International Journal of Social Robotics (2021) 13:795–831
https://doi.org/10.1007/s12369-020-00664-7

SURVEY

Socially Assistive Robots: The Specific Case of the NAO

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Accepted: 28 May 2020 / Published online: 20 June 2020

Abstract

Numerous researches have studied the development of robotics, especially socially assistive robots (SAR), including the NAO robot. This small humanoid robot has a great potential in social assistance. The NAO robot's features and capabilities, such as motricity, functionality, and affective capacities, have been studied in various contexts. The principal aim of this study is to gather every research that has been done using this robot to see how the NAO can be used and what could be its potential as a SAR. Articles using the NAO in any situation were found searching PSYCHINFO, Computer and Applied Sciences Complete and ACM Digital Library databases. The main inclusion criterion was that studies had to use the NAO robot. Studies comparing it with other robots or intervention programs were also included. Articles about technical improvements were excluded since they did not involve concrete utilisation of the NAO. Also, duplicates and articles with an important lack of information on sample were excluded. A total of 51 publications (1895 participants) were included in the review. Six categories were defined: social interactions, affectivity, intervention, assisted teaching, mild cognitive impairment/dementia, and autism/intellectual disability. A great majority of the findings are positive concerning the NAO robot. Its multimodality makes it a SAR with potential.

Keywords Socially assistive robot · NAO · Social interactions · Affectivity · Intervention · Assisted teaching · Mild cognitive impairment · Dementia · Autism · Intellectual disability

1 Introduction

In the last decade, robot's industry has expanded at an impressive speed. From the first industrial robot, Unimate, invented by George Devol in 1954 and commercialised by him and Joseph Engelberger in 1961, this field of research has come a long way [1]. We can now see all kinds of robots emerging, from the athletic robots to the socially assistive ones. They are all widely used in numerous contexts. Robotics represents a great avenue to contribute to solve problems, e.g. the engorgement of health care system, developing specific functions in many populations and stimulation of cognitive functions in elderly. According to [1], there are five robotics generation: Prototypes of Robotic, Robotics Arms, Walking Robots, Behavior Based Robots and Humanoid Robots. Currently, we are in the fifth generation of the development of robotics, namely the Humanoid Robots, since 1996. Thus, humanoid robots could be named socially assistive robots (SAR) because of their ability to simulate empathy by mimicking human gesture and to perceive emotions when programmed [2, 3].

Two main literature review on SARs have been published in the last few years, both concerning socially assistive robot for elderly [4, 5]. No literature review on SARs in general were found. First, [5] categorize the assistive robots for elderly in two categories, rehabilitation robots (assistive robotic devices) and socially assistive robots. The rehabilitation robots include intelligent wheelchair and exoskeletons. The second main category is socially assistive robot, which is itself divided in two types, namely service type robots and companion type robots. The service type robots are used to assist the person in daily activities, like eating, bathing and getting dressed. The Care-o-bot is an example of a service type robot [6]. The companion type robots are used to improve psychological well-being and health. The

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NAO robot would be part of this category, but there is not much studies concerning its uses until 2012. Furthermore, these categories are not exclusive; a social robot can be used in rehabilitation experiences or the other way around. The authors conclude their review by saying that companion type robots have proven to be effective in improving mood, loneliness and connection with others.

Since there has been numerous studies concerning SAR, [4] aimed to establish their value in eldercare. Thus, they described five roles that can be fulfilled by the robot, which are: (1) affective therapy, (2) cognitive training, (3) social facilitator, (4) companionship and (5) physiological therapy. The main findings of this study are that SAR significantly improved cognitive results, sociability and loneliness in line with the second, third and fourth roles. However, these positive effects have not been found in the affective therapy. Indeed, SAR enhances mood, but the improvement is comparable to a soft toy or a placebo robot, so one might question the financial benefits of using the robot for this only purpose. Finally, for the last set, physiological therapy, studies find positive effects of the robot on blood pressure. Although, they are hard to interpret because many external variables could influence the results obtained, like interaction with others or the affective therapy role of the robot (calming down the participant). Further research is thus needed to clarify the real impact of the robots.

