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Assistive Robots for the Social Management of Health: A Framework for Robot Design and Human–Robot Interaction Research

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Abstract
There is a close connection between health and the quality of one's social life. Strong social bonds are essential for health and wellbeing, but often health conditions can detrimentally affect a person's ability to interact with others. This can become a vicious cycle resulting in further decline in health. For this reason, the social management of health is an important aspect of healthcare. We propose that socially assistive robots (SARs) could help people with health conditions maintain positive social lives by supporting them in social interactions. This paper makes three contributions, as detailed below. We develop a framework of social mediation functions that robots could perform, motivated by the special social needs that people with health conditions have. In this framework we identify five types of functions that SARs could perform: (a) changing how the person is perceived, (b) enhancing the social behavior of the person, (c) modifying the social behavior of others, (d) providing structure for interactions, and (e) changing how the person feels. We thematically organize and review the existing literature on robots supporting human–human interactions, in both clinical and non-clinical settings, and explain how the findings and design ideas from these studies can be applied to the functions identified in the framework. Finally, we point out and discuss challenges in designing SARs for supporting social interactions, and highlight opportunities for future robot design and HRI research on the mediator role of robots.

Keywords Socially assistive robots · Health management · Human robot interaction

1 Introduction

Social life is essential for good health [1,2] but often poor health detrimentally affects a person's ability to form and maintain supportive social bonds [3] leading to a vicious cycle in which health and well-being are impacted negatively. This is especially true for individuals dealing with health conditions that require long-term assistance. Whether the impairment that restricts social life is physical as in the case of people with neuromotor disabilities, cognitive as in the case of dementia, emotional as seen in depression, or due to a neurodevelopmental disorder as in the case of autism, the effects of an impoverished social life on health range from reduced quality of life to reduced life-span [4].

As robots are becoming more common in healthcare, the social management of health is an aspect in which their assistance could be extremely valuable. Tickle-Degnen et al. [5] define the social self-management of health as "the self-care practices that ensure social comfort while supporting mental and physical well-being, such as by participating in valued social activities, maintaining rewarding interpersonal relationships, and seeking help from capable people" (p.1). Socially assistive robots (SARs) are machines that are meant to assist users through social rather than physical interactions [6]. Developed at the intersection of assistive robotics and social robotics, the focus of SARs is to provide necessary aid for humans and to do so by engaging humans socially [7]. In healthcare, SARs are envisioned to play roles such as taking medical interviews [8], monitoring and keeping a record of symptoms [9], helping with pill sorting and medication schedules [10], guiding people through therapeutic tasks [11], providing companionship [12], acting as stress reducers and mood enhancers [13], and supporting social interactions between humans [14,15].

In this paper we focus on the last role, that of robots assisting social interactions between people. More specifically, we are interested in the application of SARs to the social manage-

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ment of health of people with health conditions that restrict or negatively impact their social life. We see these robots as assistants in breaking the above-mentioned vicious cycle in which poor health negatively impacts social bonds, the weakening of which, in turn, leads to further decline in health.

Several participatory science studies have shown that people with health conditions as well as their caregivers and therapists welcome support from robots not just for physical tasks, but also for social interaction. For example, Williams et al. [16] explored ways in which robots could augment workers with intellectual and developmental disabilities. They observed a group of workers with disabilities in the workplace as they performed their tasks, and then interviewed some of them about their work experience. The study found that among the three most desired features for a SAR (as expressed by the workers) was the robot's ability to help facilitate more human connection between the workers during work, breaks and outside of work.

Another study, by Moharana et al. [17], focused on informal careregivers of people with dementia (usually spouses and close family members) and their requests in terms of robotic help with caregiving tasks. In addition to functions such as regulating food intake, prompting and delivering medication, coaching the person with dementia through physical therapy exercises and motivating the person to be active, caregivers expressed desire for the robot to also support interactions between them and the person they were caring for. Caregivers wanted robots that could facilitate positive interactions with the person they were providing care for, such as playing favorite songs and inviting both of them to share a dance. They also wanted the robot to lessen the emotional stress of the interaction when the person requiring care was agitated and asked repetitive questions. In this situation, caregivers wanted the robot to answer in their place, distract the agitated person, and redirect the conversation to more enjoyable topics. Finally, since their emotional attachment to the person they were caring for made it difficult to deprive them of personal freedoms, caregivers wanted robots to act as neutral third parties in interactions and make the person cared for do things they did not want to do, for example take their medication, exercise, or stop eating unhealthy things.

Robot assistance in social interactions is also desired for children with disabilities. Most social interactions that children engage in happen in the context of play. Introducing structure to play scenarios through robotic facilitation can therefore be helpful for children with special needs. Robins et al. [18] interviewed a panel of experts comprised of therapists, teachers and parents of children with autism to investigate how robotic toys can assist social interactions and help children discover different play styles, including cooperative play. A recurring theme in the panel's conversation was the need for motivating children with autism to play with others, sustain their interest in collaborative play and offer them support for how to engage others. Using data from this panel as well as from a review of the literature, Robins et al. [19] then explored designing robots that could facilitate different types of play with therapeutic benefits for children with autism. The goal of the project was to design robots that empower children with special needs, to prevent isolation and build different skills including social ones.

These findings suggest a few ways in which robots could assist social interactions between people for a better social management of health. While the other roles for SARs such as providing companionship or coaching focus on human–robot interaction, assisting with social life focuses on human–human interactions and how robots can provide assistance during the interaction. The functions that the robot has to fulfill and the capabilities it needs to have to provide effective social support for human–human interactions can be quite different from what is required of a robot for successful human–robot interaction alone. At this point there doesn't seem to be a concerted effort towards designing robots that can effectively support social interactions between people, but such an effort would be highly beneficial for the development of SARs that could contribute to the social management of health.

Most of the studies in social HRI focus on the role of the robot as interactant rather than as assistant to human–human social interactions. However, the field has begun to pay more attention to robots being part of and even intervening in social interactions between humans in roles such as group member [20,21], facilitator [22,23], or moderator [24,25]. HRI studies of robots intervening in human–human interactions vary widely in their scope, and are scattered across domains of application, using very different robot designs in a variety of context. Some are simply case studies (e.g., [26]), others engage larger participant samples (e.g., [27]), some studies investigate the effects of the robot in the context of specific tasks (e.g., [20]), some leave the interaction free and open to what participants want to make of it, constrained just by the robot's capabilities (e.g., [28]). Some of the robots used are designed with clinical applications in mind, such as assisting children with autism (e.g., [29]) or providing couple's therapy (e.g., [30]), but many of them are intended for general use, for purposes such as promoting inter-generational interactions (e.g., [31]). Finally, some of these studies were conducted in lab settings (e.g., [27]) while others in more naturalistic settings such as nursing homes (e.g., [32]). In this paper we draw on this growing, although disparate, literature, for insights into how robots could assist individuals with health conditions in the management of their social lives.

The contribution of this paper is threefold: (a) we offer a framework for functions that a mediator robot could perform that are motivated by the special social needs that people with health conditions have; (b) we thematically organize and review the existing literature on robots supporting human–

human interactions in both clinical and non-clinical settings and explain how the findings and ideas in these studies fit in the proposed framework; and (c) we identify and discuss the challenges of designing SARs for supporting social interactions between humans. Our framework and the summaries of the reviewed studies highlight opportunities for robot design as well as future HRI research.

2 Functions of Mediator Robots for the Social Management of Health

The social lives of people with serious health conditions are different from the norm in several important ways. First, people with health conditions can have disability-specific difficulties in interacting with others. For example, people with Parkinson's Disease, a neuromotor disorder, might have difficulty in expressing emotions in conversations with others due to poor control of their facial muscles [33,34], while children with autism might have difficulty decoding the emotions of others in interactions [35]. Second, people with serious health conditions tend to be more dependent on others for daily functioning than their healthy peers and this can shape the types of interactions they have within a relationship. For example, people with severe health conditions, such as Alzheimer's disease, in later stages, might need round-the-clock supervision and the extent to which they can make autonomous decisions about their lives and interactions with others can be limited [36]. Finally, there are types of social relationships that are unique to people with chronic health conditions, namely the relationships they form with healthcare professionals such as doctors and therapists, and their relationships with caregivers. These can pose specific challenges such as forming and sustaining fruitful therapeutic relationships [37], and adjusting to the dynamics of caregiver—care recipient relationships, which can often be fraught with frustration on both sides.

Given these special social circumstances of people with health conditions, we propose that SARs supporting human–human interactions can assist people with health conditions in their management of social life by fulfilling these functions (for a summary see Fig. 1):

1. Changing how the person with a health condition is perceived by others (e.g., by correcting other's misconceptions about impairments);
2. Enhancing the social behavior of the person with a health condition (e.g., by supplementing social behavior that the person is not able to convey);
3. Modifying the social behavior of others towards the person with a health condition (e.g., by modeling good behavior or by raising awareness of problematic behavior);
4. Providing structure for interactions between people with health conditions and others (e.g., by guiding conversation partners through a therapeutic conversation protocol);
5. Changing how the person with a health condition feels in a social context (e.g., by making the person feel listened to or at ease in a stressful social interaction).

In what follows we will look closely at each of these functions and explain why they are necessary or desirable and how studies in HRI have begun to research these functions in robots (for a summary see Fig. 2). We also offer ideas about possible robot design directions and gaps in our HRI knowledge.

