurodevelopmental disorders and acquired neurological disorders.

Specifically, neuropathological and psychopathological profiles have been identified in relation to ToM impairment (Perrotta, 2020); among the conditions referring to neurodevelopmental disorders, the following may be mentioned:

- Spectrum of autistic disorders, attention deficit/hyperactivity disorder (ADHD) and language disorders (Baron-Cohen S., et al., 1985; Baron-Choen S, et al., 1997; Perrotta G., 2019; Korkmaz, 2011); these conditions are characterised by a deficiency in the development of the meta-representation skills that underlie Theory of Mind. These aspects could explain many of the social and communication issues seen in this type of diagnosis.
- Schizophrenia (Baron-Cohen S., et al., 1985; Scherzer P. et al., 2012; Perrotta G., 2019): alterations in the mentalization and reasoning processes are also observed in this psychiatric disorder, in relation to one's own and others' representation of the world, thoughts and actions. This alteration in the functioning of meta-representation could be at the root of the difficulties in schizophrenia in terms of awareness of one's own goals and intentions and those of others, thus promoting the production of distorted inferences that does not correspond to reality about the intentions and behaviours of others.
- Bipolar disorder (Kerr N et al., 2003; Perrotta G., 2019): these clinical profiles show deficits in ToM functioning both in the early stages of the disorder and in the chronic stages; the alterations in functioning affect ‘cognitive’ and ‘affective’ component (Kerr et al., 2003). Furthermore, longitudinal studies indicate that ToM may fluctuate over the course of the disorder but remains globally impaired over time (Stix, K., et al. 2024).
- Personality disorders: Anthony Bateman and Peter Fonagy (2018) argue that some personality disorders may originate from a fragility in the ability to mentalise, especially in conditions of emotional stress, defining certain pathological personality traits as the result of a fragility in mentalization emerging in emotionally intense contexts.

Regarding conditions referring to acquired neurological disorders, the following should be mentioned:

- Symptoms related to frontal lobe lesions (Rowe AD et al., 2001): studies suggest patients with frontal lesions present significant deficits in Theory of Mind; ToM deficits appear to be more pronounced in patients with right frontal lobe lesions. The study highlights that ToM difficulties are related to executive function, but are not fully explained by or reducible to it.

- Cognitive decline: the several types of cognitive decline include issues with ToM and social cognition, which are affected to differentit is degrees, depending on the kind of dementia.

  Mild cognitive impairment (MCI), especially if anamnestic and multidomain, tends to show mild to moderate impairment in both cognitive and affective components of ToM (Morellini et al., 2022; Maggi et al., 2024).

  In *Parkinson's disease*, significant deficits in both components were already evident in the early stages of the disease (Maggi et al., 2024; Fernández Fernández et al., 2024).

  Alzheimer's disease presents severe impairments in ToM abilities at intermediate/advanced stages of the disease, causing significant difficulties in social interactions and in the management of those affected (Poletti et al., 2012; Setién Suero et al., 2022; Christidi et al., 2018).

  Furthermore, in *acquired cognitive decline* (e.g., frontotemporal dementia - FTD, vascular dementia), there is a wide range of impairment in ToM abilities, which also depends on the pathological condition: in *FTD*, there is early and severe impairment of both components of ToM, while in the *vascular form*, the picture of the condition is more heterogenous and fluctuating (Poletti et al., 2012; Setién Suero et al., 2022; Christidi et al., 2018).

Pathological ageing

Mild cognitive impairment (MCI)

Mild Cognitive Impairment (MCI) is a clinical condition characterised by cognitive impairment above that expected for age and educational level, but which may not interfere significantly with daily activities and functional autonomy. MCI represents an intermediate state between normal cognitive ageing and dementia, and is often considered a transitional phase towards neurodegenerative diseases such as Alzheimer's disease (Petersen et al., 1999; Gauthier et al., 2006; Albert et al., 2011).

Mild cognitive impairment (MCI) increases the risk of developing Alzheimer's disease (AD) or other neurodegenerative conditions (Castelli et al., 2016). Patients with MCI present a conversion rate to AD of between 6% and 25% (Petersen et al., 2001). Patients with MCI could presented impairment in several cognitive domains (e.g., attention, memory, language; DSM-5, 2013). In addition, these patients may suffer alterations in socio-cognitive abilities, such as Theory of Mind (ToM; Rossetto et al., 2020; Morellini et al., 2022; Maggi et al., 2024).

In order to be diagnosed, there must be evidence of a modest cognitive deficit in one or more domains (memory, attention, executive functions, language, perceptual-motor skills, social cognition), as reported by the patient, a reliable informant or a clinician, and confirmed by standardised neuropsychological tests (Albert et al., 2011; American Psychiatric Association, 2013). Furthermore, the impairment must not compromise the patient's functional autonomy and should not be explained by other medical or psychiatric conditions (Petersen et al., 2001; Albert et al., 2011).

MCI can be divided into two subtypes:

- Amnestic (a-MCI): when the main deficit concerns memory, often associated with an increased risk of progression to Alzheimer's disease (Petersen, 2004; Winblad et al., 2004).

- Non-amnestic (na-MCI): when other cognitive functions are involved, with possible progression to other forms of dementia (Petersen, 2004; Winblad et al., 2004).

The prevalence of MCI increases with age and conversion to dementia depends on multiple factors, including genetic predisposition, comorbidity, environmental factors and individual cognitive reserve. Italian and international guidelines emphasise the importance of early diagnosis and a multidisciplinary approach to the management and treatment of MCI.

Parkinson's disease (PD).

Parkinson's disease (PD) is a chronic, progressive neurodegenerative disorder of the central nervous system, part of the group of movement disorders. Characterised by motor symptoms such as bradykinesia, muscle rigidity, resting tremor, and postural instability, with a typically asymmetrical onset and gradual progression (Bloem et al., 2021). However, the most recent understanding of PD recognises the complexity of the clinical framework and also includes a wide range of non-motor symptoms.

According to recent data, the prevalence of Parkinson's disease is around 1–2% in the population over 60 years of age, rising to 3–5% in those over 85 (World Health Organisation [WHO], 2022; Pringsheim et al., 2022). The progressive ageing of the population suggests a further increase in incidence in the next few decades.

Due to the in-depth study of the symptoms that characterise this disease, the importance of non-motor symptoms, often present in the prodromal stages of this condition, is now highlighted. These include REM sleep disorders, anxiety, depression, dysautonomia, fatigue, cognitive impairment and chronic pain (Chaudhuri et al., 2021). These symptoms, which are not always related to dopaminergic dysfunction, may exceed motor symptoms in terms of their impact on quality of life and overall disability, particularly in the advanced stages.

Several longitudinal studies have confirmed that patients with PD have a significantly increased risk of developing dementia during the progress of the disease. Current estimates indicate that approximately 30–40% of patients develop Parkinson's disease dementia (PDD) within 10 years of diagnosis (Aarsland et al., 2021; Emre et al., 2022). PD-associated dementia has an insidious onset, often dominated by a dysexecutive syndrome, with impairment of sustained attention, planning skills, cognitive flexibility, inhibition, and goal-directed behaviour regulation processes (Goldman & Litvan, 2020; Gratwicke et al., 2021). Deficits in memory and visuospatial functions are also common. Difficulties with ToM and social cognition abilities also occur in parallel and in conjunction with cognitive deficits (Maggi et al., 2024; Fernández Fernández et al., 2024).

In the last few years, there's been growing interest in studying prospective memory—the ability to remember to do something in the future—in people with PD (Costa et al., 2021; Thiel et al., 2022).

It has also been reported that a significant number of patients with early-stage PD present with symptoms compatible with mild cognitive impairment (PD-MCI).

This Thesis

In this thesis, I propose the analysis, design and construction of a socio-cognitive training programme aimed at supporting, improving and sustaining social skills (related to Theory of Mind) and cognitive skills (attention, memory, language, etc.), which undergo physiological and pathological decline, especially in elderly population. As evidenced from the literature, non-pharmacological approaches, such as cognitive stimulation, may promote the slowing down of decline and, in some cases, improve several abilities (Buonocore, J. et al., 2025).

Despite numerous pharmacological studies, to date no pharmacological treatment has been identified that could interrupt or modify the evolutionary trajectory of cognitive symptoms in subjects with MCI and Parkinson's disease. The available therapies are mainly focused on the management of individual symptoms and have limited effectiveness on the course of the disease.

These assumptions led to an increasing attention towards implementation of non-pharmacological approaches, particularly structured cognitive stimulation training, which showed significant benefits on cognitive performance and daily functioning (Kasper et al., 2020; Sun, C., et al., 2021; Liu, Y. D., et al., 2025). Furthermore, non-pharmacological treatments reduce the risk of side effects, lack contraindications and are based on the long-established scientific principle regarding the brain's ability to create new circuits that compensate the loss of functions affected by the disease, through neuroplasticity mechanisms (Fedotchev A.I., 2025). In particular, cognitive stimulation training promote the restructuring of neural networks and contribute to mitigating the impact of cognitive decline. As highlighted in the review by Pieramico et al. (2014), even the brains of elderly people retain the capacity for functional and morphological restructuring, which could be enhanced by non-pharmacological interventions. James, C. E. et al. (2024), in a scoping review, analyse 23 years of randomised studies on the effectiveness of non-pharmacological treatments (cognitive stimulation, mental activities, aerobic and non-aerobic physical exercise) on healthy older adults, in order to measure their effectiveness on physical and cognitive decline. The review, also supported by neuroimaging (Magnetic Resonance Imaging - MRI) data, shows these interventions promote functional changes in the brain that contribute to preserving cognitive abilities and slow their decline. On the basis of these findings, various studies (Jiménez-Palomares, M. et al., 2025) demonstrate also in subjects with cognitive decline, cognitive stimulation may improve mechanisms related to neuroplasticity, promoting increased synaptic activity and hippocampal neurogenesis (Kempermann et al., 1997; 2002), functional connectivity (Chapman et al., 2015; Lampit et al., 2015) and favoring the reorganization of neural networks.

Although scientific evidence suggests that aspects related to ToM are compromised in subjects with MCI (Morellini et al., 2022; Maggi et al., 2024) and Parkinson's disease (Maggi et al., 2024; Fernández Fernández et al., 2024); few studies have been conducted focusing on the planning and validation of the effectiveness of socio-cognitive interventions in older adults with MCI and Parkinson's disease. The planning of interventions aimed at stimulating socio-relational aspects, such as the ability to recognise emotions, the capacity to infer mental states of others and the management of social situations, could promote greater autonomy, better interpersonal functioning and reduce situations of social isolation.

According to an official report (Liperoti, 2024), based on ISTAT data as of 1 January 2023, there are estimated to be 1,126,961 cases of dementia among the over-65s and 23,730 cases of young-onset dementia (<65 years) in Italy. These data reflect how there could be an increase in request for rehabilitation/cognitive stimulation services, both for therapeutic and social rehabilitation purposes, as a way to train cognitive abilities and, at the same time, share time with other people who are in the same clinical condition. This request has not been adequately satisfied by the institutions, due to a lack of the resources necessary to organise and provide a uniform, large-scale service.

Attempting to find answers to this social situation, several studies have been conducted with the aim of proposing alternative solutions to those offered by healthcare and social services.

For this purpose, some authors have considered using Social Assistive Robots (SARs), defined by Feil Seifer, D. et al. (2005) as: "*focused on assisting people through social interaction*". SARs employ robotic agents to support and enhance social care interventions aimed at vulnerable populations.

These robots, which may have a humanoid or zoomorphic appearance, are designed to promote positive behavioural changes, support psychological well-being and mediate socio-cognitive stimulation training.

The latest research suggests that implementing and designing social-cognitive interventions using SARs could have several benefits, both from a clinical-rehabilitation and organisational side.

Giansanti et al. (2025) describe how training conducted using social robots on different types of populations (older adults, children, individuals with autism and dementia) promotes improvements in various aspects: cognition, mood, anxiety, sense of loneliness and sleep quality. Nichol et al., 2024, in their umbrella review, describe interventions with the use of SARs in healthcare and social care, with the aim of providing physiological, psychosocial, cognitive and behavioural support to children, adults and elderly in different care settings; here too, the outcomes are promising and describe improvements associated with all the variables explored. Figliano et al. 2023, in a systematic review, focusing on SARs applied to socio-cognitive training for individuals with MCI, show how social robots may provide some rehabilitation activities, offering them to a larger number of individuals and more frequently than human staff could. Furthermore, the studies cited highlight the positive acceptance of humanoid robots by patients as well as improvements in the socio-cognitive components of the subjects.

These reviews show the purpose behind the use of social robots, which is to provide repeated, standardised and long-term stimulation; robots don't totally replace human staff, but they do take over some of their tasks. In addition, these protocols have been applied in both home and residential settings.

An interesting and recent study by Naseer, F. et al. (2025) highlights how Socially Assistive Robots (SARs) could be implemented in care activities for elderly population, which is expected to double by 2050, a demographic factor that would further impact national healthcare and welfare systems.

The authors propose the design of interventions that could address four important factors: reduced physical mobility, social isolation, cognitive decline and a lack of healthcare/care staff. The employment of assistive robots to support physical mobility and social robots to promote and maintain psychosocial wellbeing could contribute significantly to addressing emerging demographic and care challenges.

These studies provide encouraging results regarding the potential benefits of developing social-cognitive stimulation programmes involving the use of social robots for vulnerable populations. However, limitations and critical issues were also identified due to the heterogeneity and lack of standardisation of the protocols applied, the recruitment of small samples and limited follow-up.