In this paper, we focus on the studies that exploit one specific model of humanoid robot, namely the NAO robot (Fig. 1). It is important to note that the NAO robot was referred to as the ZORA (Zorg [Health], Ouderen [Elderly person], Revalidatie [Rehabilitation], Animatie [Animation]) robot in some studies [7]. The ZORA robot is in fact a software specifically designed for rehabilitation and elderly care. The software is combined to the NAO robot and was named ZORA, but the platform used is the NAO. The NAO (or ZORA) is a biped robot that is 58 cm tall [8]. Launched in 2006, it has evolved from the first to the most recent version, namely the sixth one, in 2018 (see [9] for a presentation of the original design of the robot). It has 25 liberty degrees, allowing it to move and to adapt to the environment, two 2D cameras, seven tactile sensors, four directional microphones and speakers to interact with humans and the environment. Vocal recognition and dialogue are available in 20 different languages. Therefore, due to theses characteristics, the NAO is considered as an appropriate SAR. We decided to concentrate our review on this robot for several reasons. First, it is one of the most popular humanoid robots in the world. It is widely used in research, education and in healthcare services. Second, its relatively low price makes it both an affordable robot and an effective one. Third, the software used to program the robot, Choregraphe, is easy to use, which facilitates its usability among professionals who are not trained in robotics. Finally, since it is a polyvalent robot, assembling all the studies using it into one paper provides an overview of what has been done yet and where we can go in the future.

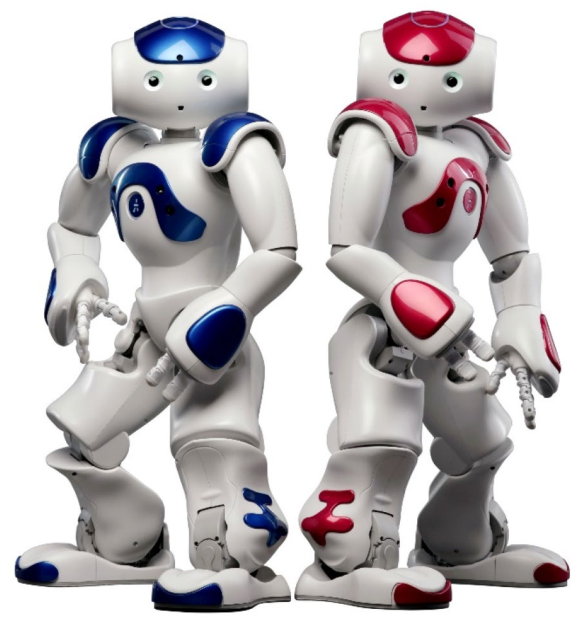

Fig. 1 Softbank robotics Europe

The aim of this literature review is to collect every study that used the NAO robot, no matter the context, into one paper. To the best of our knowledge, there is no other study that focuses only on what has been done with this robot without being limited to a particular population (e.g. the elderly). This study will thus provide a better understanding of what could be more exploited concerning the NAO robot's abilities for future research.

2 Methodology

2.1 Research Strategy

Four databases were exploited: PsychINFO, Computer & Applied Sciences Complete, ACM Digital Library and International Journal of Social Robotics. Since the aim of the present work is to review all the studies using the NAO robot, no matter the context, the research key words used were "NAO robot" and "Zora robot", so that every research paper mentioning these robots were spotted. Only the studies written in English were included and there were no restriction concerning publication date. The papers found vary from 2012 to 2019 probably because the NAO robot was launched to the public in 2011. Therefore, it seems reasonable to assume that most clinical studies were published the next year or later. Also, studies focusing on technical progress on the robot were excluded, since it does not fulfill the purpose of this review. We observed, just as [4] did, that many studies have only a few participants or are just exploratory studies. It was decided that studies would not be excluded based on their methodological quality (e.g. sample size, lack of control of external variables) because this field of research is still new. Therefore, there are not many studies with strong methodology. Although, some studies lacked important information about the sample like number of participants, sex or gender, age, and characteristics (e.g. neurotypical, autism, dementia) and were excluded. In summary, if the study contained all the methodological information, it was included, but if information was missing, it was excluded.