2.1 Changing How a Person with a Health Condition is Perceived

People react in different ways to a health condition, from impressive resilience to major distress, which can profoundly influence the prosocial responses they receive from others [38]. The way in which people with health conditions are perceived by others can have a major impact on their health. In the context of healthcare, how positive an impression a patient can make can directly affect how much care they receive. Studies have shown that doctors are more inclined to prescribe more care for more likable patients. However, doctors seem to be influenced by a patient's perceived traits at an unconscious level. For example, in a study of doctors making decisions about Intensive Care Unit (ICU) admissions, the doctors ranked the patient's "emotional state" as an important consideration only 6 percent of the times. However, when a vignette described a hypothetical patient as being "upbead and courageous" as opposed to "sad and discouraged" the same doctors were three times more likely to recommend admission to ICU [39]. Other studies have similarly shown that "likable and competent" simulated patients elicited from doctors more recommendations for follow-up visits as well as more staff time spent on the patient's education [40]. Doctors are not the only ones influenced by patients' character attributes and affect. In a study of empathetic responses to naturally-varying affect in real hospital patients, participants (who were not medical professionals) watched video-interviews of chronically or terminally ill patients talking about their quality of life. Participants showed willingness to aid those patients displaying negative affect slightly more than those displaying positive affect, but patients showing little affect were offered the least amount of help (Fig. 2).

Fig. 1 Summary of the proposed framework with examples of applications (right column)

Functions of mediator robots for the social management of health

1. Changing how a person with a health condition is perceived

a) Showcasing positive attributes	*by using language that focuses on the person's agency, resilience and competence.*
b) Facilitating demonstrations of agency and achievements	*by introducing topics that individuate, personalize and highlight the achievements of the person.*
c) Correcting misimpressions	*by alerting others to which behavioral cues are valid and which are disease-distorted.*

2. Enhancing the social behavior of a person with a health condition

a) Increasing social motivation	*by incentivizing communication, and eliciting and rewarding social behavior.*
b) Augmenting and modifying social behaviors affected by disease	*by compensating for impaired signaling such as social expressivity*

3. Supporting the social behavior of healthcare providers, caregivers and others

a) Raising awareness of effects of social behavior	*by emoting in reaction to aspects of the conversation such as speech, timing and loudness.*
b) Providing feedback that supports positive social interactions	*by detecting and alerting interactants to disagreements, interruptions or lack of interest.*
c) Promoting positive interaction goals	*by suggesting empathy goals and opportunities to meet them.*
d) Detecting and intervening in problematic interactions	*by identifying and remedying situations in which the person with a health condition is misunderstood, rushed, blamed, deprived of agency, stigmatized or met with insufficient empathy.*

4. Providing structure to social interactions

a) Anchoring interactions and focusing attention	*by behaving in captivating ways that promote conversations between people interacting with it, or by playing different roles in an interaction, such as teammate.*
b) Moderating interactions and promoting inclusiveness	*by welcoming the person with a health condition who would otherwise be left out and encouraging them to participate in the interaction.*
c) Guiding interactions through therapeautic protocols and exercises	*by introducing the rationale and rules of the exercise, engaging interactants, monitoring their progress and offerring feedback.*

5. Changing how a person with chrnoic illness feels in a social context

a) Promoting positive feelings in interactions	*by making people feel included and welcomed.*
b) Mitigating negative feelings in interactions	*by reducing stress associated with the interaction.*

Paper	Interactants	Robot	Setting/Task	What does the robot do	Robot Autonomy	Inter-action	Controls	Measures	Results
1. Changing how a person with a health condition is perceived									
Chita-Tegmark et al., 2019	health care provider, doctor and robot	general	check-in	the robot reports on the progress made by the patient	N/A	Video	other scenarios	robot emotional intelligence, trusthworthiness and acceptability, and impressions of the patient psychological attributes	When the robot acted in a patient-centered manner the robot was perceived as having higher EI and people formed more positive impressions of the person assisted by the robot. Results were replicated in dieting, learning and job training scenarios.
2 Enhancing the social behavior of a person with a health condition									
Giannopulu & Pradel, 2012	child and therapist	GIPY-1	free-play	Engages the child in an interaction by moving away, following the child or grabbing the child's attention by turning around	WOZ (teleoperated)	live	no controls	eye contact, touch, manipulation, posture, and positive emotion	The robot mediated the interaction between the autistic chid and the therapist. The child used the robot to express positive emotion playing with the therapist.
Robins et al., 2009	child with co-present adults or co-present children	KASPAR	free-play	gestures and facial expressions for interacting with a human	controlled by another adult or by the child	live	no controls	behavior	The robot served as a salient object that mediated and encouraged the interaction between children and co-present adults and between one child and another child.
Kim et al., 2012	children interacting with confederate adults	Pleo	structured play	move and make psedu-verbal vocalizations that express positive and negative emotion and interest	WOZ	live	adult, computer game	number of utterances	Children spoke more in general and directed more speech to the adult confederate when the interaction partner was a robot as compared to a human or a computer game.
3. Supporting the social behavior of healthcare providers, caregivers and others									
Hoffman et al., 2015	romantic couples	Kip1	conflict resolution	Emotes: three different physical states evocative of 3 emotions: curiosity, calm, fear in response to markers of speech such as volume	Autonomous	Live	moving but non-reactive robot	Robot Social Human traits, comfort with robot, robot similarity	More gazes to reactive robot, more social traits and human similarity attributed to reactive to robot.
Tahir et al., 2014	adult dyads	Nao	scripted conversations	provides sociofeedback: alerts speakers when the voice is too high or too low, the conversation is not proceeding well due to disagreements or interrauptions	Autonomous	live	no controls	Aspects of the feedback (conent, likability, timing) and experience of of Nao as social mediator via Godspeed questionnaire	Participants felt the timing of the feedback could be improved. The interaction felt natural. Participants agreed with the feedback received. Participants liked the feedback from Nao. Nao received high scores on the Godspeed questionnaire. 19 out of 20 participants were in favor of receiving sociofeedback. The Nao Robot was the second highest rated source in terms of preference for receiving feedback.
Short & Mataric, 2017	groups of three undergraduates	SPRITE robot	playing a collaborative game	Assits participants in playing a collaborative game by using two types of algorithms (performance-reinforcing and performance-equalizing) to offer suggestions regarding what game goals to adopts	autonomous	live	moderation vs. non-moderation; performance-reinforcing vs. performance-equalizing	Negative Attitude towards Robots Scale (NARS), Group Cohesiveness Scale, Unified Theory of Acceptance and Use of Technology (UTAUT), behavior of other participants (UTEP_ICT) dataset), scores I the game, head pose and voice activity	Participants reported increased group cohesion and more looking around in the performance-reinforcing condition. The more the robot spoke to participants, the higher group cohesion they reported and the more they helped the other participants in the group. The performance of the group was higher in the unmoderated testing sessions. Participants' "attitudes toward situations and interactions with robots" became more negative. Participants followed half of the robot's suggestions.
Shim et al., 2017	simulated interaction between patient, caregiver and robot	Nao	problems during medication-sorting task	robot detects a problem and verbally intervenes to correct patient behavior	N/A	Video	no controls	interview about situation and robot intervation actions	Participants who watched the videos thought that safety-related intervenentions were more appropriate, while the other interventions they thought to be judgemental and thus unnaceptable.
Stoll et al.	adults watching vignette interaction	?	conflict resolution	Tells different types of jokes as an attempt to mediate conflict	WOZ	Video	human	rating the funniness and approporiateness of a joke as a conflict mediation tool	Participants perceived afficliative and aggressive jokes as less appropriate when used by a robot than a human
Shen et al., 2018	child dyads	Keepon	conflict resolution	Detects conflict and guides children through conflict resolution protocol	WOZ	Live	no intervention	coding of videos for general play behavior and object posession conflict	Children were more likely to resolve conlicts constructively in the robot mediation condition.