Considering all this, during my PhD, I focused primarily on doing a systematic review, *Chapter 2*, in which I examined studies conducted on the use of Socially Assistive Robotics for socio-cognitive treatment in patients with MCI. The work followed the PRISMA guidelines; starting from the analysis of six databases, 19 articles that met the inclusion criteria were included. The review analysed both qualitative and quantitative studies. Although the studies included describe the potential of SARs and their application in socio-cognitive stimulation training, but the majority of the results focus on the acceptability of the robotic agent rather than on the outcomes of the interventions.

A significant limitation identified by review is the heterogeneity of the protocols applied from several perspectives: choice of robotic agent, socio-cognitive assessment protocol, characteristics of the enrolled sample and type of training proposed. These elements make it impossible to standardise outcomes.

In an attempt to develop and structure an intervention able to overcome the limitations observed, in *Chapter 3*, I report a preliminary study which aimed to evaluate the acceptability and effectiveness of the **Pepper** social robot in delivering socio-cognitive training. This study enrolled nine participants who attended the Day Care De Rodolfi Centre in Vigevano. The participants had been diagnosed with mild to moderate dementia, and the training programme lasted four weeks. Since this was a preliminary study, the focus of the research was qualitative; therefore, we carried out qualitative analyses of the interviews and video recordings. The results highlighted significant emotional involvement from participants, with a positive response to Pepper, greater concentration during training sessions and a genuine desire to participate in future sessions.

Chapter 4 reports the latest study, which aimed to verify the effectiveness of structured socio-cognitive training with the Socially Assistive Robot (SARs) Pepper. The study investigated the effectiveness of a 12-week programme to stimulate cognitive and socio-cognitive functions.

Two groups of people took part in training: one group included subjects with Parkinson's disease and the other group involved healthy elderly people. ToM skills and cognitive functions were assessed before and after the treatment. Results were promising, showing high compliance among participants and improvements in overall cognitive function, executive function and theory of mind skills in both groups.

These results show the promising application of SAR-based socio-cognitive stimulation training, not only in terms of feasibility, but also as a tool to promote healthy cognitive and social ageing in both healthy and pathological ageing situations.

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Chapter 2

Ageing society and the challenge for social robotics: A systematic review of Socially Assistive Robotics for MCI patients.

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Keywords

Mild Cognitive Impairment (MCI) | Social Assistive Robots (SARs) | Human Robot Interaction | Humanoid robot | Zoomorphic robot | Cognitive stimulation | Socio – cognitive stimulation|

Abstract

The aging population in Western countries has led to a rise in predementia conditions like Mild Cognitive Impairment (MCI). Social Assistive Robotics (SAR) interventions, among novel technological tools, offer a promising interdisciplinary approach to mitigate cognitive and social symptoms' progression in this clinical group. This systematic review aims to identify existing clinical protocols employing social robots for treating cognitive and social cognition skills in individuals with MCI. The review protocol adheres to the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guidelines. From six data bases, we retrieved and analyzed 193 articles, of which 19 met the inclusion criteria, featuring samples diagnosed with MCI and subjected to cognitive and/or social interventions through SAR. The review encompasses both qualitative and quantitative studies, with a focus on assessing bias risk. Articles were categorized into four primary areas: study participants' samples, types of robots and programming used, assessment of cognitive abilities, and the nature of interventions (i.e., cognitive and and social cognition skills). While the findings highlight the potential benefits of using SAR for MCI interventions in both cognitive and social cognition domains, the studies primarily emphasized robot acceptability rather than intervention outcomes. Methodological limitations such as clinical heterogeneity, absence of control groups, and non-standardized assessments restrict the generalizability of these findings. This review underscores the promising role of Social Assistive Robotics in MCI interventions, emphasizing the importance of social cognition skills interventions and advocating for increased collaboration between clinicians and robotic researchers to overcome current limitations and enhance future outcomes.

Introduction

The World Health Organization revealed that in the world around 50 million people suffers of dementia and there are nearly 10 million new cases every year [1]. Most of these countries introduced several legislative proposals to consider the social and political implications of an ageing society [2]. National healthcare systems are increasingly interested in identifying and intervening at an early stage in neurodegenerative pathological conditions, on the one hand to prevent a progression of clinical conditions, leading to a decrease in quality of life, and on the other hand to reduce the economic and social burden on the healthcare system. In this sense, Mild Cognitive Impairment (MCI) represents a particularly important clinical population for the above-mentioned purposes. MCI is a clinical condition in which individuals experience cognitive decline with minimal impairment in instrumental activities of daily life (e.g., shopping independently, paying bills, typing telephone numbers) [3]. However, this clinical condition has been widely recognized to increase the risk of conversion to Alzheimer's disease (AD) or other severe neurodegenerative conditions [3,4]. To mitigate the incidence of conversion to other neurodegenerative conditions, it is important that specialized intervention strategies and compensatory home adaptations (e.g., digital aids for remembering appointments and tracking medication) are activated to reduce cognitive decline and maintain personal autonomy. From the age of 65 years, between 10% and 20% of seniors may experience a condition of MCI[5] consisting of cognitive impairments in specific domains including memory, language, attention and visuo-spatial abilities [6,7]. Although not directly included in the diagnostic criteria, Theory of Mind (ToM) may also be affected by the general deterioration of the MCI symptomatology, leading to a considerable impairment of the subject's socialization skills [3]. ToM is the ability to understand own and others' mind and behaviors in terms of mental state (e.g., emotions, intentions, beliefs) [1,8], and it is essential for sociality and relationships. This ability is particularly sensitive to the cognitive and affective changes that occur in old age and may decline in its functioning with MCI [9,10]. The impairment of this ability negatively affects social life's activities and general well-being [2,6]. Considering the complexity of the clinical picture of MCI, an effective pharmacological treatment has not yet been identified. However, there are several non-pharmacological treat ments that efficacy slow the progress of cognitive impairments preventing a further decline in different cognitive areas [11,12]. Specifically, cognitive training is particularly recommended with MCI patients [7–9,11–26]. Among the different cognitive trainings, Cognitive Stimulation (CS) is the one most frequently employed with MCI patients [12,26]. CS consists of cognitive exercise sessions to enhance residual cognitive abilities using the principles of neuronal plasticity [27]. Classically, cognitive stimulation exercises are administered paper-and-pencil by a clinician. As mentioned above, MCI also affects the socio-cognitive domain inducing an increase in behavioral symptoms [3] and negatively influencing the quality of life of the patients and caregivers [10]. A multi-stimulation intervention for patients with AD has been adapted for MCI, showing that ToM is an important measure for evaluating treatment progress on social cognition skills [10]. More generally, social impairments in MCI are treated through occupational/recreational activities secondary to interventions on cognitive domains [28]. These secondary interventions do not allow specific assessment on social cognition components. In the last decade, cognitive and social interventions have been implemented through Social Assistive Robotics (SAR) to reduce and prevent increased MCI symptomatology [6,29–31]; to date, even though a significant increase in economic investment and the interest of the scientific and clinical community in these new types of interventions with SAR, it is not sufficiently clear their effects on cognitive decline and affective issues in this clinical population. In view of this lack of clarity regarding the benefits and efficacy of SARs in cognitive and social interventions with MCI patients, this systematic literature review aims to analyze clinical studies that employed SAR for cognitive and social interventions for MCI.

Methods

A systematic review of scientific literature has been performed to identify studies that reported research which used social robots for cognitive and social interventions for MCI. A review protocol was compiled, following the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guidelines [14].

2.1. Data sources and search strategy

Electronic literature searches were performed using ACM Library, Cochrane Systematic Reviews Database, Google Scholar, PubMed, PsychINFO and Web of Science including publications up from January 2000 to March 2022. Two researchers reviewed the potential studies individually for eligibility. Was used a list of keywords to identify the studies, including relevant interventions, through an interactive process of search and refine (see Table 1). Each data base was searched independently, according to a specific interaction research string: ("Mild Cognitive Impairment" OR "MCI") AND ("Robot" OR "Robots" OR "Human robot interaction" OR "Humanoid robot" OR "Zoomorphic robot"). No limitations regarding study design or outcome measures were used. We included only English's article. Eligible studies were those whose title or abstract specifically indicated the inclusion of MCI, use of social robots and protocol of cognitive and social interventions. There were no restrictions about the age and number of participants. In the first export were included only article with full-text available. The complete list was exported in EndNote to remove duplicates and then it was imported in Rayyan [29] for title and abstract screening.

2.2. Study selection criteria

The aim of this review was to evaluate the efficacy of social robot-based interventions with MCI patients to enhance cognitive and social abilities. The following selection criteria were applied to the articles found in databases: research studies, reviews and case reports were eligible for inclusion; chapters and not peer review studies were excluded. The abstracts of the identified publications were screened for relevance to the selection criteria. Specific inclusion criteria were: samples with MCI clinical condition; a cognitive and/or social training through a social robots. Papers that described unstructured and holistic intervention programs for patients with MCI were rejected.

Table 1. Detailed search strategy.

Mild Cognitive Impairment OR MCI AND	**PubMed**	**Cochrane Systematic Rewiev database**	**PsychInfo**	**Web of Science**	**ACM Library**	**Google Scholar**	
Robot	46	20	0	79	83	17600	
Human Robot Interaction	8	10	0	19	43	1830	
Humanoid robots	1	1	0	9	14	21200	
Zoomorphic robots	0	0	0	0	0	624	
SubTotal	55	31	0	107	140	41254	
Total							41587
Duplicated removal							333
Identified studies for Abstract and Title screen							193
Included							19

2.3. Quality assessment

The ‘Tool for assessing the risk of bias in randomized quantitative trials’ [32], which includes five domains related to the quality of the methodology in randomized trials, was used to assess the quality of the risk of bias (RoB2). Each domain was rated by two independent reviewers (GF, AT) who rated each domain by assigning it a risk of bias rating; the rating could be categorized as follows: low risk of bias; some concerns and high risk of bias. A judgement of ‘High’ risk of bias for any individual domain will lead to the result being at ‘High’ risk of bias overall, and a judgement of ‘Some concerns’ for any individual domain will lead to the result being at ‘Some concerns’, or ‘High’ risk, overall. With the purpose of calculating the risk of bias for the qualitative studies included in this systematic review, it was decided to use the tool of GRACE (Good Research for Comparative Effectiveness) that is an 11-item instrument designed to evaluate the quality of the data and the methods used either in the design and the analysis of the non interventional and observational studies of comparative effectiveness [33]. The GRACE tool is composed by two sections: the first dedicated to the data (6 items) of the study regarding the treatment, outcomes, and population; the second dedicated to the methods (5 items) with more information about the population, the control group, possible follow up etc. [33].

2.4. Quantitative studies

Concerning quantitative studies and the dimension related to the randomization process (S1 and S2 Figs), some studies [17,34–36] have a low risk of bias; this suggests a random distribution of participants to the different intervention groups and the difference in outcome between the two groups is not an indicator of randomization problems. Two studies [18,24] show some doubts, while works [16,23] have a high risk of error related to the randomization process. The second aspect explored was the deviation from the intended interventions; here only study [35] shows a low risk of bias while four works [15,18,34,36] show some concerns regarding the adopted methodology. The remained works [12,16,24] on the other hand, present a high risk of bias; this proportion is related to the awareness of the subjects and their caregivers about the intervention and to factors related to the experimental context that may have affected the outcome of the intervention. The third dimension of Rob2 concerns bias due to the lack of outcome data; this could happen when participants withdraw from the study ’dropout’ and if they do not provide relevant data; if participants die, etc. In this case, the studies can be divided into low risk of bias: [35], (relating to the outcome of improvement in visual memory), [16–18,23,34,36] and high risk of bias: [35] related to the outcome of the improvement in executive functions, [35] in relation to increased cortical thicknesses, [18] in relation with change of prose memory, [12] concerning the increase in the frequency of communication in the robot group and the increased, in both groups, of interaction with staff, and [24]. Also, with regard to measurement of the outcome, one could categorize the work into studies with a low risk of bias: [12,17,24,34–36] and studies with a high risk of bias: [35], relating to the improvement in the executive functions in robot group, [12,16,18]. When referring to measurement error, this concerns misclassification (for dichotomous or categorical out comes), the use of non-adapted tools for the measurement of the outcome being studied, the possibility that administrators may be aware of the intervention provided to subjects, etc. Regarding the selection bias of the reported result, a dichotomous situation was found in studies [17,35] and [12] show some concern on the reported results, while a high risk of bias was observed for the studies [35] relating to the improvement in the executive functions in robot group, [12,16,18,24,34,36] with respect to the increase in frequency of positive expressions and reductions of loneliness feelings in the robot group. With regard to this dimension, several studies do not report pre-specified analysis plans that were finalized before unblinded outcome data were available for analysis and lack multiple eligible outcome measurements from which to derive data. As afinal result, a global calculation of the risk of bias relating to each job can be observed; in this case, some results lead to an uncertain risk of bias [17,34–36] and in overall results with a high risk of bias [35], regarding improvement in visual memory, [12,16,18,24].