2.2 Study Selection

The authors filtered the publications in a three-step assessment process based on the work of [4], as showed in Fig. 2. First, papers found using the key words "NAO robot" or "ZORA robot" were selected according to their title and index terms. Second, the abstracts were read to assess if the NAO was used experimentally in the studies and how (e.g. as a companion or a therapist assistant). Finally, full texts were read to evaluate the relevance of the studies with the purpose of this review. The first author proceeded to the review of the studies, and it was then validated by the other authors.

2.2.1 Title and Keyword Assessment

In this first filter, only exclusion criteria were used, since the title does not always say much about what is said in the article. There were two exclusion criteria. First, when it was clear that the article assessed a technical improvement (e.g., programming, adding technical devices, improving functionalities like walking, movement, etc.). Second, the title sometimes clearly announced that the robot involved in the study was not the NAO. The fact was verified afterwards scanning the text. This could be explained by the fact that all the studies mentioning the NAO robot (or ZORA) were found, even when it was mentioned once in the introduction section or cited in the paper. In this phase, we were more sensible than specific to make sure not to exclude relevant papers.

2.2.2 Abstract Assessment

The abstract was then read to evaluate if the study seems to correspond to the purpose of the study. This phase was also more sensible than specific, so when in doubt, the study was selected for the text assessment. Here, exclusion criteria

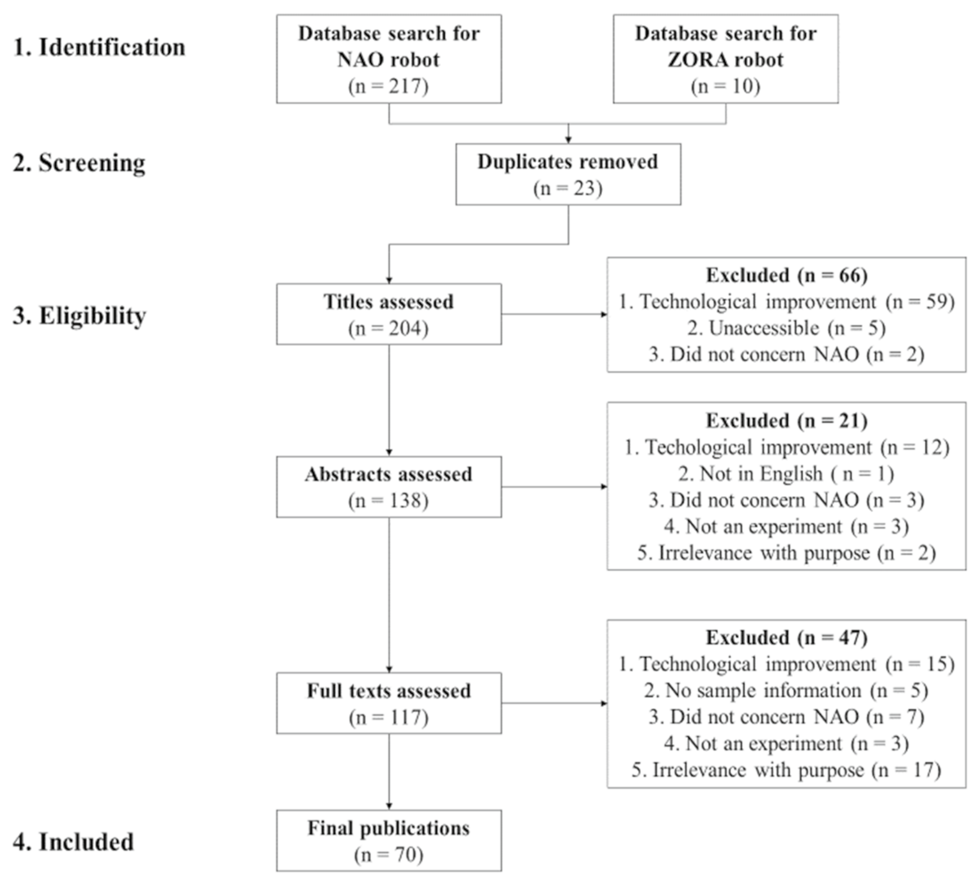

Fig. 2 Schematic review process

were also related to technical improvements and not using the NAO robot. Also, studies that clearly did not use the physical robot in an experimental context were excluded (e.g., virtual robot only, testing technical improvement). Papers that did not focus on the interaction between the robot and the human were excluded. For example, studies on acceptability only were excluded because there are reviews on the subject (e.g., Conti, Di Nuovo, Buono, & Di Nuovo, 2017). Finally, if the abstract clearly pointed that the sample did not interact with the robot (e.g., surveys), they were excluded.