Fig. 2 HRI studies of robots mediating social interactions between people (continued on the next page)

Paper	Interactants	Robot	Setting/Task	What does the robot do	Robot Autonomy	Inter-action	Controls	Measures	Results
4. Providing structure to social interactions									
Wada & Shibata, 2006	self-forming groups of elderly	Paro	spontaneous communication	Paro: move, blink, make sounds and respond to being held or stroked	Autonomous	live	no controls	Density of social networks, amount of interaction with robot and others	The residents' social network density increased and improved reaction to stress.
Wada & Shibata, 2007	self-forming groups of elderly	Paro	spontaneous communication	Paro: move, blink, make sounds and respond to being held or stroked	Autonomous	live	no controls	Time spent in public area, experiences with Paro and other residents	The time spent by residents in the public area increased after the introduction of Paro, the topics of conversation became more positive and residents who had trouble communicating with others because of their dialect were motivated to do so by the robot's presence.
Kidd et al., 2006	small groups of elderly	Paro	spontaneous communication	reacts to touch and speech; becomes focus of the interaction	Autonomous	live	Paro off	Social engagement, engagement with the robot, behavior of group and their unstructured feedback	The robot Paro can stimulate social interactions and this effect is increased by the presence of caregivers or experimenters.
Robinson et al., 2013	groups of elderly	Paro	spontaneous communication	Paro: move, blink, make sounds and respond to being held or stroked	Autonomous	live	real dog, other activities	amount of conversation	More residents were involved in discussion about the robot and more conversation about the robot was initiated by staff and by residents.
Wood et al., 2015	pairs of unaquainted individuals	Paro	free interaction	Becomes the focus for the interaction	Autonomous	Live	inactive Paro, active Pleo	Quality of interaction with the other; Opinion of other participant; Evaluation of robot	Interaction was more positive when interacting with the active Paro
Joshi & Šabanović, 2019	groups of childre and older adults	Paro, Joy, Cozmo, Nao	various activities: petting, dress-up, game play, conversations	Paro: move, blink, make sounds and respond to being held or stroked ; Joy for All - cat robot that can purr and meow and resond to petting; Nao: humanoid robot that can walk, speak, gesture; Cozmo: move, speak, express feelings	Paro & Joy - autonomous; Cozmo, Nao WOZ	live	different robots; different activities	principles for designing activities; types of social engagement during activities	The robots provided opportunities for both inter-generational and peer interactions. The Paro and Joy robot were most conducive to inter-generational interactions because of the slower pace of the interactions which did not overwhelm the older adults and made children impatient and inquisitive.
Werry et al., 2001	child dyads	?	play	avoids obstacles, follows a heat source and generates simple speech and phrases	Autonomous	live	no controls	Interaction structures	By providing a focus of attention the robot facilitated interesting interaction structures such as instruction cooperation and possibly imitation.
Short et al. 2017	inter- generational family members	SPRITE robot	playing group games	assists game play as competitor, performer and supporter	Autonomous	live	different types of games	Behavior towards robot, attitudes towards robot, impressions of game and feasability for using in home	Variations both between groups and between generations in terms of how much they spoke how they enjoyed the game and how the robot was perceived
Short et al., 2016	groups of four adults	SPRITE robot	storytelling interaction	The robot moderates the interaction by addressing participants and asking questions to make sure everybody participates in the discussion	Autonomous	live	moderated vs. unmoderated interaction	NARS (interaction and social role subscale - pre and post intervention Group Cohesiveness Scale	Higer scores on the group cohesion questionnaire in the moderated condition, marginally significant. Participants spoke more in the moderated than in the unmoderated condition (marginally significant).
Tennent et al., 2019	groups of three undergraduates	Micbot	problem solving	Engagement behavior: follow - rotate to the person speaking and encourage - roated towards the participant who spoke the least and lean in	autonomous	live	no movement, random movement	backchanneling behavior coded from video, performance on problem solving task	The robot device in the engagement condition increased evenness of backchanneling behavior compared to no movement condition and in turn the evenness of engagement increased team problem solving scores.
Mutlu et al., 2009	adult male dyads	Robovie	conversation with a robotic travel agent	The robot acts as a travel agent asking participants about their travel preferences and through its gaze determines the role of each participant: as an addressee, overhearer or bystandard.	WOZ	live	different roles: addressee and overhearer, addresse and bystander, addressee and addressee	behavior, recall of information presented by robot, subject's affective state, perceptions of the robot's characteristics, feelings of closeness to the robot, feelings of groupness and ostractism, enjoyment and attention to task, demographics.	The robot was able to manipulate the roles of the subjects in the conversation through gaze. Subjects whose presence the robot acknowledges (addressees and bystanders) like the robot more than those whose presence is not acknowledged (overhearers). Those who were communicated the role of addressee by the robot and who contributed to the conversation had higher feelings of groupness and attended to the task more.
Matsuyama et al., 2015	groups of 3 with robot as a 4th participant	?	conversation	detects whether a diad monopoloizes the conversation and attempts to include the third side-participant	N/A	video	various ways of intervening	appropriateness of robot behavior, robot timing and sense of groupness	Participants felt that the robot behaved most appropriately and there was a stronger sense of groupness when the robot attempted to include the side-participant by initiating a procedure without shifting the topic of conversation. Participants felt that intervening after two rounds of back-and-forth between the engaged participants was more appropriate than after the first round.
Utami & Bickmore, 2019	romantic couples	humanoid robotic head by Furhat Robotics	couples therapy	Guides couples through two positive relationship techniques/exercises	WOZ	live	no controls	Positive and Negative Affect Scale (PANAS), Inclusion of Other in the Self (IOS), Closeness and Intimacy, Attitudes Toward Robotic Facilitator, Enjoyment of the interaction, Perceived partner's responsiveness	The robot-led counseling session improved couples intimacy and positive affect.
Chandra et al., 2015	child dyads	Nao	collaborative learning	greets, explains the activity, guides children through activity	WOZ	live	human facilitator	Feedback given, amount of gaze, amount of learning	The child in the teacher role felt more responsible when the facilitator was a robot.
5. Changing how a person with chrnoic illness feels in a social context									
Pettinati et al., 2016	experimenter interviewing participant, robot listening	Nao	Interview session	Active listening - head movements that follow source of speech	WOZ	Live	static robot & stuffed robot	Negative Attitudes towards Robots Scale (NARS), interviewee's comfort, video coding of intimacy and expressiveness	There was no difference in the interviewee's depth of disclosure when the robot was listening to the conversation.

Fig. 2 continued

2.1.1 Showcasing Positive Attributes

Although there is much opportunity for exploring ways in which robots could accentuate one's positive and empathy-inviting features and behaviors, to our knowledge only one HRI study has investigated how a robot can change people's perceptions of a person with a health condition. Chita-Tegmark et al. [41] conducted a vignette study in which robots partook in a conversation between a patient and a health-care provider: the robot gave a summary of the patient's treatment progress. In doing so, the robot used either task-centered language, emphasizing the patient's level of compliance to the treatment plan, or patient-centered language emphasizing the patient's choices and difficulties with regards to the treatment plan. Through its use of language, the robot was able to manipulate participants' impressions of the patient: in the patient-centered condition people perceived the patient more positively: they thought the patient was more competent, honest and self-disciplined rather than disruptive, hostile and disorganized. The same results were replicated in other contexts: dieting, learning how to dance or job training. Given how important it is for people with health conditions to be perceived in a favorable way by others, there is a great opportunity for SARs to positively impact these people's health through social support. SARs could contribute to interactions between people with health conditions and others in such a way that highlights the positive attributes of the person with the health condition. SARs could do this very subtly through choosing language that focuses on the person's agency, resilience, competence etc., like the study above has done.

2.1.2 Facilitating Demonstrations of Agency and Achievements

Another way for robots to influence how a person with a health condition is perceived is to introduce in conversations topics that individuate, personalize, and highlight the achievements of the person. To humanize patients, Haque and Waytz recommend that, at a minimum, reminders be offered to the medical professionals and others about the patient's past or present profession, hobbies and family life [42]. Additionally, creating opportunities to reflect on the creative overcoming of challenges caused by the health condition, instead of the impairments associated with it, can be a fruitful way of changing for the better the way the person with the health condition is perceived. This is especially important for interactions between patients and healthcare providers, which tend to be focused on the disease and its negative effects on the patient, with little room for discussing the patient's achievements and thus with little opportunity to observe the patient exhibit positive affect.

2.1.3 Correcting Misimpressions

Additionally, it is often the health condition itself that leads to negative impression formation. For example, people with Parkinson's Disease are often perceived to be less extraverted and more neurotic [43] and, if a woman, as less supportive [34]. This is due to a symptom of Parkinson's Disease called facial masking, which affects facial muscles and facial expression. In these situations, in which the health condition is the root cause of the misimpression, SARs could intervene by correcting misconceptions and alerting people to which behavioral cues are valid, and which are not. In the context of Parkinson's Disease, for example, SARs could instruct interactants to pay attention to what the person with Parkinson's Disease is saying as a better indicator of their personality and mood, rather than their facial expression, which is affected by the disease [44]. In addition to supporting others in forming better impressions of people with health conditions, SARs could also assist people with health conditions by compensating for a variety of social impairments caused by the health condition itself.

2.2 Enhancing the Social Behavior of a Person with a Health Condition

Many health conditions can affect a person's ability to engage in positive social behaviors. A disorder that has received much attention from the robotics community is Autism Spectrum Disorder (ASD). Social impairments are a core symtpom of ASD, a neurodevelopmental disorder affecting 1 in 59 individuals [45]. ASD is characterized by persistent social deficits across multiple contexts, such as: abnormal social approach, failure to initiate and respond to social interactions, abnormalities in in eye contact and body language, difficulties in sharing imaginative play or absence of interest in peers. Several case-studies have documented the potential for robots to support social behavior in children with ASD by incentivizing communication and evoking, eliciting rewarding and reinforcing social behavior.

2.2.1 Increasing Social Motivation

Giannopulu and Pradel [26] have documented a case of a child with autism using a robot as a mediator for his interaction with a therapist in a free play scenario. The robot had a very simple design: a schematic face-like cover made of geometric shapes (circles for eyes and mouth, and triangle for nose) on top of a remote-controlled locomotion hardware, able to move forward, move back and swivel. An operator manipulated the robot wirelessly in the following way: if the child approached, the robot moved back; if the child moved away, the robot followed the child; and if the child was motionless, the robot turned itself around to grab the child's attention. After establishing an interaction with the robot, the child began to use the robot to express positive emotion, an interaction cue directed at the therapist. When the child interacted in a standalone manner with the robot, the positive emotion expression was quasi-absent, leading the authors to believe that the expression of enjoyment was the indication of a 'passage' from child-robot interaction to a child-therapist interaction. The authors interpret this as an indication that the child was using the robot as a tool for human–human interaction and that the interest elicited by the robot was an essential stepping stone for facilitating the interaction with another person.