2.5. Qualitative studies

With regard to data on qualitative studies, two independent assessors compiled the GRACE scale (S3 Fig) [33] and then compared the results and reached an inter-judge agreement. The Grace scale is subdivided into two macro sections: a first section on data and a second section on methods [33]. We will begin the analysis of the results of the papers included in the review from the first section which is concerned with investigating whether the study data are ade quately recorded (D1-D2), whether they are clinical outcome (D3), whether they have been validated on similar populations in terms of diagnosis (D4), and whether the data have been measured on a comparison group (D5). What emerged from the evaluations was that all studies correctly recorded data except the one of [37] where, although both qualitative and quantitative measures were implemented in the study, the latter were recorded through methods that are closer to a qualitative and observational methodology. Moreover, the contents of qualitative survey measures such as comments and open-ended questions are not specified in the paper, therefore, there is insufficient information in the publication to allow us to say whether the treatment data has been adequately recorded. Moreover, most of the studies did not have a clinical outcome expect for the following works: [5,22,38]. Most of studies were pilot studies or focused on new types of populations, the only studies that have used a protocol or previously validated measures in other populations are [39–41]. Regarding the reproducibility of the results in a hypothetical control group, we find that the only one studies have this condition [38]. Finally, the recording of important covariates was not found in any of the included work. Overall, what emerges was that, limited to the data section, most of the studies mentioned presents what could be defined as a high risk of bias expect for one work [38], which could be interpreted as a study with a medium risk of bias. Considering the methods section, we found how for the first item (M1) all studies, except for [38], included new initiators instead a population already under treatment, whereas, for the second item (M2) the studies which used an historical comparator group were: [20,38,40–42]. For the third item (M3) the studies which take into account important confounding and effect-modifying variables were: [40,41]. Finally, none of the studies was free of “immortal time bias” (M4) and none of them has conducted meaningful analyses to test the key assumption which primary results were based (M5). In conclusion, regarding methods section, all the studies included presented what we could define as a high risk of bias. These results suggest how the novelty of the used protocols in ’human-robot interaction’ studies, particularly in the rehabilitation context, are still in the development and validation phase all these aspects would be discussed and deepened later.

3. Results

After removal of duplicates, title and abstract screening of electronic database search results and identification of eligible articles through other sources, 193 articles were full text screened. A total of 19 articles were included and 4 systematic reviews was consulted (see Table 2 for the summary of the studies). See Fig 1 for study selection flow chart. In this review were included: nine Randomized Control Trial; nine qualitative observational studies; one pilot study. The results are organized with respect to the following sections: characteristics of recruited samples; types of assessment for clinical evaluation and intervention outcomes; types of robots; and aim of the interventions, subdivided into cognitive and social.

Table 2. Papers about evaluation.

Authors	Research goal	Subjects	Type intervention	Assessment	Results	Limitations
[35]	Compare traditional cognitive training with robot-assistive cognitive training	48 participants from 60 years old with starting symptoms of cognitive impairment	24 participants: traditional cognitive training 24 participants: Robot (SILBOT and MERO) cognitive training Training: multi-domain exercises	Pre and post neuropsychological assessment and MRI: Alzheimer’s Disease Assessment Scale (ADAS-Cog); Cambridge Neuropsychological Test Automated Battery (CANTAB)	Greater improvement of visual memory in traditional group Improvement in the robot groups in executive function performance	It was impossible to control participants’ daily cognitive activity at home The presence of more females than males within the sample
[39]	Improve the quality of life of elderly individuals with moderate dementia and/or depression through conversation and cognitive games	6 participants with moderate dementia and/or depression in a Senior Community	Memory games mediated by a robot, RYAN, with personalized contents (like quiz, music and video); they could give oral answer or through tablet	Observation and interviews to caregivers and participants; interaction’s analysis; they used two geriatric scale for subjects: SLUMS e PHQ9	It was a good acceptance of robot by elderly people and an improvement of participants’ mood (reported by caregivers)	Exercises were too easy for subjects with initial cognitive impairment
[38]	Memory games to train memory’s functions through a humanoid robot, PEPPER, and tablet. Authors want to understand subjects’ preference	14 participants, age above 65 years old and diagnosis of MCI	Musical quizzes: subjects had to recognize sings or singers. One group train with PEPPER and one with Tablet	Likert scale to understand satisfaction’s grade of participants and caregivers	All participants ended without difficult musical quizzes; subjects and caregivers were satisfied	There aren’t multiple difficulty levels

[16]	Explore the robot’s potential to engage participants in the intervention and its effects on their emotional state	21 patients with MCI, aged between 45–85 years old	Therapist assisted by NAO propose memory training to little group	Neuropsychological assessment (a complete test battery) ADL and IADL	In the subjects are generated positive emotions towards robot and they consider it as if it was a real companion with real intentions	Small sample and short time for the study
[18]	Evaluate the effectiveness of human–robot interaction to reinforce therapeutic behavior and treatments adherence and improve memory functions	21 subjects MCI; 45–85 years old	There are two groups: one group did memory training mediated by NAO and one group did traditional training with psychologist	Neuropsychological pre and post intervention: digit span test, prose memory and fluency; clinical assessment: anxiety and depression	Training with NAO resulted in an increase of visual gaze from patients and reinforce of therapeutic behavior depressive symptoms. Changes in prose memory and verbal fluency	Results not generalizable due to small sample size
[36]	Demonstrate the effects of our newly developed home- based cognitive intervention with robot BOMY on cognitive function in MCI patients	46 patients with MCI; there are two groups: robot group and control group	5 programs for home-based multi domain cognitive training for four weeks	Seoul Neuropsychological Screening Battery	Improvement of working memory in robot group	Larger samples and longer study periods are required to demonstrate the effects of these programs
[17]	It investigated whether multi-domain cognitive training programs, especially robot-assisted training, could improve cognitive function and depression decline in community-dwelling older adults with MCI	135 volunteers with cognitive impairment aged 60 years old or older There are two group: one robot-group and a control group that do traditional cognitive training	Multi-domain cognitive training conducted by SIL-BOT for 12 times, twice a week for 6 weeks	MMSE-Ds, Cerad-K, Sgds-K	Robot-assisted cognitive training group had significantly greater post-intervention improvement in memory, executive functions and depression. Traditional cognitive training group had improvement in memory and executive functions	Lack of integrated approach for improving the physical and emotional functions of the elderly; gender, age, and years of education affect the effectiveness of training program

Table 2. (Continued)

Authors	**Research goal**	**Subjects**	**Type intervention**	**Assessment**	**Results**	**Limitations**
[15]	To preliminarily evaluate how acceptable robot-mediated pet-therapy is for older people with light cognitive deficits (MCI)	24 subjects with aMCI and more advanced degrees of decay	Experimental sessions in which the patient interacts with AIBO (through operator mediation) and answers questions related to the potential use of the robot	Mini Mental State Examination	AIBO is perceived as friendly	Preliminary study
[20]	Evaluation the seal-like robot PARO in the context of multi-sensory behavioral therapy (MSBT)	10 elderly nursing home residents with varying levels of dementia (from mild to moderate)	PARO engaged participants through multimodal sensory stimulus in group therapy, one a week for seven weeks	Researchers observe and videotape interactions	Increase of verbal communication with PARO and of the interaction between participants	Small sample size and short period of interaction
[21]	Observe acceptance of a zoomorphic robot, PARO, as a companion to reduce sense of loneliness	30 subjects in single room in an elderly's residence, someone with mild/moderate dementia (19), some with severe dementia (11)	18 months, every 3–6 months individual sessions for 15 minutes; an experimental group interacts with PARO and a control group interacts with a stuffed animal (Lion)	Hasegawa's Dementia Scale to assess the level of dementia. Video recording interactions and recording the frequency of certain behaviors	In the robot group, an increase in the frequency of positive expressions is observed and a reduction in the feeling of loneliness is reported. Subjects talk more to PARO than to Lion; in both groups, is observed more interaction with staff	Small sample
[24]	Compare the effect of different rehabilitation sessions with different modalities and different robots: NAO and PARO	Group sessions (9–15 persons) for mild to moderate dementia, individual sessions for more severe dementia	3 times a week for 3 months. Various types of activities: sensory, cognitive, socialized, and different levels of difficulty	Neuropsychological assessment pre and post training with MMSE, sMMSE and NPI	Robot-managed daily routine could support and reassure individuals	Several participants left the center or unit or died, and several patients joined the study late
[40]	The aims to show how the engagement between two social robots, SOPHIE and JACK, in Australian residential care facilities can improve care quality	139 participants, 65–90 years old, (43 males, 96 females) with different stages of cognitive impairment in an elderly care facility	Designed to communicate in speech mode, touch panel	Behavioral reactions observed: approaching the robot in a positive way; the pleasure during interaction with the robots; interaction frequency with robots and interaction frequency with other staff and/or residents	These innovative social robots could improve the quality of care for people suffering from dementia	There isn't an objective neuropsychological and ToM assessment
[41]	Focuses on the service design and the effectiveness of the engagement and acceptability while interacting with a social robot	115 participants in Australian residential aged care: with dementia aged 65–90 years; the participants had mild to advanced dementia	MATILDA has been designed to communicate in speech mode, touch panel mode, and facial recognition mode; it proposed games, musical quizzes, orientation activities	The measures of engagement were coded based on the guideline for video coding of engagement proposed by Jones et al. (2015). Emotional engagement in people with dementia was assessed via facial emotional responses based upon a modified version of the observed emotional rating scales of Lawton	An increase of involvement respect to the baseline	There isn't an objective neuropsychological and ToM assessment

Table 2. (Continued)

Authors	Research goal	Subjects	Type intervention	Assessment	Results	Limitations
[22]	Evaluates effect on behavioral and psychological symptoms of KABOCHAN in subjects with MCI	Subjects: 74 elderly people aged 65 years with mild impairment, residents in elderly care facilities	Living with a communication robot	Administration of: IADL, STAI, QOL; administration of questionnaires before and after two months following interactions	Sleep, nutrition and conversation improve after one month of living with the robot. Reduction in anxiety after one month. Physical functioning improves after one month	There isn't an objective neuropsychological and ToM assessment
[23]	Facilitating conversations between a social humanoid robot, NADINE, and cognitively impaired elderly at a nursing home. We analyzed the effectiveness of human–humanoid interactions between our robot and elderly, to promote their emotive, cognitive and social impairments	14 elderly people with cognitive impairment in a nursing home—One-to-one interactions	NADINE could talk, recognize and answer to resident's emotions. Robot may personalize arguments' core thanks the memorize information of the subjects. Residents could ask to NADINE to listen music or watching video	Pre and post assessment: Deep Neural Networks (DNNs); Observed Emotion Rating Scale (OERS); Menorah Park Engagement Scale (MPES)	An improvement of residents' wellness and cognitive skills; increased productivity by augmenting or reducing human resources	There isn't an objective neuropsychological assessment
[37]	Social robot PEPPER provides the music which supports positive self-disclosures of personal memories	7 individuals with dementia and their caregivers	Group's interaction with PEPPER, participants and their caregivers. Listening to music, changing songs and creating a personalized playlist. Stimulating the evocation of memories and their narration by increasing emotional involvement	There isn't a neuropsychological or ToM's assessment	Elicit positive responses and individuals with dementia understand everything that is said	The participants suffered from slurred speech and often PEPPER wasn't able to understand them properly; the explanations given by PEPPER were too long for them to stay focused; it was not always clear to the participants what actions they were asked to perform or not perform
[34]	Evaluation of the level of involvement of participants in the activities offered by the KABO-CHAN robot	103 participants diagnosed with moderate/severe dementia residing in elderly care facilities: age 67–108	Cognitive stimulation exercises in the form of quizzes	The cognitive level was assessed by Hong Kong Montreal Cognitive Assessment 5-minute Protocol (MoCA)	Specifically, resident-robot behavioral engagement moderately improved attitudes towards technology perceived usefulness	Clinical heterogeneity of the sample precludes generalization of the results
[25]	Exploring the use of a home-based robot JAMES, during lockdown from COVID-19 to evaluate its use in cognitive activities and loneliness reduction	4 elderly people diagnosed with MCI living in semi-autonomous housing (age 70–90) for a duration of two weeks	Subject interaction activities (robot implemented following a preliminary interview on subjects' interests)	Pre-test: 5-point questionnaire; post-test: semi-structured interview	Reduces feelings of loneliness and social isolation and is a motivator and facilitator in cognitive activities	Small number of subjects and short trial duration
[42]	Robotic architecture system with NAO to engage pairs of older adults in multimodal activities to reduce apathy	Seven pairs (14 individuals); ages ranged from 70 to 90 years. Three adults were screened as having normal cognition, 10 had mild cognitive impairment, and 1 adult self-reported a diagnosis of Alzheimer's disease	Each activity had a physical, cognitive and social components, 3 weeks for 6 sessions	MOCA scores to classify the individual as possible mild cognitive impairment or dementia (<19). Cohen-Mansfield's Observational Measurement of Engagement	Engagement measures (visual, verbal, behavioral) varied by type of activity; SAR activities had positive impact on engagement	Possible presence of apathy was not examined. The pairs remained the same throughout the three weeks and familiarity with one another may have impacted the engagement level. One participant opted out due to a physical limitation