2.2.3 Text Assessment

This filter is meant to be more specific than sensible. Therefore, only the papers fulfilling the purpose of the present survey, which is the use of the NAO robot in different contexts, were included. Exclusion criteria still included technical improvement, use of another robot than the NAO and acceptability only. It was also decided that studies would not be excluded based on their methodological quality. However, some papers lacked important information about sample (gender, age, and context) and were therefore excluded. Inclusion criteria were use of the NAO in an experimental setup, interaction between a robot agent and a human agent, comparison of the NAO with other robots. Studies on both technical improvements and the effect of these improvements on the interaction were included, but not the one that only tested the efficacy of the improvements. Finally, when more than one paper was found regarding the same study (e.g. congress communication and article on the same study), the most complete paper, which was usually the most recent publication, was kept.

2.3 Data Synthesis and Analysis

To synthesize the information found, groups were made according to the general theme and population with which the robot was used. These categories were decided retrospectively because they offer the better classification system to what was presented in the articles. This strategy is based on the work of [4], who also created subjective categories for the robot's use.

3 Results

3.1 Search Results

Initially, 227 papers were found in the different databases and were selected for the review (see "Appendix" for the full list). The Fig. 2 represents the schematic review process of the articles. The final sample of studies that were reviewed is composed of 70 publications, all using the NAO robot. Together, the studies include 2 880 participants.

The studies selected will be presented according to the six defined categories: social interactions, affectivity, intervention, assisted teaching, mild cognitive impairment/dementia, and autism/intellectual disability. The categories were identified retrospectively to facilitate the understanding of the robot's use.

3.2 Social Interactions

The studies focusing on social interactions in general were grouped in this category. Those studies (1403 participants) assess particularly the relationship between the human and the robot: attitudes of the users toward the robots, social engagement of the users (e.g. gaze, duration of speech, distance between robot and user), influence of matching personalities between human and robot, and general communication (Table 1).

3.2.1 Attitudes

Eight studies (578 participants) focused on the effect of the robot on the participants' attitude. In a Japanese study, two NAO robots were used in a hotel to inform the guests about multiple services [9, 10]. The authors wanted to evaluate how users respond to robot's different types of verbal interaction. In order to do so, they investigated if either direct or indirect (robot talking to the other robot) speech had the biggest impact on guests. The direct form of speech was represented by the robot giving information directly to the guests, whereas the indirect speech was represented by two NAO robots sharing information to each other, therefore giving the information indirectly to the guests. The results show that direct speech is more attractive to the guests, while indirect speech enhances human–human interactions. In another study also investigating the effects of direct or indirect speech, but this time with product advertising, the authors did not observe any difference between the two types of speech for changing the participants' attitude towards the advertised product [11]. The results of the two previous studies show that the effect of direct and indirect speech is still not clear in human–robot interaction. Then, [12] examined the effect of the robot making communication errors (e.g. repeating itself, asking the user to repeat or not answering at all when it is supposed to) on the relation between the participant and the robot. The authors observed that the earlier the errors appear (i.e. at the beginning of the interaction) the better it is for the robot's influence, which is preserved. Otherwise, latter errors will affect the capability of the robot to influence the user. In addition, if the errors occur after a good performance from the robot, they will be more harmful to the relation between the human and the robot. The authors