Robins et al. [29] described three case studies conducted with minimally verbal, low functioning children with autism. In the studies, a humanoid robot facilitated interactions between these low functioning autistic children and other people. Notable behaviors that the children engaged in included reaching for the experimenter's hand, which was surprising to both the experimenter, parent and therapist given the autism severity of the child. Another example of engaging in social behavior in the context of playing with the robot was exploring the teacher's eyes and face after exploring the robot's eyes and face as well as sharing excitement with the teacher by reaching out to her and asking her to join in the game. Finally, a child was gradually able to participate in an imitation game with the therapist taking turns controlling the robot and imitating the robot. Through this game the child learned to look at the therapist to see how she imitated the robot. Eventually the child was able to successfully engage in the same imitation game with another child. The authors argue that the robot allowed the children to demonstrate some interactional competencies and generalize this behavior to the co-present others.

Beyond case studies, Kim et al. [46] showed that in a structured play interaction, children with autism spoke more with an adult confederate when the interaction partner was a robot than when it was another human or a computer game. The researchers used Pleo, a dinosaur shaped robot which was programmed to show interest in different objects and exhibit positive and negative emotions. The children were excited and interested in the robot and were thus motivated to ask how the robot works, whether it "was real" and what the robot was doing. The authors suggest that the inclusion of the robot in the task can thus serve as an embedded reinforcer of social behavior.

In the case of autism elicitation and maintenance of social behavior is a challenge specific to the disorder and robots can help by increasing social motivation and evoking and reinforcing social engagement. These robot functions are also generalizable to other health conditions. For example, this type of assistance might also be useful for people with depression or anxiety where social behavior might be absent or insufficient because of emotional difficulties [47].

2.2.2 Augmenting and Modifying Social Behaviors Affected by Disease

In the context of other health conditions robots might be useful in enhancing social behavior not by eliciting more of it, but by modifying or adding to it in specific ways. For example, in the case of Parkinson's Disease, it has been proposed that a robot could be used to convey emotions that the person with Parkinson't Disease is incapable of expressing due to facial masking [5]. Arkin and Pettinati [48] have proposed the development of a robot co-mediator that would increase the emotional communicative bandwidth of the person with PD in such a way that would facilitate empathic response in a caregiver. The robot would express through body motions and postures the mental states of the person with Parkinson's Disease with the goal of eliciting empathy when incongruences arise between the mental state of the person with Parkinson's Disease and the other interactant.

Most of the studies on how robots can help enhance the social behavior of people with health conditions are observational case studies or conceptual proposals. More HRI studies are needed to determine how robots can address social interaction needs that are specific to various health conditions. Most of the studies in which robots help with social interactions focus on autism, but there are many other health conditions that negatively impact the ability to engage in effective and appropriate social behavior that SARs could assist with. However, in social interactions it is not only the social behavior of the person with the health condition that matters, but also that of the interaction partner. Robots could provide support for those interacting with people with health care conditions with the aim of making such relationships stronger and more positive.

2.3 Supporting the Social Behavior of Healthcare Providers, Caregivers and Others

In social interactions people with health conditions run the risk of being reduced to their impairments. In relationships with others, especially with those that provide care, they can be seen almost exclusively through the lens of their needs, which can harbor dehumanization. Specifically, people with health conditions may be treated less like persons and more like objects or nonhuman animals [42,49]. It is not that empathetic and humanizing care is not an aspiration of those providing it; in fact, it very much is, but often dehumanization ensues because of the need of health care providers and caregivers to create distance and emotional barriers to protect themselves from the emotional drain ensued by dealing with health care problems on a daily basis [42,50,51]. Caregiving relationships can be emotionally taxing and accompanied by frustration, thus in spite of best intentions, the social behavior of those providing care can often lack in empathy. However, empathy and humanization of care has been shown to be beneficial for health outcomes and many studies highlight the importance of empathy and patient-centered approaches in medical practice [52–54]. It has been proposed that admissions for medical school be based on empathy and emotional intelligence aptitudes [55], and that training in empathetic behavior be required for health care professionals [56].

SARs could be used to support health care providers and caregivers when interacting with people with health conditions to ensure that dehumanization is avoided. Based on studies in HRI so far, we propose four main ways in which SARs could support the social behavior of health care providers and caregivers: (a) by raising awareness of one's social behavior and its effects on others, (b) by providing feedback that supports empathetic behavior, (c) by helping people set and maintain empathy goals for their interactions, and (d) by detecting and intervening when problematic interactions occur.

2.3.1 Raising Awareness of Effects of Social Behavior

A first requirement for self-correcting one's problematic social behavior is being aware of it and of its effects on others. However, oftentimes people remain oblivious to what they are doing and how it affects those around. Hoffman et al. [57] used an emoting and empathy-evoking robot, Kip1, to increase awareness of the effect of one's behavior in an interaction. The robot monitored nonverbal aspects of the conversation (speech, timing, silences and loudness) and responded with a gesture indicating curious interest when the conversation was calm and a gesture indicating fear when the conversation was aggressive. They used the robot as a peripheral companion in conflict conversations between couples. Couples were asked to discuss a topic they had high disagreement about in the presence of the robot. After the interaction, couples reported the same level of comfort in conversing next to the reactive robot as to the control, non-reactive robot which did not behave in response to their conversation. Also, couples attributed social human characteristics to the reactive robot. No quantitative data was reported on how the robot's reactions might have changed the conversation, but a qualitative account suggests that couples sometimes reacted to the robot's gesturing by adapting their own behavior, for example, pausing and taking the conversation in a different direction. Such capabilities in robots could also be used in the context of caregiving. This could assist health care providers and caregivers in monitoring their own social behavior and correcting unintended, dehumanizing or unempathetic aspects of the interaction.

2.3.2 Providing Feedback that Supports Positive Social Interactions

A step further in assisting people with the management of their social behavior is to provide feedback that supports positive social behavior. Tahir et al. [58] used a Nao robot for providing real-time feedback to participants in a dyadic conversation. The Nao sensed and recorded conversational cues (e.g., number of natural turns, speaking percentage, interruptions etc.) and prosodic cues (e.g., amplitude) and then used machine learning algorithms to determine the social state of the participants (level of interest, agreement and dominance). Based on its model of the participants' state, Nao would alert the speakers when their voice was too high or too low or when the conversation was problematic due to too many disagreements or interruptions. The robot provided sociofeedback, alerts through speech accompanied by body postures in the following situations: when the conversation partners seemed uninterested in the discussion ("You both seem uninterested."), when one person was speaking too much ("You are talking a lot."), when one person was being too aggressive ("Please calm down."), when someone's voice was too loud ("Please lower your volume.") or not loud enough ("I am sorry, I cannot hear you.") and when the conversation was proceeding normally ("Good, carry on."). To validate the use of the robot as a social mediator, participants were asked to produce certain behaviors such as talk too loud, too much or to interrupt frequently. Participants felt that Nao's performance was good in terms of clarity: whom it was addressing and what it was saying. In terms of timing, some participants felt interrupted by the Nao. Most importantly participants indicated that they liked receiving socio-feedback from Nao and voted the Nao as their second favorite platform for receiving sociofeedback after virtual humans.

As opposed to the study by Hoffman et al. [57], in which the robot had a peripheral role in the interaction, in this study the robot intervened in the conversation. Also, while in the study by Hoffman et al. the robot's behavior was evocative, in this study it was evaluative. Although the results of the study seem promising (participants reported favorable impressions of the robot and a desire to receive sociofeedback), it is unclear how welcome the sociofeedback would be in a real interaction, one in which behavior was not acted, especially when the robot points out undesired behavior. People might feel uncomfortable having their interaction evaluated in this manner by the robot.

Although research remains to be done to determine the ecological validity of this particular approach, the general idea of having robots infuse interactions with supportive social cognitions through sociofeedback merits further attention. In the context of caregiving, sociofeedback could help rapidly deescalate tense interactions and further encourage positive ones. The nature of the sociofeedback could be adjusted to the specific problems encountered by the caregiver and the robot could even act as an emotion regulation tool. Moharana et al. [17] recounts the desire of a caregiver who wanted a robot that could remind her that her husband's anger was not because of her poor care towards him but because of his dementia. Such reminders could be incorporated in the sociofeedback given during an interaction. Also, the sociofeedback need not be primarily negative. Activating positive social cognitions could be useful as well, for example the robot could point out how attentive the conversation partner is, how excited she is about the topic, or how much joy it brings her to be part of the interaction. Such cognitions could perhaps be empathy-inducing for the caregiver and humanize the person receiving care.

2.3.3 Promoting Positive Interaction Goals

Another way in which robots could support caregivers is by helping them set and maintain positive goals for their interactions. This could be highly beneficial in care scenarios especially in interactions that have competing and perhaps even conflicting goals, for example, making sure a person with dementia takes their medication on time, while also maintaining a patient, tolerant attitude in the face of their forgetfulness. Wilson et al. [59] have developed a framework for evaluating the design of human–robot relationships when tradoffs appear between the succesful completion of task, and the maintainance of positive relationships with the human user. This framework could be adapted to scenarios involing robot mediation of human–human interactions that require the balancing of different types of goals.