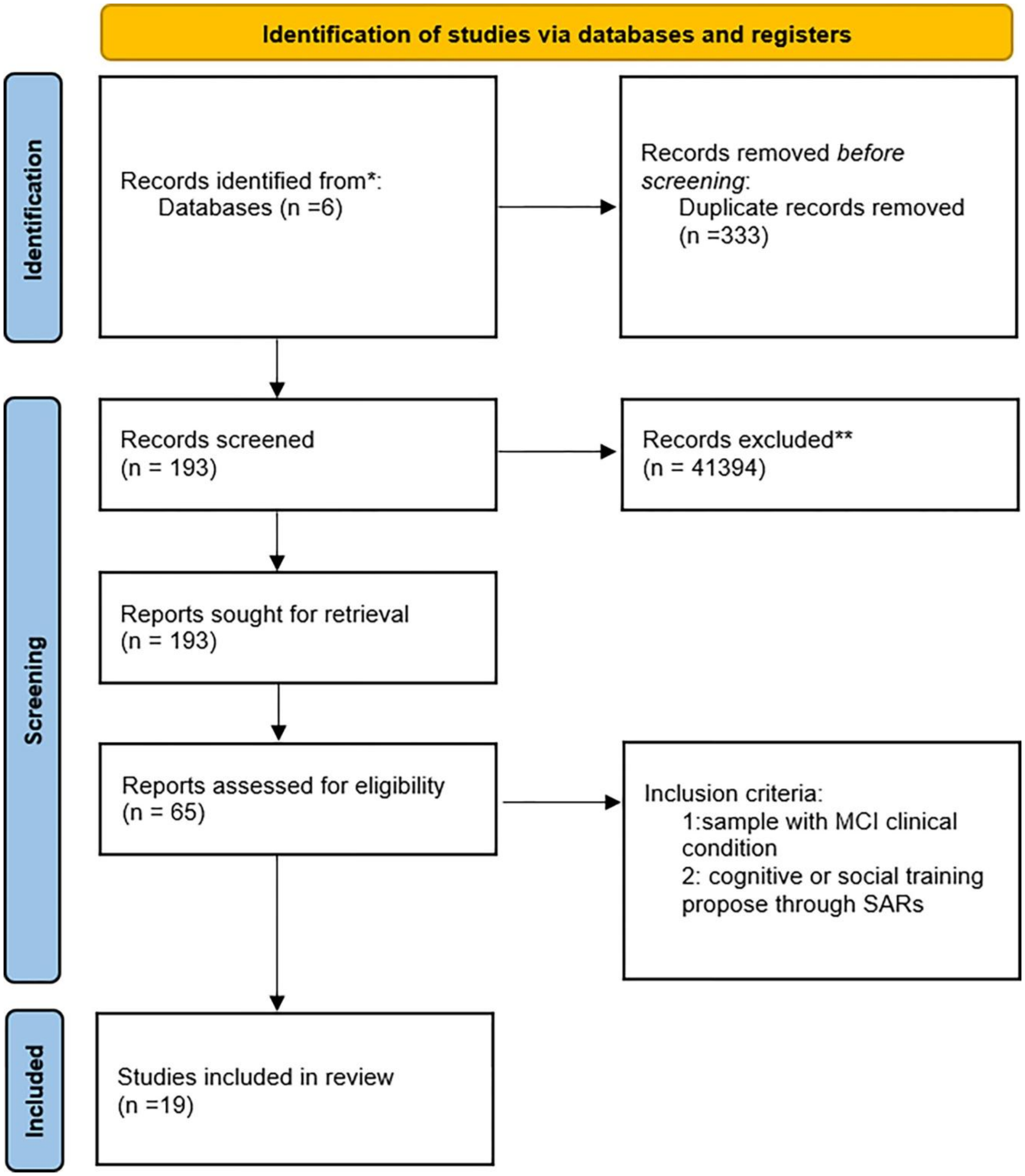

Fig 1. Research methodology for review process

3.1. Participants

A first important finding relates to the clinical pictures that compose the study samples. As a matter of fact, only seven studies involved people with a diagnosis of MCI [16,18,25,35,36,38], while the remaining twelve included mixed samples (i.e., MCI and patients with mild/moderate/severe dementia) [15,17,20,21,23,24,34,37,39–42]. This result highlights that the selected studies do not have homogeneous samples of MCI, despite the studies declared as aim the exploration of the effects of interventions with social robots in this clinical population. Underlining the lack of clarity of the studies with respect to sample recruitment, only in one of the nineteen studies reported the specific cognitive area of impairment (i.e., anamnestic MCI; [18]). Thirteen studies administered cognitive or social training to MCI without control groups [15,16,18,20,22–25,34,37,39–41] while six studies recruited control groups [17,21,35,36,38,42] that, however, they did not compared MCI patients involved in robot-based interventions with other MCI patients without robot-based interventions. This finding shows that the lack of control groups may reduce a real evaluation of the positive effects on maintaining and/or improving cognitive and social skills in MCI. Another relevant aspect is where the interventions with MCIs were conducted. Eleven studies were carried out in residences for the seniors or nursing homes [17,20–24,34,37,40–42], two studies offered a home-based protocol [25,36], and in six studies the interventions were conducted in specialized centers for cognitive disorders and dementia [15–18,35,38]. This is relevant because the outcome of an intervention may vary depending on contextual conditions, again underlining the generalization problem of these studies. Finally, the interventions were conducted in different countries: four in Italy [15,16,18,38]; three in Korea [17,35,36], two in Australia [37,41], Japan [21,22] and USA [20,39]; one in Belgium [25], China [34], Ireland [42], Netherland [37], Singapore [23] and Spain [24]. Cultural differences also could have an important influence on the clinical conditions and the practices to approach to them. This is addition to element that prove the heterogeneity of this filed of research.

3.2 Type of robots and programming

Another interesting issue that characterizes most of the studies is the heterogeneity of social robots used. Fifteen studies used humanoid robots (BOMY, JACK, JAMES, MATILDA, MERO, NADINE, NAO, PEPPER, RYAN COMPANIONBOT, SILBOT and SOPHIE)[16 18,23–25,35,35–42] and three used zoomorphic robots (AIBO and PARO) [15,20,21]. The heterogeneity of the social robots employed in the various studies does not allow generalization of the data to social robots and remains open if a specific social robot is more effective with MCI than others. One study used both the humanoid robot NAO and the zoomorphic robot PARO [24]. One study compared the effectiveness of two different types of humanoid robots (SILBOT and MERO)[35], and one study used two humanoid robots simultaneously (JACK and SOPHIE, [40]). Although these few studies used different social robots and claimed in the objectives to compare the effectiveness of these, the analyses did not report any specific results on this issue, thus leaving unanswered which robot is more effective. Regarding cognitive interventions, all the studies used anthropomorphic social robots: one the BOMY [36], one both MERO and SILBOT [35], two the NAO [16,18], one the PEPPER [38], one the RYAN COMPANIONBOT [39] and one SILBOT [17]. This result highlights the importance of anthropomorphic features of robots for interventions that focus on the residual cognitive functions of MCI. However, there is no detailed consideration with respect to which anthropomorphic features are most functional for this clinical condition. Regarding social interventions, eight studies proposed the use of anthropomorphic social robots: two the KABOCHAN [22,34], one the JAMES [25], one the MATILDA [41], one the NADINE [23], one the PEPPER [37], one the NAO [42], one both JACK and SOPHIE [40]. Four employed zoomorphic robots: one the AIBO [15], two with PARO [20,21], and one both the NAO and PARO[24]. The use of these two types of robots, anthropomorphic and zoomorphic, evidences a greater openness in interactions by MCIs toward robot design features in the emotional-relational sphere. This seems due to the caring behaviors that zoomorphic robots solicit in MCIs by supporting residual social skills. All studies used the Wizard of Oz technique, and no autonomous interaction system was developed. This underlines how, to date, it is difficult to hypothesize interventions with social robots that can be actively applied by non-technicians in MCI care settings as well as within the homes of people with this clinical condition.

3.3. Assessment

Regarding the assessment of cognitive abilities of MCI, there is a wide variability of psychometric tests in literature and there are no standardized assessment protocols. In general, MCI neuropsychological assessment aims to identify the presence of specific cognitive impairments, quantify the severity of the disorder and, with respect to interventions, verify their effectiveness [19]. Regarding Theory of Mind abilities in MCI, they are measured through different classical tasks and tests (e.g., False Belief Tasks, Strange Stories, Reading the Mind in the Eyes) [13,43]. Regarding cognitive interventions, of the seven selected studies, only two studies used pre and post-intervention neuropsychological assessment. One study used Cambridge Neuropsychological Test Automated Battery (CANTAB) [35], while the other one assessed episodic memory, short term memory and verbal fluency [18]. Of these two, only one assessed patients pre- and post-intervention with MRI

[35]. All of the remaining five studies did not adopt a post-intervention assessment. Two studies specified the neuropsychological batteries used: specifically, the Seoul Neuropsychological Screening Battery [36], and the Mini-Mental State Examination—Dementia Screening (MMSE-DS) and Consortium to Establish a Registry for Alzheimer's Disease Korean version [17]. One study adopted a pre-intervention neuropsychological complete battery and two functional scales (Activities of daily living and Instrumental activities of daily living [16]). Other two studies used clinical observations of the participants and clinical interviews with participants and caregivers. Of these two, one specified the observational protocol and clinical interviews (i.e., Saint Louis University Mental Status Examination to detect mild cognitive impairment; [39]) and the other one stated that they analyzed neurocognitive characteristics without specifying the tests, trials, and/or interviews adopted [38]. With respect to social interventions, of the twelve studies includes, only three studies conducted a pre and post-intervention neuropsychological assessment: using the Mini Mental State Examination (MMSE), Severe Mini Mental State Examination (sMMSE and Neuropsy chiatric Inventory, NPI) [24]; emotional through analysis of interactions using Deep Neural Networks (DNN) techniques and Menorah Park Engagement Scale (MPES) [23]; individual sense of well-being International Quality of life Assessment (QOL SF-8) and residual skill level Tokyo Metropolitan Institute of Gerontology Index of Competence (TMIG-IC) [22]. Other three studies did only an initial screening of cognitive competence through the use of MMSE [15] and Montreal Cognitive Assessment (MoCa [34,42]). The remaining six studies did not explicitly state the assessment procedures because the objective primarily was to study the acceptance of social robots by MCI patients. Of these six studies, three conducted only an observational assessment [20,40,41], one assessed the level of dementia through a scale [18], one proposed a pre and post intervention questionnaire and semi-structure interview [25] and, finally, one didn't declare a neuropsychological or ToM's assessment [37]. Overall, quantitative assessment protocols of both cognitive and social interventions are extremely heterogeneous, lack standardized procedures, and, in addition, only a few studies present pre- and post-intervention evaluation. From a clinical perspective, these limitations prevent a full understanding of the actual benefits of the interventions (e.g., amnestic, language). At the same time, qualitative evaluations present similar issues since neither standardized procedure are applied nor observation protocols stated.

3.4. Type of training

3.4.1 Cognitive interventions.

Cognitive interventions are non-pharmacological treatments that employ specific cognitive exercises with the aim of slowing down cognitive decline and enhancing residual abilities. Of the seven studies that declared to conduct cognitive interventions, the main objective of five studies was to evaluate the effectiveness of using social robots on maintaining and/or enhancing cognitive function [17,18,35,36,38] while two studies aimed to evaluate the acceptance of social robots with MCI [16,39]. No study has thoroughly detailed the intervention protocol implemented in the social robots. One study on acceptance proposed memory games with personalized contents (e.g., quiz, music and video) through RYAN COMPANIONBOT [39]. Although the robot was used for long-term memory exercises, the main goal was to investigate the acceptance of the robot. Regarding the cognitive training no significant results were reported, while for acceptance the results showed that users established a good relationship with the robot (i.e., accepting it as a companion) and it positively affected MCI's general mood. The other study on acceptance explored the potential of the robot to engage MCI during cognitive intervention and an evaluation of the effects on acceptability and emotional involvement in the interactions with the robot [16]. The training consisted of memory tasks (i.e., story reading, story comprehension questions, word learning, word recall, and song-singer matching) in which the NAO asked participants to respond verbally to its questions. The NAO was equipped with a system designed to analyze participants' facial expressions during the training. The results showed an increase in positive emotions toward the robot and involved it within their activities as if it were an interactive partner. Another study compared the acceptability of memory training (i.e., music quizzes in which patients have to recognize singers or vocalists) by comparing PEPPER and a tablet [38]. In both cases, users enthusiastically completed the training sessions, but no differences were found between the two modalities, robot and tablet. Although these studies claimed to target the efficacy of cognitive interventions, the protocols were constructed to primarily assess the acceptability of social robots by patients with MCI by overshadowing cognitive assessments. With respect to the studies that directly trained cognitive functions, one study compared a multi-domain cognitive training administered by a clinician and by two different social robots, SILBOT and MERO[35]. Three groups were compared: a first one that did the training with the clinician, a second one with the social robots, and a control group. The results showed compared with the control group an improvement in executive functions alone in the social robot group, while an improvement in general cognitive abilities in the group with the clinician. Although these results are interesting, the study did not report possible effects due to the two different robots. Another study proposed memory training by comparing the intervention of a clinician and the NAO [18]. In addition, treatment adherence in the robotic condition was evaluated. The results found both an improvement in various cognitive abilities (i.e., memory, attention, and verbal fluencies) and a decrease in depressive symptoms in the NAO condition. In addition, participants adhered positively to NAO treatment. Another study compared the effectiveness of multi-domain cognitive training when performed by a clinician or the SIL BOT robot [17] and its effects on depressive symptoms of MCI. The results found a significant improvement in some cognitive domains (i.e., memory and executive functions) in both the condition with the clinician and the robot, while an improvement in depressive symptoms only in the condition with the robot. Finally, another study evaluated the effects of a home based multi-domain cognitive intervention (i.e., memory, language, computation) developed with the BOMY robot [36]. The results showed an improvement in working memory in the group with the robot compared with a control group without cognitive intervention. Cognitive interventions that have pursued the goal of analyzing their effects on different cognitive domains revealed that robots positively affect at least memory and executive functions similarly to human clinicians. In protocols where different robots have been used, there are no data on possible effects due to the type of robot. Finally, improvements in mood are also noted as secondary effects of the interventions.