Short and Matarić [20] used robots as mediators in collaborative tasks, which influenced the interactions by promoting different types of goals. They developed two algorithms to specify the robot's behavior: one in which the robot suggests goals that are optimal from a performance-maximizing standpoint (performance-reinforcing) and an algorithm in which the robot suggests goals that the poorest-performing team member can help accomplish (performance-equalizing), thus increasing the collaborative contribution of this member. Contrary to their hypothesis they found that group cohesion was higher in the performance-reinforcing rather than the performance equalizing-condition. Group performance was also higher in the performance-reinforcing condition. They also found that the more a robot spoke to a participant, the higher the group cohesion they reported and the more they helped the other participants in the group. Participants completed over half of the robot's suggestions, although as the authors note there are further opportunities for improving the timing and salience of the robot's suggestions. Also, participants took more of the robot's advice in the performance-reinforcing condition than in the performance-equalizing condition. After the task, participants' attitudes towards robots on the *Attitudes towards Situations and Interactions with Robots* subscale of the Negative Attitudes towards Rorobts Scale became more negative.

The findings of this study are particularly promising because they clearly show that robots can modify people's social behavior in interactions. Additionally, the study develops and tests two different ways in which the robot could behave. This is important because further development of SARs for the social management of health will require a lot of fine-tuning and personalization of the robot's behavior to meet the specific needs of the user, determined by the user's particular health situation as well as personality and preferences. Through future research, it will be important to understand which suggestions or types of suggestions people readily take from robots and which they ignore. Also, a cause for slight concern is that participants seemed to have a more negative attitude towards the robot after completing the task, thus it will be important to understand how that would affect long-term use.

2.3.4 Detecting and Intervening in Problematic Interactions

Finally, SARs could help detect and intervene in problematic interactions between people with health conditions and their caregivers or health care providers. The idea is that when an interaction becomes problematic and a person with a health condition is misunderstood, rushed, blamed, deprived of agency, stigmatized, or met with insufficient empathy, the robot would intervene to remedy the situation. The robot's intervention could take different forms, focusing on adjusting the behavior of the person with the health condition as a way of helping the caregiver, focus on adjusting the caregiver's behavior or both.

Shim et al. [60] implemented and evaluated a mediator robot that intervenes in situations that might lead to the stigmatization of people with health conditions. Their approach was to focus on modifying the behavior of the person with the health condition, however, evaluative data from participants indicated that this might not be the preferred approach. The researchers implemented an intervening ethical governor model onto a robotic platform (the Nao robot), which models the relationship between the patient and caregiver, detects discordances between the patient's level of embarrassment and the caregiver's level of empathy, and intervenes through speech and movement to correct these gaps in communication and incompatibilities between emotional states. The researchers devised four different scenarios illustrative of four ethical rules of interacting: prohibition of angry outbursts from the patient, prohibition of withdrawal from the patient, obligation of the patient to stay in the therapeutic activity/session, and the obligation of the patient to follow safety requirements. Four videos were recorded of acted problematic interactions illustrating the intervention of a mediator robot who followed the rules above. Qualitative data was obtained from nine elderly participants who were shown the videos and who were guided through standardized open-ended interviews about the scenarios depicted in the videos. Participants felt that the most appropriate and essential type of intervention of the robot was the one corresponding to the "safety-first" rule, in which the robot made sure the patient follows safety requirements. Participants had a negative reaction to the robot's intervention in the other scenarios, feeling that the robot sounded judgmental, commanding and critical of patients, which was deemed unacceptable. In the videos, the robot always addressed the patient rather than the caregiver and the rules referred to the patient's behavior rather than that of the caregiver. Participants indicated that it would be more appropriate for the robot to indicate to the caretiver situations needing intervention. The robot should do this in a subtle way and then allow the caregiver to remedy the situation instead of the robot intervening.

Further research is clearly needed to establish the best ways in which robots could intervene in problematic situations. As we have seen, the robot intervention itself can increase the feeling of blame and criticism, which was perceived as unacceptable. Also, as participants imply when talking about their preference for the caregiver to handle the remediation, some actions might be seen as appropriate coming from a human interactant but not from a robot. An example, perhaps not of an appropriate intervention per se in the social management of health context, but of a study that has systematically attempted to compare human with robot intervention is [61]. Stoll et al. [61] studied the use of humor by robots for conflict mitigation. Humor has been shown to alleviate tension in interpersonal conflict, which makes it a commonly used strategy for diffusing conflict [62]. Participants watched videos of robots or humans using humor to diffuse a conflict situation between two roommates. Although affiliative and aggressive humor was perceived as less appropriate when used by a robot rather than a human, self-defeating humor was well received from both. Unfortunately, the study does not report how effective people felt the humor was at diffusing conflict.

Oftentimes the behavior of both interactants needs to be adjusted for a problematic situation to be remedied. A study by Shen et al. [23] offers an example of how a robot could intervene and guide the remediation of a problematic situation. Principles from this study could be extended and adapted to applications in the context of caregiver-care recipient relationships. Shen, Slovak and Jung used a mediator robot to support children in resolving interpersonal conflicts constructively. What is interesting about this robot is that its actions were programmed around formalized steps from a conflict negotiation procedure: Teaching Students to be Peacemakers (TSP). Examples of steps are: stating what you want and giving your underlying reason ("I want…because…") or expressing how you feel ("I feel mad or sad."). The robot facilitated the conflict resolution by identifying when a conflict was happening, alerting the children and then guiding them through the negotiation steps by using prompts matched to the protocol steps, such as: "Telling each other what you want/how you feel can help. Can you try that?". This robot was operated in a Wizard-of-Oz manner, so more development is needed in terms of making the robot autonomous and robust to the messiness of natural dialogue. Attention should be paid to proper timing and pacing so that the robot can intervene at the right time and follow an appropriate progression through the protocol steps. Using protocols for supporting interactions can, however, be a very fruitful approach for designing mediator robots, because of the scripted nature of conversation protocols, which are easier to handle by robots. Conversation protocols are good tools for structuring interactions. In the following section we summarize and expand on studies which have investigated how robots can provide structure to interactions through conversation protocols and other methods.

2.4 Providing Structure to Social Interactions

Providing structured interactions for people is perhaps the most valuable way in which SARs could support the social management of health. People with health conditions, especially the elderly, are at high-risk for isolation, which can have serious detrimental effects on health [63]. It is thus valuable for SARs to create opportunities for people with health conditions to interact with others and participate fully in social life. Structuring social interactions in ways that make it easier for people with health conditions to join in and follow along is thus crucial. There are different levels, of increasing complexity, at which SARs could structure social interactions for people: (a) by serving as the focus of attention and anchoring the interaction, (b) by moderating an interaction, providing participation opportunities through speech and acts of encouragement, and overall promoting inclusiveness, and (c) by guiding people through standard interaction protocols or exercises.

2.4.1 Anchoring Interactions and Focusing Attention

The lowest level of structure for an interaction is offering anchoring, serving as a point of focus and through that creating an opportunity (or an excuse) for interaction. To accomplish this, the SAR does not need to have very sophisticated capabilities, it simply needs to behave in a way captivating enough that it prompts conversation between people interacting with it. This low-level support for structuring human–human interactions by robots has already been fairly widely explored especially with older adults.

Wada and Shibata [32] used the Paro robot in a care-house for the elderly in Japan. Paro is a pet-like robot in the form of a seal pup which responds to sounds and touch by making noises and moving. The robot was placed in a public area where the residents of the house could meet to interact with each other and was activated for 9 hours every day. The researchers found an increase in density of the residents' social networks after the introduction of Paro, which suggests that the robot stimulated communication among residents, strengthening their social ties. Additional data from this research project presented by Wada and Shibata [64] showed that the time residents spent in the public area increased after the introduction of Paro. Qualitative data suggest that residents who felt impaired in their communication due to speaking in a different dialect found Paro useful in breaking down this communication barrier and felt more comfortable talking to others. Additionally, caregivers and residents remarked that the topics talked about became more positive when Paro provided an anchoring for the conversation.

In the United States, Kidd et al. [28] used the Paro robot in two nursing homes to investigate whether robot interactions generated more social activity. People who interacted with Paro in its "On" mode had more social interactions and this effect was further increased by the presence of caregivers or experimenters participating in the interactions. The authors conclude, drawing also from previous experience with using robots in nursing homes, that robots could be useful at stimulating small group engagement and could be a beneficial addition to the very impoverished social setting of elder-care facilities, which usually consists of the TV room where people, even if in each other's presence, do not engage in conversation with each other.

Robinson, MacDonald et al. [65] also used the Paro robot in a residential care facility and compared its effect on social interactions with the effect of an actual pet. The facility benefited from visits from a dog belonging to the activities coordinator. The behavior of the residents was observed during various activities, during the dog's visit and during group interactions with the Paro robot. Observations showed that more residents were involved in discussions about the robot in comparison to discussions about the resident dog, and the robot appeared in more conversations amongst residents and with staff members than the dog. This could simply be due to the fact that no special activities were organized around the dog, while group gatherings to interact with Paro were organized, even though the specific way in which participants interacted with the robot was not prescribed.

For a more systematic (although perhaps less ecologically valid) investigation of Paro's effects on social interactions, Wood et al. [27] conducted an in-lab study using the Paro robot for social mediation in human–human interactions. Participants were asked to interact with the robot together in any way they wanted to. The study presents more direct, quantitative data on the effects of the robot on social interactions. Participants in the active Paro condition (the robot being "On") rated the quality of the interaction and the enjoyment of interacting with the other person as higher. Although Paro is not designed specifically to encourage interaction between people, the robot's social mediation effect likely came from serving as a focus for the interaction.

Paro, is not the only robot that has been used to elicit human–human interactions. Joshi and Šabanović [66] investigate the use of a variety of robots for stimulating intergenerational interactions in a nonfamilial setting: a co-located preschool and assisted living center for older individuals with dementia. They used four commercially available robots: Paro, Joy for All, Nao and Cozmo, which have different capabilities. Paro and Joy for All are pet-like robots that react to being held or stroked. Nao is a humanoid robot that can speak, move and track people, and Cozmo is a palm-held robot that can drive, speak in short sentences and express emotions. The experimenters worked in collaboration with the preschool and assistive living center staff to design activities that would lead to interactions between the residents and the preschoolers, customizing for the values and goals promoted by the center: increased inter-generational contact, increased peer engagement, meaningful interactions for both adults and children, opportunities to collaborate and share, and reduced need for outside management of the activity. By observing the behavior of the participants during the interactions, the experimenters found that activities involving robots were often able to provide more opportunities for intergenerational interactions than other types of activities such as drawing, puzzle solving and making music, and also required less intervention from staff members. The best robots for inter-generational interactions were Paro and Joy given their slow pace for responding which prevented older adults from getting overwhelmed and made the children impatient and inquisitive, giving the older adults opportunities to interact with the children. The Cozmo robot, although it facilitated peer interactions among children was not engaging for the older adults. The study is a great example of possibilities for introducing robots that can enhance interactions in real-world settings by working closely with the community members involved.

Robots' abilities to stimulate social interactions has also been studied with children with autism. Werry et al. [67] used a mobile robot in dyadic play interactions between children with autism. They observed three pairs of children interact with the robot and with each other, and concluded that by serving as a focus of attention, the robot facilitated interesting types of interaction structures between children, such as instruction, cooperation and even possibly imitation. This was one of the first observational studies exploring interaction structures in autism afforded by the introduction of robots as an anchor for human–human interactions.

A more sophisticated way of anchoring and eliciting interaction between people is to go beyond using the robot simply as an attention focus, and instead have a robot play different active roles in an interaction. Given the current limitations of robots, and the fairly narrow number of tasks any given robot can perform, games can be a suitable context in which mediator robots can be used. Short et al. [31] studied family groups as they played games with a robot, with the goal of improving intergenerational family interactions. The robot played different roles depending on the game, being a competitor, a performer (one game consisted of working as a team to make the robot dance), or supporter - making positive comments about the family's collective creation in a scrapbooking creative game. Unfortunately, the study does not explicitly measure how specific robot behaviors affected the interaction between family members. The study was instead focused more on how the different group members perceived and interacted with the robot and their engagement with and thoughts about the games. However, this study is a great example of a protocol that could be used to study robot support for "gamified" interactions. For people with health conditions, especially for children with health conditions, therapeutic game-play supported by SARs can be a motivating way to develop and practice social skills.

2.4.2 Moderating Interactions and Promoting Inclusiveness

The studies explored so far in this section focus on increasing the motivation of people to participate in social interactions. However, even when the motivation to interact exists, people with health conditions often encounter challenges in terms of entering ongoing interactions and keeping up with them. For example, people with Parkinson's Disease, due to slowness of speech and word-finding difficulties, have a hard time entering a conversation or keeping up with the rapid pace of one [68,69] . Children with autism have difficulties producing appropriate social behaviors to initiate and maintain social interactions [70]. People with social anxiety or simply people that are unusually shy can also have a difficult time to get a piece in edgewise in a conversation. SARs could support these people by moderating social interactions, offering assistance for conversation and group entry, and generally promoting social behaviors that lead to inclusiveness.

For example, Short et al. [25] used a robot to moderate a group storytelling activity. The robot kept track of participation (how much each group member spoke) and asked general or specific questions at fixed time intervals to the participant with the least speech in the last time interval. Each group participated in the task twice, one time with the robot as moderator and one time with the robot as "active listener"—the robot watched the speaker and produced an utterance such as "huh" or "okay". They found marginally significant results for an increase in group cohesion in the moderated condition and increased speech in the moderated as opposed to the unmoderated condition.

Another example of study in which a robot was used to promote conversation inclusiveness was conducted by Tennent et al. [71] who used a peripheral robotic object to increase group engagement and also to improve problem solving performance. They designed a robotic microphone that exhibited two engaging behaviors: following—turning towards the person speaking, and encouraging—rotating towards the participant who spoke the least and leaning towards that participant as an invitation to speak. The authors found that the robotic device, when operating according to the above described engagement algorithm, increased evenness in backchanneling: namely the participants took a more even number of turns to engage in active listening of one-another. The evenness of group backchanneling turns then significantly predicted problem-solving performance on the Desert Survival task (participants were discussing the rank order of 15 most useful items for surviving in the desert, their response as a team being compared to that of experts).

These studies show that speech, and even minimal non-verbal gestures can be successfully used by robots to promote inclusion of others in social activities. Furthermore, Mutlu et al. [24] have shown that robots with fairly low capabilities can be effective in shaping the roles of people in conversations: as addressees, bystanders or overhearers. Through gaze cues alone, by looking or not looking at the participant when talking, the robot was able to manipulate who participated and attended to a conversation as well as the participant's feelings of groupness and their liking of the robot. Participants to whom the robot communicated the role of addressee attended to the task more and felt stronger feelings of groupness. Participants whose presence was acknowledged by the robot, those in the role of addressee or bystander liked the robot more.

A more detailed investigation into the specifics of how a robot should act to make sure people can participate meaningfully and equally in conversation is described by Matsuyama et al. [21]. They used a robot for facilitating a conversation between three participants in which two participants had a strong engagement with each other evidenced by lots of back-and-forth conversation turns, and one of the participants was left out (side-participant). The robot acted as a fourth participant to the conversation and its goal was to "harmonize" the conversation, by engaging the person left out. The robot had to detect the strength of the engagement between participants and identify the participant who had a side role. Then the robot intervened to include the unengaged participant. Videos were recorded of conversation scenarios and participants were asked to rate the appropriateness of the robot's behavior, the feeling of groupness and the timing of the robot's intervention. The robot intervened in the conversation either by directly addressing the participant who was left-out or by initiating a procedure: first addressing a comment to one of the engaged participants (i.e., claiming an initiative), waiting for a response (i.e., approval of the initiative) and then yielding the floor to the left-out participant. In this process, the robot either maintained the topic of conversation or initiated a new topic. Participants felt that the robot behaved most appropriately and there was a stronger sense of groupness when the robot attempted to include the side-participant by initiating a procedure without shifting the topic of conversation. Participants felt that intervening after two rounds of back-and-forth between the engaged participants was more appropriate than after the first round.

These studies demonstrate that robots can meaningfully moderate interactions to encourage the inclusions of people who would otherwise be left out. All these studies were conducted with healthy participants, but the robot design features presented can be applied also to the social management of health, addressing the needs of people with health conditions for participating more fully in social life. Further research is needed to determine what adjustments in the robot behavior might be needed to address specific needs related to health conditions. For example, robots might need to engage in additional special behavior in order to slow down a conversation to make sure someone with poor processing capacities has enough time for comprehension.

2.4.3 Guiding Interactions Through Therapeutic Protocols and Exercises

The highest level of interaction structuring that SARs could provide is to guide people through structured interaction tasks or protocols. Therapeutic programs often incorporate structured interaction exercises, which are easier for robots to handle than free dialogue. SARs could be used as facilitators of such therapeutic exercises focused on improving interactions between people as a supplement and reinforcer to human-delivered therapy. For example, Utami and Bickmore [30] explored robot-driven couples counseling using a humanoid robotic head. The robot was operated in a Wizard-of-Oz manner and it guided couples through a rapport-building task and two counseling exercises: a gratitude exercise in which the couples were asked to recall and share three recent positive behaviors of their partner and the Caring Days exercises (commonly used in the Behavioral Couples Therapy) in which each partner made a request for a behavior that the other member of the couple could perform to show that they cared. The robot explained the rationale for the exercises, asked the couples to engage in the exercise and provided feedback. The study found a significant decrease in participant's negative affect post-intervention and a significant increase in self-reported intimacy. The couples indicated that they enjoyed the interaction with the robot and with each other and they rated their partner's responsiveness as high. Also, intimate behaviors such as touching and comforting were observed during the session. The post-session open-ended interviews revealed interesting insights about people's experience with the robot. Participants felt that the robot's responses were very generic and that the interaction was too structured, which could perhaps be improved in future iterations of the study by having the robot engage in some naturalistic, random behavior extraneous to the task. However, what is encouraging is that even though participants thought that a human counselor would be more genuine and better at understanding non-verbal behaviors (such as facial expressions) some participants felt that the advantage of the robot was its ability to stay non-judgmental and unbiased. Also, very promising is that participants indicated that the interaction with the robot was preferable to reading self-help material and practicing exercises by themselves. They recognized the robot as being helpful in structuring the interaction as a "neutral third party". Even couples who were familiar with the skills practiced with the robot liked being reminded of them. Using SARs for therapeutic exercises like these which could also be relevant for strengthening the bonds between caregivers and care recipients are very much in line with what participants in the study by Moharana et al. [17] expressed: a desire for robots to help accentuate positive shared moments with the person they were caring for and act as neutral parties to diffuse tension when unwanted tasks needed to be completed (e.g., adherence to treatment). Guidance through structured interactions can be used not just for creating positive connections but also for remedying strained ones. We have already discussed in the previous section the study by Shen et al. [23] which is an example of an interaction protocol for conflict resolution.