3.4.2 Social interventions.

Interventions aimed at improving social abilities through SARs have been implemented either through anthropomorphic robots or zoomorphic robots in sessions of interactions between single patients and social robots or between groups of patients and social robots. Studies will be presented below according to these two main vari ables: type of robot (anthropomorphic and zoomorphic) and individual or group sessions. Regarding the studies that used zoomorphic robots, one study evaluated the acceptability of pet-therapy mediated by the AIBO robot [15]. In individual sessions, patients interacted with the AIBO and were asked to give their opinion about their interaction with it. Analysis of the interviews revealed a friendly perception of the AIBO by the MCI. Another study compared the reduction in feelings of loneliness in one-to-one sessions at a specialized care center for the elders [21] by comparing PARO with a stuffed animal (i.e., Lion). Participants were free to interact in their own room with either PARO or Lion. Qualitative analysis of the interactions showed a greater increase in positive emotional expressions and verbal interactions and a greater reduction in feelings of loneliness in the group with the PARO than in the group with the Lion. Another study with PARO developed a multisensory therapy (physical, visual and verbal) with patients with different levels of dementia including MCI within residences for the elders [20]. Participants interacted in small groups in which PARO was present and the therapist mediated interactions between patients and between patients and PARO. Results showed an increase in verbal communication with PARO and interaction between participants. The use of zoomorphic robots was employed with heterogeneous samples including MCI patients with an emphasis on the decreased of sense of loneliness and increased communicative initiatives. Regarding studies that have used anthropomorphic robots, one study used KABOCHAN, a robot with child like features, in which participants were free–after a training session–to interact with the robot in individual sessions [34]. Participants' caring behaviors toward the robot were observed. Qualitative analyses found caring behaviors toward the robot and good user acceptability of the robot. Another study that used the KABOCHAN again in individual sessions with MCI in dementia care residences found improved sleep, feeding and language production, and reduced anxiety [22]. Another study that employed the NADINE robot in individual sessions where participants could ask it questions and ask to watch videos or play music assessed psychological well-being and its effects on impaired cognitive and social domains [23]. Results showed improvement in psychological well-being and some unspecified cognitive abilities. Another study explored in individual sessions in the apartments of an elderly residence during lockdown the effects of the JAMES robot [25] on feelings of loneliness. The results showed a reduction in feelings of loneliness and social isolation. Overall, these studies aimed to assess the acceptability of robots by MCI patients in care settings, also showing improvements on feelings of loneliness and general psychological well-being as secondary outcomes. Regarding interventions that offered group activities, one study used NAO in multimodal activities (physical, cognitive and social) to decrease patients' feelings of apathy in pairwise activities in which the therapist was also present [42]. Results showed that participants felt more engaged (i.e., visual, verbal, and behavioral engagement) in activities where the NAO was activated compared with parts of sessions where only the therapist was present. One study used SOPHIE and JACK to improve the quality of life (i.e., reduced feelings of loneliness and psycho logical well-being) of residents of a dementia nursing home [40]. The robots offered musical quizzes and games (i.e., Bingo) in groups. Qualitative analyses of the sessions found increased involvement in the games proposed by the robots with a positive attitude and improved social skills defined as interactions among residents and between residents and therapists. Another study used MATILDA robot for games (e.g., Bingo), music quizzes, and orientation activities in groups, showing an increase in social involvement among individuals compared to the baseline condition in which the robot was not present [41]. One study using PEPPER involved MCI in small groups where caregivers and the therapist were present [37]. In these sessions, the robot played some of the participant's favorite songs and asked them to recognize the song and evoke memories related to this song. The results showed increased positive emotions in patient-care giver interactions and elicited autobiographical memory. One study compared the effect that interactions with different robots (NAO and PARO) and a dog had on psychiatric symptoms [24]. Patients performed individual therapeutic activities (e.g., identifying numbers, words and colors using flash cards), showing an improvement in apathy in the group with NAO and a reduction in disturbing behaviors at night in the group with PARO. The use of the robots in the patient groups mainly indicated an increase in interactions between resident of the care homes and between patients and therapists. No direct results on the effect from the point of view of social cognition were considered as an effect of the interventions.

4. Discussion

MCI is a borderline clinical condition between healthy aging and the development of more severe neurodegenerative conditions, such as Alzheimer Disease. To date, only non pharmacological interventions can slow down cognitive decline and support residual social skills. Current technological development enabled the possibility of implement classical paper-and pencil interventions through therapist via anthropomorphic and zoomorphic social robots. Internationally, the recommendation to use social robots is related to the opportunity to maximize the positive effects of cognitive and social interventions for MCI because they could always be available to people and execute protocols systematically in different settings. How ever, today's scientific picture on this topic is not entirely clear, and it was therefore necessary to systematically analyze the studies conducted so far through social robots with MCI to provide suggestions for future studies from both a robotic and clinical point of view. The present systematic review focused on two domains that are particularly relevant to MCI functioning and are progressively impaired: cognitive and social domains. The studies identified for this review were mainly aimed at analyzing whether and how much training employing social robots could improve cognitive and social skills in MCI.

The discussion will be organized by indicating on the one hand the state of the art on the use of robots and the types of interactions implemented for MCI interventions and on the other hand identifying the clinical limitations.

4.1 Social robots in cognitive and social interventions

Regarding cognitive interventions, the robot was used only in individual sessions with multidomain cognitive exercises, and this is in line with classic intervention protocols in which activities are proposed individually and, given the complexity of the clinical picture, focus on multiple cognitive dimensions. Conversely, in social interventions, robots were used in group sessions whose main goal was to solicit the interest of participants and be mediator/animator of social exchanges among them. In general, in cognitive interventions the robot is used as a device to administer tasks, proposing activities that the participant needs to complete. These tasks by stimulating specific cognitive abilities enable their enhancement. Studies have mainly focused on two cognitive domains: memory and executive functions (i.e., working memory). With respect to memory, tasks concerned music quizzes (i.e., recognizing the title of a song and associating the song with the singer) and quizzes on selected texts (e.g., answering questions about them and remembering key words), while executive functions were not directly addressed by cognitive trainings but were considered indirectly in social trainings. Specifically, in social interventions, the game of bingo was implemented as it allows training working memory by remembering the numbers of the draws. With respect to social interventions, these were implemented with both anthropomorphic and zoomorphic robots, while cognitive interventions only anthropomorphic robots were adopted. Zoomorphic robots due to their animal features were not considered tools to support cognitive functions probably because if they spoke, they would lose their resemblance to the animal. This limitation from the cognitive side, on the other hand, represents a strength for social interventions because their characteristics solicit care taking of the robot by participants supporting relational components. More specifically, zoomorphic robots are particularly relevant in more severe dementia conditions while patients with MCIs whohave different residual abilities, the use of anthropomorphic robots may be equally effective. This bias could be due to advanced cognitive impairment that reduces initiative in interactions and, therefore, it is easier to have an interaction on the sensory level occurring with zoomorphic robots that can be picked up and stroked. Although most of the studies claimed to examine the effects of interventions with social robots, they actually examined the acceptability of the robots by the participants. Although the studies presented patients with different levels of cognitive decline, in all studies there were no episodes of rejection toward social robots regardless of the type of robot used. Even in cases characterized by a more severe clinical picture, both anthropomorphic and zoomorphic robots were easily integrated into daily and rehabilitative activities and generated curiosity fostering greater involvement in the therapeutic sessions. Despite these very positive results related to the acceptability of robots by the elderly, it is not possible to generalize the results related to cognitive and social interventions.

4.2 Clinical issues

From a clinical perspective, the studies report several methodological problems, the main ones are: clinical heterogeneity of samples; absence of standardized, pre/post-intervention and brain assessment protocols through functional techniques; and absence of control samples. With respect to clinical samples, studies are mostly presented with mixed patient groups (MCI andmild/moderate/severe dementia), and those with only patients with MCI do not report specifics regarding the most impaired areas, except for one study with amnestic patients (aMCI). Prospectively, studies should build their samples by considering only MCI clinical populations by specifying the clinical subpopulation (i.e., amnestic, non-amnestic, and multidomain). This would allow the creation of customized interventions that could have more precise effects based on the specific needs of different clinical subpopulations. In fact, the studies analyzed in this review indiscriminately used cognitive exercises on memory without considering that MCI patients might have memory skills that are still functioning, but instead need specific exercises, for example, on executive functions. The problems in detecting clinical subpopulations of MCI also relates to the heterogeneity of the assessments used and the absence of functional brain assessments. Most importantly, not all studies report the assessment procedures adopted, and those studies that have reported them do not present structured protocols integrated with functional brain techniques. Future studies should detail more precisely the assessment tools adopted and consider assessments at different levels, including neurofunctional ones. The absence of control groups is an important methodological limitation because it results in a reduction in the generalizability of the positive results of the cognitive and social interventions. Future studies should consider including homogeneous MCI samples as control groups or compare different clinical populations grouped homogeneously with respect to the characteristics of the MCI sample involved (e.g., mild dementias with specific memory issues).

4.3 Robotics issues

Regarding the robotic area, there are two critical aspects to highlight: the variety of robots used and the use of the Wizard of Oz technique for all interventions. In recent years, it has emerged clearly in the literature on human-robot interaction how the type of robot strongly affects the perception and interactions with humans [43,44]. A few studies have tried to address this issue by comparing different robots (i.e., different anthropomorphic robots or an anthropomorphic robot vs. a zoomorphic robot), but the results do not present clear results because specific analyses were not carried out and, therefore, it remains open whether some social robots may be more effective than others in performing cognitive and social interventions. Another issue is the use of Wizard-of-Oz technique in interactions, highlighting a reduction in the scalability of these interventions. As a matter of fact, it would be difficult in specialized care institutions and people’s homes to use robots if the programs must necessarily be run by technicians.

5. Conclusion

This systematic literature review following the PRISMA guidelines examined cognitive and social interventions through social robots with MCI patients. The overall goal was to explore the state of the art and to identify suggestions for future research in both robotics and clinical fields. In general, the studies showed that both anthropomorphic and zoomorphic social robots are accepted by MCI patients. On the cognitive side, although the results showed that social robots can support some cognitive functions (e.g., memory and executive functions), the intervention protocols are not yet clinically standardized and mainly represent feasibility studies on the implementation of cognitive stimulation exercises with social robots. On the social side, studies have used robots mainly as mediators of the relationship between patients with MCI and facilitators of group sessions. However, there is no evidence of the effectiveness of robots on the basic social-cognitive skills (e.g., ToM) of patients with MCI, which the clinical literature has revealed to be susceptible to decay. With respect to the types of social robots used, we are still on a universalistic side, where we refer to robots in the singular without con sidering that different social robots have different impacts on how users perceived them. This is even more important in care settings where different devices can affect the effectiveness of interventions. Furthermore, the preference for the Wizard-of-Oz technique in interventions demonstrates the need to develop social robots with semi-autonomous interactive sequences. This would have a positive effect on the scalability of interventions in settings where technicians might not be present (e.g., in the homes of patients with MCI). On the clinical side, there is a need to promote more accurate patient assessment protocols so that the effects of interventions in different clinical subpopulations with MCI can be more accurately identified. In addition, it would be highly desirable to identify pre- and post-intervention assessment protocols that can precisely identify the effects of interventions on the most impaired cognitive and social domains. Standardized assessment protocols would also allow the identification of homogenous samples of MCI patients and their control groups, which would be essential for generalizing the results of interventions. Prospectively, socio-cognitive and neurofunctional assessments (e.g., MRI) should be considered in addition to cognitive assessments. In conclusion, this literature review systematized the state of the art of Social Assistive Robotics in patients with MCI from both robotic and clinical perspectives, highlighting promising results of social robots in cognitive and social interventions while critically reporting insights for future research by recommending greater synergy between clinicians and robotic researchers.

Supporting information

S1 Fig. This figure shows the percentage of studies in terms of risk of bias (Low risk in green; Some concerns in yellow; High risk in red) subdivided by RoB 2 scale macro-cate gory. (DOCX)

S2 Fig. This figure illustrates the ratings of each macro category of RoB 2 and the final computation of risk of bias ("Overall"). The rating levels are divided into: Low risk (green); Someconcern (yellow); High risk (red). (DOCX)

S3 Fig. This figure illustrates the ratings of each study subdivided for every item of the GRACE scale. The rating levels are divided into: Yes + (green); Not applicable (yellow); No, or not enough information in article (red). (DOCX)

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Chapter 3

“Tom and Pepper Lab”. Robotics for cognitive stimulation and social skills: A preliminary study

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Cognitive and socio-cognitive training | Social robots | Cognitive decline | Theory of Mind (ToM) | Social competence | Elderly intevention.

Abstract

Dementia affects over 55 million people globally, with early cognitive decline, such as Mild Cognitive Impairment (MCI), often preceding neurodegenerative diseases. This decline impairs memory, attention, and Theory of Mind (ToM). Early intervention is crucial, and assistive robotics has emerged as a promising non- pharmacological approach in this regard. This preliminary study evaluated the acceptability of the social robot Pepper and tested the structured cognitive and socio-cognitive training delivered by the robot. Nine participants, aged 68–93, ranging from mild to moderate dementia, were engaged in a four-week training program. A qualitative analysis of the interviews and video recordings of the training sessions was conducted. Results showed high participant engagement, increased autonomy and focus, and positive emotional responses. These data are promising in demonstrating structured training implemented in social robots has the potential to positively impact cognitive function and emotional well-being through structured training.

General introduction

Dementia currently affects over 55 million people globally, with most cases occurring in low- and middle-income countries. Approximately 10 million new cases are reported annually, making dementia the seventh leading cause of mortality and a major source of disability among the elderly (World Health Organization, 2023). Early forms of cognitive decline, such as Mild Cognitive Impairment (MCI), often precede Alzheimer's and Parkinson's diseases, impacting memory, attention, language, and executive function (American Psychiatric Association, 2013; Castelli et al., 2016; Saredakis et al., 2019). MCI also affects Theory of Mind (ToM), i.e., the ability to understand one's own and others' mental states (Premack, Woodruff, 1978), which may worsen with age and cognitive decline (Knopman et al., 2014; Moreau et al., 2015; Rossetto et al., 2020; Winblad et al., 2004). Early intervention in neurodegenerative conditions is critical to preserving cognitive function, and assistive robotic interventions have emerged as a promising non-pharmacological approach to cognitive and social training in recent years (Heitmueller et al., 2014; Knopman et al., 2014; Marchetti et al., 2018, 2022; Wenisch et al., 2007). However, despite scientific interest, interventions remain inconsistent and lack structured protocols (Figliano et al., 2023)

1.1. Preliminary study aims

The present study was conducted as part of a research project that will explore the feasibility of cognitive and socio-cognitive training programs mediated by the social robot Pepper. The main objective is to address the current lack of systematic approaches in training programs for elderly individuals using social robots (Figliano et al., 2023). To this end, this preliminary study aims to evaluate the acceptability of the social robot Pepper and to test the feasibility of the training. Additionally, the impact of the robot on the therapeutic relationship was observed, thus paving the way for a more comprehensive study aimed at optimizing this innovative approach.