Finally, robots can assist people assist others by guiding them through assistance-giving protocols. Many caregivers are family members, not trained professionals, and it can often be difficult for non-professionals to gauge the right amount of support needed by the person requiring care, so that their autonomy does not get impaired. Robots are far from being able to replace human caregivers altogether, not to mention that for most situations this is likely an undesirable goal. Therefore, the teaming of humans and robots in assistance-giving is the objective we are proposing. Robots can help structure assistance giving interactions between caregivers and care recipients. An example that doesn't come from the health care context, but from teaching, illustrates some possible functions for the robot: providing instructions for the task, assigning roles, and prompting the caregiver to offer different types of input that could be corrective feedback, praise, encouragement etc. Chandra et al. [22] compared a robot and a human facilitator of a collaborative learning activity. Children engaged in a learning-by-teaching task, in which one child taught the other how to write different letters or words. Either a robot or a human acted as facilitators by introducing the task, assigning roles (teacher or learner), providing instruction throughout the task and prompting the teacher-child to provide corrective feedback to the learner child. The video and audio recordings of the session were coded. Teacher-children provided more extended corrective feedback with the robot facilitator and more minimal corrective feedback with the human facilitator. Authors argue that the teacher-children felt more responsible regarding their performance in the presence of the robot. Combining these results with the duration of gaze that the facilitator directed towards the children (the robot made longer-duration gazes than the human facilitator) the authors conclude that two different patterns of interpersonal distancing emerged: in the case of the robot facilitator children followed the reciprocity model (responding to closeness with closeness), in the case of the human facilitator they followed the compensation model (responding to distancing with closeness).

The overall goal of having structured interactions is to ensure that they are meaningful, positive and inclusive. This is beneficial for the strengthening of relationships between people with health care conditions and health care providers, caregivers, and others. Most importantly, these robot-assisted interactions should improve the quality of life and sense of well-being of the person with the health-condition. This is why one of the functions of SARs needs to be that of engendering positive feelings for people with health conditions in social contexts.

2.5 Changing How a Person with Chronic Illness Feels in a Social Context

Social situations can be stressful for people with health conditions. This can be due to the specifics of the health condition, for example, people with Post-Traumatic Stress Disorder can feel uncomfortable in social situations that trigger traumatic memories [72], but more generally it can be caused by the stigma associated with health conditions [73]. Stigma can take various forms: feeling ostracized, devalued, scorned [74]. Many people with health conditions experience psychological distress from perceived stigma from others [75].

2.5.1 Promoting Positive Feelings in Interactions

We've already discussed studies of robots that can help people experience more positive feelings in social interactions. These ideas can be used to create SARs that help combat some of the negative effects of stigma. For example, behaviors of the robot used by Tennent et al. [71], such as inviting people to join a conversation through movement, could be used for developing and testing robots that help people with health conditions feel welcomed and encouraged to participate in social interactions. Also, behaviors from the robot used by Mutlu et al. [24], such as the use of gaze to suggest conversation roles, could be adapted to create feelings of inclusiveness for people with health conditions.

An example of a robot specifically designed for influencing how a person feels in a social interaction with another human was tested by Pettinati et al. [76]. They used a social robot (Nao) for active listening. The robot was envisioned as a peripheral addition to an interaction between two people. The robot indicated active listening by turning its head towards the person speaking. Participants perceived the active robot as having more of a social presence than the controls (a non-active Nao and a plush toy) but participants felt equally comfortable self-disclosing in front of the active robot. The lack of a negative impact of the robot's presence for self-disclosure is encouraging for the prospects of designing a mediator robot that does not detract from the interaction between humans. The absence of negative effects is a start, but further research is needed to establish whether the robot contributed any additional positive psychological effects of feeling listened to when disclosing personal information to another person.

2.5.2 Mitigating Negative Feelings in Interactions

In this paper we specifically review studies that used robots to support social interactions between people, but many ideas from human–robot interaction studies can be adapted to the social mediation context. For example, roboticists are developing pet-like robots to assist with stress reduction during counseling sessions [77]. Stress-reducing robots could also be used to help people with social anxiety in a variety of social circumstances.

Although still in its initial stages, the development of mediator SARs for the social management of health is replete with opportunities for further design and HRI research. However, challenges of designing, testing and beneficially integrating these systems into our lives and health management also warrant discussion.

3 Challenges of Designing and Using Mediator SARs

There are four classes of challenges that exist with regards to designing and using SARs for the social management of health: (a) challenges related to the status and well-being of the person with the health condition, (b) challenges related to the impact of SARs on human–human interactions, especially the unforeseen or unwanted effects, (c) challenges related to the broader social and cultural context and (d) challenges related to the features and usefulness of the robot itself. For a successful embedding of SARs in the caregiving context, these challenges will need to be overcome through ingenious design and most importantly careful research.

3.1 Challenges Related to the Status and Well-Being of the Person with the Health Condition

3.1.1 Preservation of Autonomy and Dignity

In a mediator role, SARs will assist interactions between two or more people. However, the health and well-being of the person with the health condition using the SAR is of primary importance, as this is the reason for developing SARs in the first place. The challenge with giving any type of assistance (but perhaps even more importantly when giving assistance through the use robots) is the preservation of the person's autonomy and dignity. Sharkey and Sharkey [78], warned that careless use of assistive robots could lead to a loss of control of important aspects of one's life and feelings of objectification, and Wilson et al. [79] proppose that the concepts of autonomy and personal dignity, which are guiding ethical principles in occupational therapy, should be incorporated into the desgin process of social robots. Because people with health conditions are a vulnerable population, there is concern that robotic assistance would lead to a loss of personal liberty. One way in which this could happen is through overreliance on the robot, leading to enfeeblement and then dependence. If the robot completely takes over a certain task or important aspects of it (with regards to the robot functions proposed by this paper, one such task is the management of interactions) the worry is that people might lose the ability to perform the task themselves. For example, if a person becomes overly reliant on the robot alerting them to problematic nonveral aspects of a conversation (a function explored in Sect. 2.3.1) instead of using the robot's feedback to improve one's attention to cues from the interlocutor, this might lead to more problematic interactions in the future when the robot is not present. With some tasks this might be fine, as the person might have already lost that ability because of the health condition (for example, for severe dementia the function of redirecting conversation to non-repetitive topics might be needed for the remainder of the person's care), but with others, effortful attempts to maintain abilities might be desirable for independence. SARs involved in the social management of health should thus support rather than take over the task of initiating and sustaining interactions between people. As mentioned above, the right level of direction and assistance should be established through research.

3.1.2 Ownership, Control and Authority of the SAR

Another way in which personal liberty of people could be encroached on has to do with the status of the person with the health care condition with regards to the SAR: who owns the SAR and who controls it? [80] Also, what obligations does that SAR have towards the different people that are part of the caregiving ecosystem? [81] This is an especially important consideration for the SAR functions that we propose in this paper. We are focusing on robots that can manage social interactions between people, and although the ultimate goal of the robot is to support the social management of health of the person with the health condition, precisely because it is a robot designed for supporting interactions between humans, the robot would serve multiple people, including health care providers, caregivers and other people belonging to the social circle of the person with the health condition. Also, given that health conditions can impair people's judgement, it is not always feasible that the authority over the robot and its use remains with the person with the health condition. In fact, in some situations it might be desirable that the robot itself exert authority over the person with the health condition. We learned from the study by Shim et al. [60] that people felt that the robot should never have the authority to judge patients. On the other hand, participants in the Utami and Bickmore study [30] welcomed the mild social pressure from the robot when the robot successfully prompted them to perform the therapeutic interaction exercises. Even more so, caregivers participating in the study by Moharana et al. [17] wanted a robot to have much more authority and adopt the role of a neutral third party who would determine the person receiving care to do things that they do not wish to do, but need to for their own good, for example, taking their medication. Some participants even envisioned that the robot would do this using the doctor's voice. The balance between assistance and autonomy should be decided preferably on a case by case basis and by taking into account the context. However, the functions we specify in this paper are very much subservient to the goals they try to achieve, which is not just preventing isolation, but also preserving autonomy and preventing dehumanization and stigma.

3.1.3 Deception and Unidirectional Emotional Bonds

Another aspect of using SARs that has been flagged as potentially contributing negatively to the life and dignity of the person assisted is the issue of deception [17], infantilization [78] and inauthenticity of the human–robot interaction [82]. SARs capitalize on the deeply ingrained human propensity to engage with lifelike social behavior and use this engagement for natural interaction with people [6].