2. Methods

2.1. Participants

Nine participants (Table 1), aged between 68 and 93 years (8 women; mean age = 84.55, SD = 8.15), were recruited at the Day Care Centre De Rodolfi, in Vigevano, Italy. These individuals presented various cognitive profiles, ranging from mild to moderate dementia. Inclusion criteria included being 65 years or older, having a diagnosis or probable diagnosis of dementia (documented in medical records), and possessing the capacity for verbal communication and comprehension. Exclusion criteria ruled out those diagnosed with Alzheimer's disease and individuals with other medical or neurological comorbidities. One participant was excluded for not meeting these criteria. 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 received on 08/05/2024, reference number 89/24). Written consent was obtained from the participants or from their relatives in cases where the patients scored below 23 on the Mini-Mental State Examination.

2.2. Measures

Semi-structured interviews explored participants' perceptions, concerns, motivations, and expectations regarding interactions with Pepper. These face-to-face interviews took place in a private room at the Daycare Center, and strategies, such as brief and direct questions, were used to accommodate patients' cognitive impairment (Lloyd, Gatherer, and Kalsy, 2006). The interviews were audio recorded. Neuropsychological assessments included Addenbrooke's Cognitive Examination - Revised (ACE-R; Pigliautile et al., 2012), which evaluated attention, memory, language, and visuospatial skills, and Mini-Mental State Examination (MMSE; Magni et al., 1996), whose scores were collected by the geriatrician of the Daycare Center between April and June 2024.

2.3. Procedure of training program

The training program took place twice a week for four weeks in July 2024, alternating between cognitive and socio-cognitive sessions. Each session, lasting 20–25 min, was carefully structured, with Pepper providing verbal instructions, feedback, and visual support through its tablet. Two researchers supervised the sessions, which were audio- and video-recorded. The following training aims to systematize interaction between humans and robots through rigorously designed sessions that present content validated in the literature (Cattelani and Corsini, 2012; D'Arma et al., 2023; Irving et al., 1970; Wilson, 1987; Wilson et al., 2009). At the same time, the sessions are carefully structured to ensure that interactions between humans and the robot are both plausible and engaging. The cognitive training focused on enhancing memory and attentional-executive functions through tasks, such as text and image recall (Cattelani and Corsini, 2012; Irving et al., 1970; Wilson, 1987; Wilson et al., 2009). The socio-cognitive training, inspired by a previous study (D'Arma et al., 2023), focused on ToM, emotional intelligence, and social competence. Pepper served as the primary storyteller, guiding participants through the narratives. The robot took on the role of learner, prompting participants to offer assistance. All questions and feedback were carefully designed to encourage reflection and active engagement. By posing targeted questions and providing constructive feedback, the robot facilitated a dynamic and reciprocal interaction that allowed participants to see themselves as knowledge holders, thereby enhancing their motivation. The researcher assumed the role of facilitator, providing supplementary guidance in the event of incomplete comprehension of instructions or difficulties (Fig. 1). All scenarios were designed and implemented through 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 facilitates the programming of Pepper, allowing customized interactions, dynamic dialogues, and real-time data collection on participants' performance.

Table 1.

Participants characteristics

	Mean (n=9)
Age *(Mean, SD)*	*84.55 (8.15)*
Cognitive function	*Mean (range)*
MMSE score	17.63 (13-27.2)
ACE-R Tot.	49.75 (21-77)
ACE-R Orientation	10.5 (3-18)
ACE-R Memory	7.75 (0-20)
ACE-R Fluency	3.62 (0-6)
ACE-R Language	18.5 (11-22)
ACE-R Visuo-spatial	9.37 (5-13)

Fig. 1. Participant interacting with Pepper robot.

2.4. Data analysis

Two experimenters conducted a qualitative analysis of the interviews and videos using a priori coding scheme (Gibbs, 2014) and followed the six-step inductive thematic analysis of Braun and Clarke (2006). This analysis involved viewing and transcribing the audio content of the interviews and training session videos. Initial codes were then generated for (1) how the participants interacted with the robot (e.g., touching it, looking at its face or the tablet, giving it compliments or criticism, etc.), (2) the emotions and the experiences elicited during the interaction, and (3) the frequency and nature of the participants' requests for the ex- perimenter's intervention. The codes were then grouped into broader conceptual themes (Braun and Clarke, 2006).

3. Results

3.1. Overall findings

Three main themes (**Table 2**) emerged according to the analysis of participants' interviews and videos: (1) participants' behaviors; (2) participants' experiences; and (3) triadic relationship (participant- researcher- robot).

Table 2

Main themes and codes that emerged from the transcripts of the in- terviews and the videos of the training sessions.

Themes	Codes
PARTICIPANTS' BEHAVIORS TOWARD PEPPER	Physical appearance; Mental trait; Touch the robot; Positive attitudes.
PARTICIPANTS' EXPERIENCE	Positive emotions; Reminiscence; Focus.
TRIADIC RELATIONSHIP	Frequency; Type of interventions.

3.2. Theme 1 – participants' behaviors toward Pepper

The human-like features of Pepper, including its eyes and gestures, led participants to perceive Pepper as a relational entity, attributing intelligence and emotions to it. For example, some described Pepper as "very intelligent" and "handsome," while others projected human-like qualities and biological needs onto the robot, with one participant suggesting that the robot "ate" while it was charging. Remarks such as "This robot thinks of too many things" and "What a brain!" suggested that the robot was viewed as having its own mind. This perception fostered positive engagement and comfort during interactions, with one participant stating, "Look how he looks at me… he almost seems to understand me!"

Although physical contact with Pepper was rare, with only one participant patting it on its face, patients consistently greeted the robot upon entering the room and thanked it at the end of each session, highlighting the emotional connection they felt. See **Table 3** for more examples.

3.3. Theme 2 - participants' experiences

The emotions most often elicited by Pepper were joy and surprise, especially when the robot provided positive feedback or addressed participants by name. This was evident during interactions with Pepper where participants frequently exhibited laughter and smiles. Pepper's non-judgmental feedback created a relaxed atmosphere where patients felt comfortable making mistakes. See **Table 4** for more examples. This interactive, personalized approach boosted participants' confidence, with many expressing satisfaction and happiness after sessions. In one notable case, a participant was emotionally moved, suggesting that Pepper's meaningful interactions sometimes evoke deeper emotional responses beyond joy and surprise.

As reported in **Table 5**, Pepper evoked memories and triggered reminiscences in the participants, as seen when they shared personal stories during interactions with the robot. These interactions suggest that Pepper can encourage the recall of past events, promoting a sense of connection and nostalgia. However, the involvement of a therapist is necessary to facilitate and monitor this process.

The structured training helped to focus and attract attention, as evidenced by the case of a patient who often told stories about her son who worked in a local hospital. In human-human interactions, keeping her concentration was challenging as she often wandered off into her narratives. However, during the sessions with the robot, whenever the patient began to lose focus, Pepper would seamlessly continue the training, effectively redirecting her attention back to the task. The interactive nature of the proposed training provided a structured environment that encouraged the patient to remain focused, demonstrating Pepper's effectiveness in supporting engagement.

3.4.Theme 3 – the triadic relationship between participant, researcher, and Pepper robot

The structured protocol facilitated a clear triadic relationship between the patient, the researcher, and Pepper. The robot acted as a mediator, guiding patients through tasks and exercises while the researcher provided support as needed. In each session, participants answered independently, and Pepper provided immediate feedback, offering encouragement for a correct response and repeating the question after an incorrect one. In response to an interview question, all participants indicated that, if necessary, they would turn to the researcher—not the robot—for assistance. In line with this, when patients struggled after a second attempt, Pepper prompted the researcher to intervene, ensuring a balance between patient autonomy and guided support. Over time, participants showed increased attention to Pepper, smiling, nodding, and looking at the robot's face. The researcher's main role was to paraphrase questions and explain how to interact with the tablet while also becoming more independent in using the tablet and engaging with the exercises.

Table 3

Participants' beliefs about the Pepper robot as revealed by the interviews and training sessions.

I must thank you [Pepper] because you are good! Very pretty, good, and intelligent. (OBBS03G5L – MMSE 13)
Are you putting him in charge? Ah, you see, he must eat too… (XCC56BTYJ – MMSE 25)
Is there a tape inside to make him talk? (WKH6USUAH – MMSE24)
It was exciting to talk to him. Look how he looks at me… he almost seems to understand me! (ZDDRWLAUI - MMSE 15)
This robot thinks of too many things (UZZHCP8HF – MMSE 17)

Table 4

Emotions experienced by participants when interacting with Pepper.

I tried to make him happy, as I am happy! (OBBS03G5L – MMSE 13)
How good! I was amazed by the talking robot. I thought I had done everything wrong, but instead… how cool we are! (377UYUL5E - MMSE 13)
Alright I'm happy, I thank you for keeping me company (UZZHCP8HF – MMSE 17)

Table 5

Participants' memories triggered by Pepper

Yes, even me, when the children were not at home, I would tidy up and then they would say, 'Mummy, where did you put my toy? or my book…'. And I said, 'the toy is where all the toys are'. (ZDDRWLAUI – MMSE 15)
Something like this happened to me with my nephew. I threw the toy soldiers out and he looked for them. He said, 'where are the toy soldiers, grandma?' but I threw them away because they bothered him. But later he looked for them. (GSSWCO303 – MMSE 15)
When we went to the sea, we didn't take our dinghies. We didn't have them. We brought food and toys for the children. (1LL4RY8TC – MMSE 17)

4. Discussion

The interviews and video analysis revealed three main themes that are named as (1) participants' behaviors toward Pepper; (2) participants' experiences; and (3) triadic relationship. The first theme includes behaviors such as touch, attributing mental traits, and positive and negative verbal responses. The second category of codes was used to categorize the emotions and experiences that the participants had during their interactions with the robots. The final category documented the frequency and nature of the participants' requests for the experimenter's intervention. In line with previous literature, Pepper was well accepted by participants (Manca et al., 2021). Pepper's anthropomorphic features led participants to attribute human-like qualities to it, fostering emotional engagement, laughter, and smiles. One possible reason for mood improvement appeared to bring back people's memories of the time they spent with their familiar care. Other studies have indicated that the use of robots has the potential to evoke previous memories and have discussed the benefits of reminiscence (Birks et al., 2016; Moyle, et al., 2016; 2017). The robot's structured feedback system helped maintain focus, redirect attention, and create a supportive environment. Its continuous flow of interaction and verbal prompts enabled participants to redirect their attention back to the task. Throughout the sessions, participants became more autonomous in using the tablet to respond to questions. Initially, the researcher's mediation was essential to paraphrase questions and provide directions, but over time, participants became more autonomous. Pepper's feedback system – where it repeated questions after wrong answers and asked the therapist to intervene after two mistakes – helped to scaffold learning and create a safe environment for trial and error. By the later sessions, patients showed increased confidence, interacting more directly with Pepper. This improvement indicates that Pepper's consistent feedback and patient-centered interaction fostered a gradual increase in independence. Our data, in line with the literature (Talassi et al., 2007), suggest that the use of structured training is more effective in supporting cognitive and socio-cognitive function among elderly participants. As highlighted in the systematic review by Figliano et al. (2023), existing interventions aimed at slowing cognitive decline in elderly patients are often unstructured, lacking the consistency and precision necessary for long-term effectiveness. To address these limitations, we developed a structured intervention program that includes validated training protocols, measurable outcomes, personalized strategies, and systematic feedback. This approach proved beneficial in enhancing engagement and adherence, with the broader aim of slowing cognitive and socio-cognitive decline in aging individuals, which will be the subject of a future study.

5. Conclusion and limitations

Overall, the present study suggested that the participants accepted Pepper well, and the structured training helped to maintain their attention, improve their autonomy, and create a positive and emotion ally supportive environment. Positive feedback from Pepper worked well, especially when tailored to the individual (e.g., mentioning the name of the participant). This kind of feedback was identified as a key factor influencing interaction engagement. The triadic relationship between the patient, researcher, and Pepper proved to be essential in balancing guidance and independence, potentially reducing the therapist burden while enhancing the therapeutic relationship. The Pepper structured feedback system and patient-centered interaction show promise in contributing to both socio-cognitive stimulation and emotional well-being. Although this preliminary study shows promising results, some limitations must be acknowledged. The study was conducted with a relatively small and heterogeneous sample, limiting the generalizability of the results. Indeed, the current findings were collected from a group of individuals with diverse cognitive profiles, ranging from mild to moderate dementia, introducing variability that may affect the consistency of the results. A larger and more homogeneous sample would enable more representative conclusions about the target populations. Despite this, the eight participants provided relevant data to the study aim, that is, the fine-tuning of the protocol and the need for further refinement of interactions with Pepper to better accommodate individual needs and cognitive capacities. Furthermore, the training program was relatively short, which limits the ability to fully evaluate the long-term effects of using structured training programs. Extending the duration of these interventions would provide a more comprehensive understanding of how repeated and prolonged exposure to training sessions with Pepper could affect cognitive and socio-cognitive outcomes over time. To achieve this objective, in addition to quantitative measures, such as standardized neuropsychological tests and socio-cognitive tasks, are required. This approach will allow to demonstrate in the future the effectiveness (or lack of it) of the structured training program in improving cognitive and socio-cognitive functions, including memory, executive function and mentalization ability. This prospectively could enhance the reliability of the study.