Robots today can behave in lifelike, social ways, but they are neither alive nor do they actually feel any social emotions. But the person assisted by the robot, especially those who are struggling with cognitive impairments, can be tricked (much like children are), by the robot's behavior into believing the robot is something it is not. Especially when features such as touch (which would very likely be available in a healthcare robot) may amplify feelings of intimacy [83]. This could lead to the formation of unidirectional emotional bonds in which the person harbors feeling for the robot but the robot is ontologically unable to reciprocate [84]. This could be particularly problematic when the SAR is used for long periods of time and attachment is developed. As Sharkey and Sharkey, discuss, there are different levels of "buying into" the robot's behavior and acting "as if" the robot truly had social feelings, some of which are acceptable and some which border ethical concern. The functions we envision for SARs in this paper, namely that of supporting social interactions, could perhaps mitigate some of the concerns regarding deception and formation of problematic emotional bonds. In its most offending form, deception from SARs is when people start believing that the SAR is a companion that understands and shares their deepest feelings. The functions we propose for SARs shift the focus from the human–robot relationships to the human–human relationships, for which the robot simply offers support. The purpose of the robot intervening is not for it to offer companionship, but to optimize the ways in which people offer companionship to each other. Additionally, having another human in the loop (often the caregiver), can help with the supervision and correction of any problematic aspects of the relationship between the robot and the person assisted.

3.2 Challenges Related to the Impact of SARs on Human–Human Interactions

3.2.1 Potential Reduction in Human Contact

With regards to human–human interactions, a common concern raised in relation to SARs in general is the potential drastic reduction in human contact [17,78]. If caregiving tasks are taken over by robots, the fear is that humans needing assistance will end up interacting mostly with robots rather than other fellow humans, and this will have detrimental effects on their social life and health. This concern is especially pertinent to the function of SARs as providers of companionship. However, the vision presented in this paper, is quite the opposite. We suggest that SARs should adopt mediator roles and assist people with health conditions in their social management of health. We propose not for robots to diminish or replace human social contact, but on the contrary, to increase and enhance it. This paper thus proposes functions for SARs that are different from the ones evaluated by Sharkey and Sharkey, which focused on SARs assisting with daily tasks, monitoring behavior and health and providing companionship.

3.2.2 Alteration of Human–Human Interactions

However, our vision is subject to a different concern: that mediator robots would inadvertently alter and negatively impact human–human interactions. A robot embedded in an interaction could detract from it by being an unwelcomed distraction [71]. Instead of focusing on each other, people would instead focus on the robot and change their interaction to accommodate the robot. A way to think about this issue is in terms of foregrounding or backgrounding of interactions by robots, and the amount of direction they offer [17]. Based on the specific needs of the interaction and of the interactants, the robot could take a peripheral role, subtly cueing people to potential opportunities or problems in their interactions, or a more leading role, directing the interaction between people. Moharana et al. suggest for example that in the early stages of dementia, and when the interaction is positive and satisfying for both the caregiver and the person receiving care, a mediator SAR could have a peripheral role in interactions. However, as the disease progresses and interactions become more frustrating, for example, because of agitation and forgetfulness, the robot could take on more the role of conversation partner in the interaction, taking over the stressful task of answering repetitive questions and providing redirection. However, it is important for the robot to not only intervene in negative situations, but also when it detects opportunities for positive social interactions, lest it be perceived as a "watchdog" and its interventions associated with unpleasant events [23]. In the sections above, we've seen examples of mediation from both peripheral robotic devices, such as the ones from Hoffman et al. [57] and Tennent et al. [71], and also mediation from robots in leading roles, offering high amounts of direction such as those developed by Shen et al. [23] or Utami and Bickmore [30]. Further research is needed to establish the factors that should dictate the degree of robot involvement in an interaction. The factors proposed by Moharana et al., namely stage of health condition and positivity of interaction, are a good start, but more factors need to be tested, including but not limited to the preference and personality of the interactants or the type of interaction.

3.2.3 Disruption of Intimacy and Privacy of Interactions

SARs, through their social presentence could also disturb the intimacy and privacy [78] of the interaction and actualize the proverbial "two is company, three is a crowd". As we've seen, Pettinati et al. [76] found promisingly that the robot's presence did not have any negative effects on self-disclosure when embedded in an interaction between two people, however more research is needed to establish that this is the case across contexts. Pettinati et al. only showed this in the context of a conversation between two strangers, an interviewer and an interviewee, not between, for example, people who know each other and have a long relationship history. On the other hand, the robot's presence might in some cases be more tolerable than that of another person. Participants in the couple's therapy study by Utami and Bickmore [30] indicated that it was easier for them to perform the exercises and disclose things in front of the robot than it would have been in front of a human therapist. More generally, Mutlu et al. [24] showed that robots can have an effect on how people feel about an interaction. Of course, this possibility is a great opportunity to use the robot's leverage to create positive interactions between people, but it is also a warning sign that unintended negative effects might also occur, and they should be carefully researched.

3.3 Challenges Related to the Broader Social and Cultural Context

The caregivers and the care recipients assisted by the robot are not the only ones that need to be considered in designing the SAR. It is important that the robot is seamlessly embedded in the social and cultural context. Cultural differences exist with regards to caregiving and illness [17] which result in different roles, degrees of autonomy, and experiences for the caregiver and the person being cared for. Also, different cultures may have different attitudes towards robots, their form and functions [85]. An example of how to ensure the robot fits the needs of the community it serves, is the study by Joshi and Šabanović [66], which worked with the local community to better understand their goals in terms of integrating robots in the context of social interactions. For example, prior to designing the activities and introducing the robots, Joshi and Šabanović, conducted extensive interviews with the staff at the preschool and the assistive living-dementia care center where the robots would be used. The interviews helped them identify the following community goal: to engage older adults and children in activities that were meaningful for both groups, with the purpose of facilitating relations similar to grandparents and grandchildren. The authors then systematically investigated the usefulenes of different robots for achieving this goal. They conclude that some robots were not well suited for what that community wanted. For example the Cozmo robot led to activities that were too fast-paced for the older adults, and which distracted the children from meaningful intergenerational engagement rather than facilitating interaction.

3.4 Challenges Related to the Features and Usefulness of the SAR

3.4.1 Ability to Adapt

A key challenge and feature of the SAR, in order for it to be successful, will be its ability to adapt [6,17]. Adaptability is important to keep pace with the progression of the health condition and the changing needs and contexts of the person assisted. In many of the studies discussed, the positive effect of the robot on social interactions stems from the robot being an interesting gadget that prompted people to interact with each other about it. However, we know little about what would happen once the novelty effect wears off. Ideally, the robot and its repertoire of interventions would continue to change over time both as technology progresses and as more research establishes new effective interventions. The SAR should also be personalized to the preferences and needs of the person using it [6,17]. People react differently to different intervention styles. A major gap in the literature describing uses of robots as mediators of human–human interactions, is the lack of studies focusing on individual differences and how they modulate the robot's effect.

3.4.2 Creation and Meeting of Expectations

Connected to the challenge of deception explored above, SARs should be designed in mindful ways that do not create expectations that are not met [71]. For example, just because a robot can offer suggestions of conversation topics, it does not mean that it has an understanding of what people talk about. The status of the mediator robot as something in between a tool and a social interaction partner needs to be given proper consideration. As mentioned above, features that subconsciously convey social signals and imply capabilities that the SAR does not have (such as touch conveying social bonding and a capability for affection) should be carefully researched before being implemented. Roboticists should also be mindful about expectations regarding avaiability of the SAR. As discussed above, the SAR should not lead to enfeeblement and loss of autonomy.

3.4.3 Robustness and Safety

Finally, SARs need to be robust in terms of their ability to carry out the functions they are designed for. Since SARs for the social management of health are envisioned to assist vulnerable populations, potential technical problems need to be reduced to a minimum [71]. When robots that simply provide entertainment fail, the failure might be more tolerable and less costly, but when people rely on robots for tasks that have significance for their health, technical issues become seriously problematic.

4 Conclusion

In this paper we proposed five classes of functions for SARs that would support the social management of health by assisting human–human interactions. We've identified the research gaps in our understanding of how a robot could change the way a person with a health condition is perceived by others. We have illustrated through some previous results, mainly from case studies, how robots could enhance the social behavior of people with health conditions by addressing the impairments specific to the health condition. We summarized the research on how robots can modify the social behavior of people both for further enhancing positive interactions and for correcting negative ones. We surveyed the research studies that have used various levels of robot intervention to structure human–human interactions in both clinical and non-clinical settings. Finally, we exemplified through previous findings how people's feelings in a social context might be changed for the better by the introduction of a robot into the interaction. While reviewing the literature relevant for the mediator role for SARs, we have identified opportunities for further research and robot design. We discussed potential challenges in the design and use of SARs and showed that when the focus of the SAR's intervention is on the enhancement of the human–human interaction not on the replacement of caregivers, many of the general concerns with regards to SARs can be mitigated. The existing literature and the promising research avenues identified suggest that the development of SARs for the management of social interactions could yield important benefits for health.

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Compliance with Ethical Standards

Conflict of interest The authors declare that they have no conflict of interest.

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