It can thus be concluded that Pepper and the interventions it delivers were positively received by participants, who showed positive emotions and successful socio-relational involvement. However, the efficacy of these training programs in enhancing or maintaining the cognitive and socio-cognitive functions of the elderly experiencing a decline in these domains remains to be investigated in more depth.

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Declaration of Competing Interest

The authors declared that there is no conflict of interest.

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Chapter 4

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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Abstract

This study evaluated the efficacy of a 12-week Socially Assistive Robot (SAR) training for socio-cognitive and cognitive functions in 11 individuals with Parkinson's disease (PD) and 9 healthy older adult controls. Both groups underwent the same intervention with the robot Pepper. Pre- and post-assessments were analyzed using mixed-model 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 $p<.05$). Crucially, no significant Time*X*Group interactions were found, indicating that both groups improved at a parallel rate. These findings suggest that a SAR-based intervention is feasible and effective. The parallel improvement is the study's central finding, demonstrating that individuals with early-stage PD retain cognitive and social plasticity comparable to that of their healthy peers. This pattern also suggests that SAR-based interventions may be beneficial not only for individuals with mild cognitive impairment but also for older adults experiencing subtle, age-related cognitive changes. This finding highlights 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), is 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, inevitably compromises social competence. Specifically, a failure in social cognition often manifests as a deterioration of 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 & 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 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 disease (Sugiyama & 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 enhances 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: none 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, there is an occurrence of early forms of cognitive decline, including Mild Cognitive Impairment (MCI)(Baiano et al., 2020; APA, 2013). MCI affects a wide range of domains such as executive functions, memory, attention, and visuospatial abilities (Goldman & Sieg, 2020). Furthermore, social cognition appears to be impaired in this population, inevitably 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 all reasons above, PD population in the early stages of the disease represents 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. 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 work is an experimental study building 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 for the stimulation of socio-cognitive and cognitive abilities in older adults with PD, using a healthy older adult sample as an active comparison group. We hypothesized a “catch-up effect,” predicting that the PD group would show a greater magnitude of improvement from a lower baseline compared to controls (Luu et al., 2011). This hypothesis was tested by examining the significance of the Time*X*Group interaction in our statistical analyses.

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

2. Methods

2.1 Participants

The final sample consisted of 20 participants, divided into two groups. The experimental group included 11 individuals with a clinical diagnosis of Parkinson's disease (PD group: mean age = 70.3 years, *SD* = 6.13; 30% women). The control group was composed of 9 healthy older adults (Control group: mean age = 60.11 years, *SD* = 5.88; all women). PD participants report 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.

Participants were recruited from an initial pool of 24 individuals. Inclusion criteria for the PD group required a formal clinical diagnosis of the 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.

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).

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 Intervention

The training program, conducted between January 2025 and April 2025, consisted of twelve individual weekly sessions, each lasting approximately 20 minutes. The program comprised six socio-cognitive training sessions alternated with six cognitive training sessions. The socio-cognitive sessions featured complex stories with multiple-choice or open-ended questions to stimulate empathy, ToM ability, and perspective-taking, based on a validated protocol by d'Arma et al., 2023. The cognitive sessions targeted memory, attention, and language, drawing upon validated training protocols (Cattelani & Corsini, 2012; Wilson, 2002)

Each session began with a familiarization phase, during which Pepper greeted the participant and introduced the activity, seeking to establish a collaborative and engaging work environment. The main part of the session consisted of a story, based on ToM tasks (with the aim of enhancing social competence abilities) or on a narrative text (when the session was focused on stimulating cognitive abilities). Pepper proceeded to narrate the story, while story's images were displayed on its tablet. Participants were then asked a series of multiple-choice questions assessing their understanding of characters' beliefs, intentions, and emotions, or to stimulate the reenactment of events and characters' details. For each response, Pepper provided immediate feedback, reinforcing correct answers or offering corrective prompts in case of errors.

The interaction was organized in a triadic format (robot-therapist-participant; Figure 1): 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 they were invited 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 intervention standardization.

Figure 1. The triadic approach: participant's interaction with Pepper robot is facilitated by the experimenter.

2.3 Measures

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

Cognitive measures:

- Mini-Mental State Examination (MMSE) for general cognitive screening (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).

Socio-cognitive measures:

- *False-Belief Tasks*, including the *Unexpected Transfer task*, the *Look Prediction task*, and the *Say Prediction task (Liverta Sempio, 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, 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 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.

The effects of the intervention were evaluated using mixed-model 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.

Given the quasi-experimental design, which includes an active control group rather than a no-treatment group, the analytical strategy was focused not only on whether the training induced improvements, but more importantly on whether it produced *differential* improvements. A simple main effect of *Time*, indicating that both groups improved, would be insufficient to claim a specific efficacy of the training for the clinical population.

Our primary hypothesis, therefore, was centered on a potential “catch-up effect.” We postulated that the PD group, starting from a lower performance baseline on socio-cognitive measures, would exhibit a greater magnitude of improvement compared to the healthy controls. Such a finding would suggest that the intervention is particularly effective for individuals with initial deficits, allowing them to partially close the performance gap. Statistically, this hypothesis is tested by the *Time* X *Group* interaction in the mixed-model ANOVA. 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

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.

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 for 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 1 for means and standard deviations).

Table 1 - Means and standard deviations of cognitive measures at baseline (T0) for the Parkinson’s disease (PD) and Control groups.

	Clinical condition	*Mean*	*Std. Deviation*
MMSE T0	Control	26.90	1.59
	PD	26.25	2.88
FAB T0	Control	14.39	2.38
	PD	13.74	1.77
TMT-A T0	Control	41.33	10.51
	PD	45.70	17.31
Attentional Matrices Test T0	Control	38.06	6.68
	PD	34.26	6.32
Fluences Phonemic T0	Control	26.55	7.86
	PD	33.40	12.47
Fluences Semantic T0	Control	48.02	6.76
	PD	42.98	5.93

DIGIT-SpanT0	Control	5.60	1.11
	PD	6.01	1.198
Immediate recall T0	Control	5.72	2.08
	PD	4.0	2.32

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, confirming a socio-cognitive impairment at the initial stage (see Table 2 for means and standard deviations).

*Table 2- Means and standard deviations of socio-cognitive measures at baseline (T0) for the Parkinson's disease (PD) and Control groups. * significance level at p<.05.*

	Clinical condition	*Mean*	*Std. Deviation*
TOM tot T0	Control	4.11*	.78
	PD	2.90*	.99
SS T0	Control	5.67	1.22
	PD	5.30	2.11
ET T0	Control	11.67	2.87
	PD	11.40	2.46

TRAINING PROGRAM OUTCOMES. The effects of the intervention were analyzed using mixed-model repeated-measures ANOVAs. No significant Time*X*Group interactions were found for any measure (all $p>.05$), indicating that both groups improved in parallel. Therefore, we proceeded to analyze the main effects of Time.

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(1,17)=20.99, $p<.05$, partial-η2=.55, δ=.99, and executive functioning (FAB), F(1,17)=25.93, $p=.004$, partial-η2=.40, δ=.89. Verbal memory also showed a main effect of *Time* F(1,17)=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 3.

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 Figure 2 (PD group) and Figure 3 (Control group).

Table 3 – 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)*

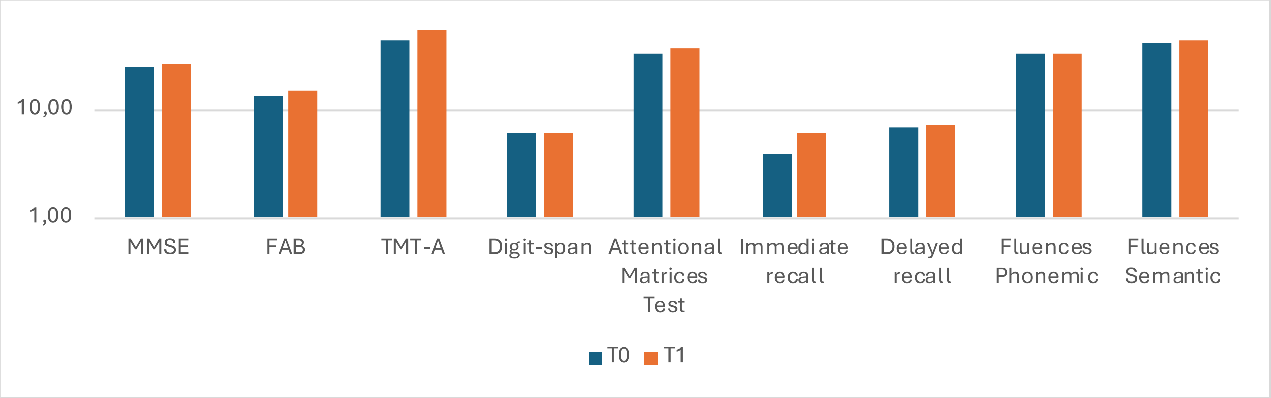

Figure 2 - Cognitive performance of the Parkinson's disease (PD) group before (T0) and after (T1) the training. Asterisks denote significant pre–post differences (p<.05)

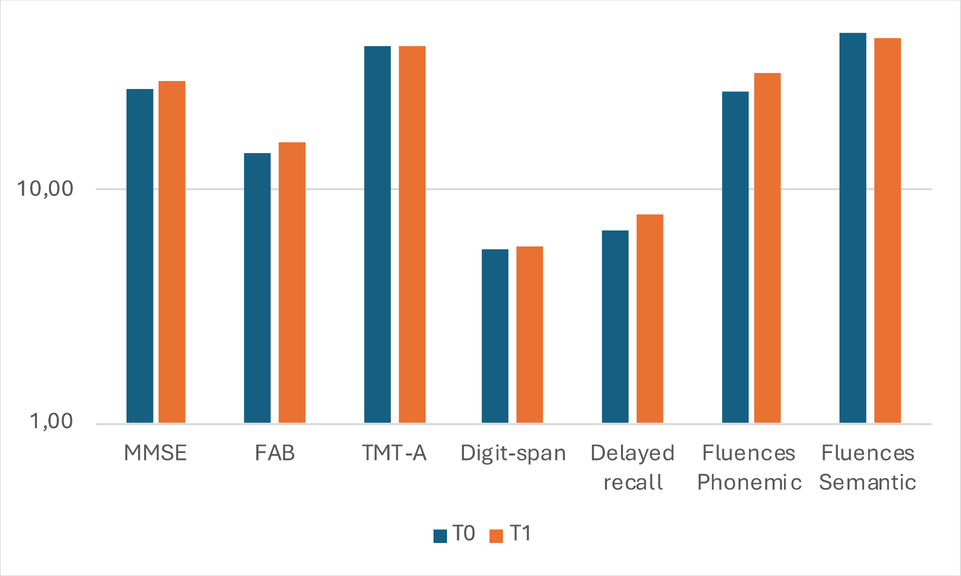

Figure 3 - Cognitive performance of the Control group before (T0) and after (T1) the training. Asterisks denote significant pre–post differences

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(1,17)=12.73, *p*<.002, partial-η2=.43, δ=.92, and the Strange Stories Test, F(1,17)=18.84, p <.001, partial-η2=.53, δ=.98. As detailed in Table 4, post-hoc comparisons confirmed that both the PD and control groups showed significant post-training improvements on these measures. This indicates an enhanced ability to infer and represent others' beliefs and intentions and a better comprehension of irony, indirect speech, and other subtle social cues.

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 Figures 4 and 5, these results suggest the training effectively enhanced cognitive ToM (False Beliefs and Strange Stories), while affective ToM abilities were preserved over time.

Table 4 – 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)*

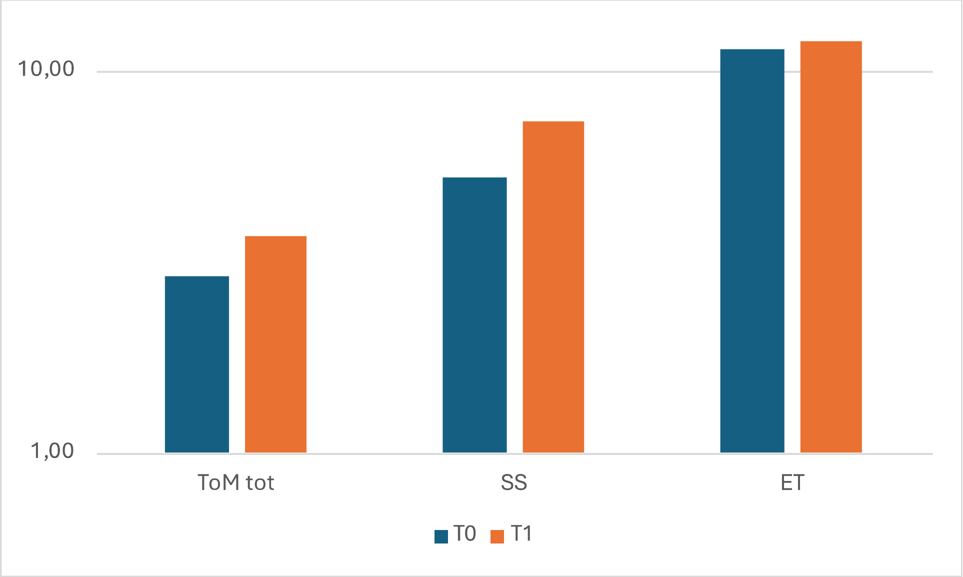

Figure 4 – Socio-cognitive performance of the PD group before (T0) and after (T1) the training. Asterisks denote significant pre–post differences (p<.05)

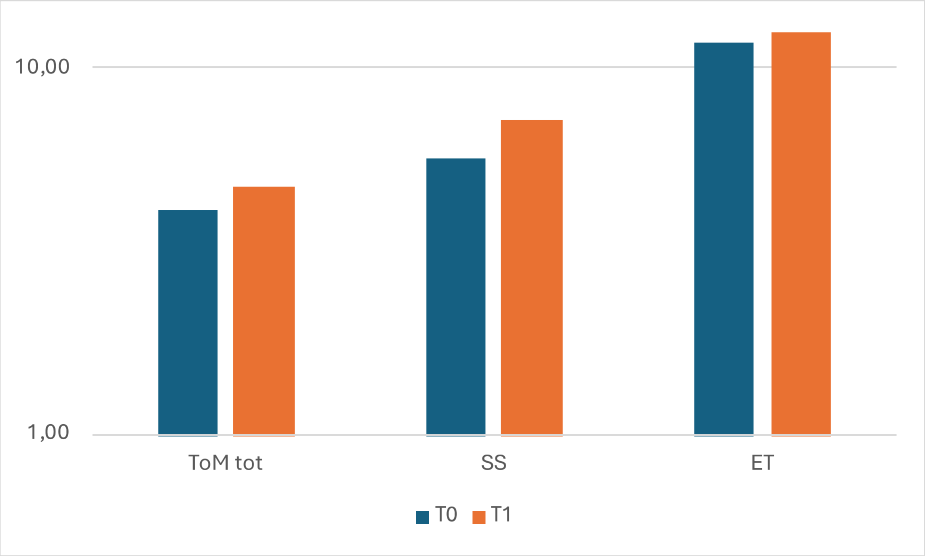

Figure 5 – Socio-cognitive performance of the Control group before (T0) and after (T1) the training. Asterisks denote significant pre–post differences (p<.05)

4. Discussion

The present study evaluated the efficacy of a robot-mediated training program in older adults with PD compared to a healthy control group. The findings were threefold. First, the intervention was feasible and well-accepted, confirmed by a high adherence rate (90%). Second, the training was effective, demonstrated by a significant main effect of *Time* on key outcomes, including global cognition (MMSE), executive functioning (FAB), verbal memory, and core socio-cognitive measures (False Belief and Strange Stories tasks). Third, the central finding was the *absence* of a significant Time*X*Group interaction. This indicates that, contrary to the "catch-up" hypothesis, both groups improved at a parallel rate—a positive outcome suggesting that the PD group retains a responsiveness to training comparable to healthy controls.

This high level of adherence supports the acceptability of the robot-mediated training format - a relevant outcome considering the difficulties that elderly 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 (Figliano et al., 2025), 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.

The mechanisms underlying this general effectiveness warrant closer examination. Specifically, increases in MMSE and FAB post-training scores indicate an improvement in global cognitive abilities and executive functions. This is presumably attributable to enhanced attentional regulation and problem-solving strategies (Cerasa et al., 2014; Naismith et al., 2013). 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 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. A central finding of this study was the absence of a significant Time*X*Group interaction, particularly in the socio-cognitive domains where the PD group had a baseline deficit (i.e., ToM tasks). While we had hypothesized that the PD group might show a greater magnitude of improvement, the data indicated that their rate of improvement was statistically parallel to the control group. This is a positive outcome, suggesting that the neurodegenerative process at this stage of PD does not diminish the brain's plasticity or responsiveness to a structured socio-cognitive intervention. The ability of the PD group to learn and improve at a pace equivalent to healthy controls underscores the training's potential. Although the affective component of ToM, measured by the brief version of the Reading the Mind in the Eyes Test (Baron-Cohen, 1997), did not show significant improvement, the slight increase in scores is a positive outcome, given the tendency of emotional inference abilities 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.

Taken together, these results can likely be attributed to the structured, repetitive, and feedback-based nature of the training (Figliano et al., 2025), as they 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 & 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 robust main effect of *Time* across groups.

In conclusion, the interactive and relational nature of the training appears to have played a key role in sustaining engagement and fostering improvement across domains. This study highlights that a structured, robot-mediated intervention based on validated protocols can promote measurable cognitive and socio-cognitive benefits in older adults. Most importantly, it demonstrates that individuals with early stage of PD retain a cognitive and social plasticity comparable to healthy controls, responding equally well to this targeted training. The parallel improvement 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 impairments 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 sociocognitive abilities in older adults, including those with PD. Participants exhibited significant improvements in global cognition, executive functioning, verbal memory, and ToM. The central finding was the parallel improvement observed in both the PD and control groups, with no significant interaction effects. This suggests that individuals with early-stage PD, despite baseline socio-cognitive deficits, retain a cognitive and social plasticity comparable to healthy controls and respond equally well to the intervention. Importantly, the fact that the Control group also showed significant improvements highlights that such training programs may not only compensate for mild impairments but also serve a preventive and stimulating function in healthy aging.

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 (90%) 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.

Despite these encouraging findings, several limitations must be acknowledged. First, the sample size was relatively small, which limits the generalizability of the results and the statistical power to detect more subtle effects, particularly concerning affective ToM. Second, the study design did not include a long-term follow-up, which prevents an evaluation of the persistence 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 definitively disentangling the specific effects of the robot-mediated training from potential non-specific effects, such as the social contact with the therapist, the novelty of the experience, 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.

Finally, a limitation concerns the demographic composition of our sample. The control group consisted exclusively of female participants, which introduces a potential confound and limits the generalizability of the findings from this group. Although baseline comparisons did not reveal significant cognitive differences between groups, potential gender effects on socio-cognitive performance cannot be entirely ruled out. Therefore, the interpretation of the between-group effects should be approached with caution. Replicating these findings with gender-balanced samples will be crucial to corroborate the present results and ensure their broader applicability.

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 qualitative 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.

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Declaration of Competing Interest

The authors declared that there is no conflict of interest.

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Chapter 5

General conclusion

"Older people are our history, the bridge that connects who we were to who we could become".

My experience working with elderly people led me on to explore strategies and tools that would not only enable them to achieve clinical benefits from cognitive training sessions, but also engage participants' curiosity and stimulate them, improving their skills and encouraging personal involvement. The idea of 'walking, passing' is summarized by the etymology of the word 'bridge, pons – pontis', which refers to a structure used to cross a river or obstacle, and by its Indo-European origins. These definitions summarises the main idea behind my PhD programme: suggesting social and cognitive training sessions through the use of a humanoid social robot. The aim of this proposal was to allow people belonging to a generation unfamiliar with technology, robotics and artificial intelligence to experience first-hand this type of innovation, which cannot be easily accessed, in order to familiarise themselves with it and to carry out an activity using it from which they could benefit.

Furthermore, SARs could be one answer to the ageing population in our countries and the ever-increasing demand for healthcare and social care, for which the services in numerous nations are not equipped to meet, either in terms of available personnel or in financial terms.

In this context, Italy ranks as one of the longest-living countries in the world, with one of the highest percentages of elderly people in Europe.

As a result, there has been a significant increase in demand for care, including multidisciplinary home care, residential and semi-residential services, financial support and assistance for family caregivers. Based on the experience of some residential and semi-residential care facilities, which have introduced social robots as mediators of activities for the elderly, the first doctoral thesis study aimed to review the literature for research protocols able to validate and demonstrate the acceptability and effectiveness of using SARs (with zoomorphic and anthropomorphic robots) to offer socio-cognitive training to elderly people in the early stages of cognitive decline.

The first study, "*Ageing society and the challenge for social robotics: A systematic review of Socially Assistive Robotics for MCI patients*", is a systematic review based on the PRISMA guidelines. The study analysed 193 articles from six databases, selecting 19 that included people with MCI involved in cognitive and/or socio-cognitive interventions mediated by social robots. The reviewed studies, both qualitative and quantitative, focused on four main areas: participant characteristics, robot types and programming, cognitive ability assessment and nature of interventions. Overall, the results indicate potential benefits of SARs in cognitive and socio-cognitive domains, but most research focuses on robot acceptability rather than clinical outcomes. Based on this review, several methodological limitations can be identified: sample heterogeneity, absence of control groups and lack of standardised protocols; these factors reduce the generalisability of the results.

The second study, '*Tom and Pepper Lab. Robotics for cognitive stimulation and social skills: A preliminary study,*' took a step towards designing a better-structured social-cognitive stimulation programme for people with cognitive decline. The study aimed to evaluate the effectiveness of structured cognitive and socio-cognitive training delivered by the robot to 9 subjects with mild to moderate dementia who attended the Day Centre De Rodolfi in Vigevano. The training program lasted a total of four weeks. The results show that the participants welcomed Pepper and the training encouraged the activation of skills such as attention, autonomy and emotional involvement with the robotic agent. The therapist facilitated and mediated the relationship between the subject and the robot, also promoting compliance in the triadic relationship. The results are promising overall and indicate the potential of this type of intervention to stimulate socio-cognitive skills and emotional well-being in elderly people with dementia. However, even in this case, the sample was small and heterogeneous, with different cognitive profiles, limiting the generalisability of the data. This experience provided the necessary foundation for the development of the subsequent study, which was planned in a more structured and standardised manner in order to assess the effectiveness of the programme on functions such as memory, executive functions and mentalisation and to improve the reliability of future conclusions.

Finally, the third study: '*Efficacy of a Social Robot-Assisted Training for Socio-Cognitive and Cognitive Functions in Parkinson's Disease: A Comparison with an Active Control Group*' assessed the effectiveness of a 12-week socio-cognitive training programme with a social robot (SARs) in 11 people with early-stage Parkinson's disease and 9 healthy ageing adults; both groups were involved in the same programme with Robot Pepper. Assessments of cognitive and social skills were conducted before and after treatment, and their analysis showed a significant improvement over time in several functions: global cognition, executive functions, verbal memory and Theory of Mind. A relevant aspect was that the improvements were parallel in both groups, indicating the effectiveness of non-pharmacological treatment in activating neuroplasticity processes even in people with Parkinson's disease. Furthermore, the control group also benefited from the training, a result that suggests the potential preventive value of stimulation for healthy ageing. Another aspect to consider is the gap that the study attempts to fill by proposing a structured robot-mediated protocol based on validated procedures. Nevertheless, there are some limitations: the sample is small and not very homogeneous limiting the generalisability of the results and, the absence of follow-up, does not allow for an assessment of the duration of the benefits over time. Furthermore, the control group consisted only of women, introducing a possible confounding factor. Future studies with larger, gender-balanced samples and follow-up will be necessary to confirm and expand on these results.

Overall, all the work analysed and performed indicates how cognitive and socio-cognitive training provided through the use of SARs generates positive outcomes from various perspectives: acceptance of the robotic agent by elderly people and promotion of the preservation and improvement of cognitive and social skills in individuals with Parkinson's disease and healthy individuals.

Furthermore, the high participation of subjects in the training sessions confirms the motivational value of the triadic relationship between patient, robot and therapist and indicates the possibilities for developing scalable non-pharmacological interventions to promote rehabilitation and preventive measures for cognitive health, social involvement and better quality of life in elderly populations.

These results support the theoretical framework on neurodegeneration described in Chapter 1, suggesting that even when neurodegenerative diseases occur, the brain retains a residual capacity for functional and structural reorganisation. The evidence collected supports studies underlining the effectiveness of non-pharmacological interventions in supporting neuroplasticity processes, with significant benefits on cognitive and daily functioning (Kasper et al., 2020; Sun et al., 2021; Liu et al., 2025). This perspective supports the principle that the adult brain may create new neural circuits to compensate for functional loss due to disease (Fedotchev, 2025).

A relevant factor that emerged from the study is the improvement not only in basic cognitive abilities but also in socio-cognitive abilities, such as the ability to recognise emotions, understand others' mental states, and manage complex social interactions. These results further reinforce the theory that neurodegeneration does not uniformly compromise all neural networks but leaves scope for recovery and enhancement, especially in functions depending on distributed and highly plastic circuits. The literature has already highlighted how cognitive stimulation could encourage the restructuring of the fronto-temporal and limbic networks involved in socio-cognitive processes (Pieramico et al., 2014), and the data from this study confirm this direction.

From a methodological point of view, the robot-mediated procedure adopted represents an innovative and significant contribution. The use of a structured, standardised procedure based on validated tasks made it possible to rigorously control variables such as intensity, duration and mode of stimulation delivery. This approach allowed the improvements observed to be attributed more reliably to the intervention itself, reducing the influence of external factors.

The empirical data collected not only support the theory presented in Chapter 1, but also provide further evidence, demonstrating how a structured, technology-mediated, non-pharmacological intervention could support brain plasticity, mitigate the effects of neurodegeneration, and promote healthier and more socially competent ageing.

Future Directions

Based on the outcomes, a crucial step in advancing robot-mediated socio-cognitive training could include clinical scalability and the systematic implementation of the PRIS platform in healthcare centres, residential care homes and local social services. The standardisation of the protocol and its organisation into replicable modules suggest the potential for large-scale, phased roll-out, which could involve several stages:

- multicentre validation studies, necessary to test the intervention in different settings and with heterogeneous clinical populations;
- the development of a certified training package aimed at therapists, professional educators, rehabilitation technicians and psychologists, enabling practitioners to deliver sessions via PRIS independently and with minimal supervision;
- the integration of the platform with existing clinical systems (electronic health records, therapeutic progress monitoring systems), so as to ensure continuous data traceability, reduce the workload on staff and facilitate informed decision-making.

After the validating phase has been completed, widespread roll-out could be achieved through regional implementation hubs, which would provide technical support, quality monitoring and regular updates to the training content. Finally, the possibility of integrating PRIS into home-based and telerehabilitation settings paves the way for nationwide scalability, with protocols accessible even to frail users or those with limited mobility, ensuring continuity, frequency and intensity of treatment – three key elements for maximising the effectiveness of robot-assisted training.

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