Table 1 Selected studies in social interactions

Theme	Author	Sample	Design	Findings on NAO[a]
Attitudes	Pan et al. [9, 10]	150 participants (unknown gender, unknown age)	Hotel promotion for guests. Experimental study	+ Direct speech more attractive + Indirect speech triggered more human–human interactions
	Lopez et al. [11]	10 participants (4 males, undergraduate students, unknown age)	Advertising. Experimental study	= No differences between direct and indirect speeches
	Lucas et al. [12]	165 participants (48.7% male, mean age 29.2 years)	Ranking task. Experimental study	+ Errors at the beginning do not harm the relation – Errors after a good performance of the NAO are harmful (contrast effect)
	Kuchenbrandt et al. [13]	45 participants (25 males, mean age 24.81 years)	Team game, NAO being an in- or an out-group member. Experimental study	+ Higher acceptance, favoritism and positive evaluative judgement when NAO is an in-group member
	Sandoval et al., [14]	60 participants (39 males, mean age 26.5 years)	Prisoner's dilemma and ultimatum game. Experimental study	– People tended to cooperate more with a human than with the robot = Norm of reciprocity also applies to HRI – Higher openness and agreeableness rates were perceived in the human agent + When both the human and the robot used the TfT (Tit for Tat) strategy, they were perceived as more extroverted and agreeable than when the Random strategy was used
	Seo et al., [15]	36 participants (18 males, unknown age)	Sorting task to evaluate rapport building. Experimental study	+ Participants had a positive rapport with the robot and thought it would make a good collaborator and colleague + Participants showed positive behaviors toward the robot like complimenting and thanking = They did not perceive the robot as a human, although not as a cold machine
	Wang et al. [16]	60 participants (33 males, aged around 20 to 30 years)	Decision making task. Experimental study	+ The physical NAO robot had more influence on the participants' decision-making + The physical robot was perceived as more trustworthy and induced more attachment than other embodiments + The physical robot allowed a more fluid communication
	Stanton and Stevens [17]	52 participants (14 males, mean age 22,5 years)	Trust towards the robot. Experimental study	= Participants tended to trust more the robot as the difficulty of the task increased – Constant gaze had a negative impact on females' trust towards the robot + Male participants may have perceived the continual gaze as a friendly sign from the robot – Gender effects must be interpreted cautiously because of the small number of male participants

Table 1 (continued)

Theme	Author	Sample	Design	Findings on NAO[a]
Social engagement	Sandygulova et al. [18]	74 participants (40 males, mean age 5.81 years)	Pretend play interaction. Observational study	+ Robot's gender was recognized by the children + Decreased or unchanged distance between participants and male robot – Increased distance in boys interacting with female robot
	Sandygulova et a., [19]	107 participants (56 males, aged 5 to 12 years)	Playing game with the robot. Experimental study	= Younger children (5 or 6 years-old) are not able to identify adequately the gender and age of the robot = Matching gender does not really matter in rating the child-robot interaction, but mood changes were observed between same-gender condition and opposite gender condition (lower mood in opposite- than in same-gender condition) + When facing the female robot, the children had more positive reactions regardless of their own gender = Younger children would prefer to interact with a robot that is the same gender as them, and the robot's gender do not matter for older children
	Tokmurzina et al. [20]	26 participants (13 males, mean age 4.8 years)	Child-robot proxemics. Pilot study	– Younger children tended to stay further from the robot
	Ahmad et al. [21]	23 participants (7 males, aged 10–12 years)	Snakes and ladders game. Empirical study	+ Emotion and memory adaptation maintained children's social engagement – Game adaptation is not enough – Speech recognition problems. The robot did not hear the children and remained silent
	Ahmad et al. [22]	24 participants (12 males, mean age 10.52 years)	Snakes and ladders game and vocabulary learning. Empirical study	+ Consistent social engagement over the sessions (4 sessions, 24 min each) + Positive emotional feedback had the better effect n learning and social engagement – Speech recognition problems. The robot did not hear the children and remained silent
	Shinohara et al. [23]	First study (experiment 1): 73 participants (45 males, mean age 21 years) First study (experiment 2) and second study: 30 participants (18 males, mean age 21.1 years)	First study: Analysing the optimal mimicry rate. Replicability study Second study: Helping behavior induced by mimicry. Experimental study	First study: + Optimal mimicry rate: 83% + Increased mimicry results in increased likability, which may enhance a positive impression of the robot Second study: + Increased likability seemed to promote helping behavior when participants were asked explicitly

Table 1 (continued)

Theme	Author	Sample	Design	Findings on NAO[a]
	Johnson et al. [24]	First study: 8 participants (5 males, mean age 33.5 years) Second study: 19 participants (11 males, mean age 63.47 years)	First study: Validation of designed gestures for surprise and curiosity. Pilot study Second study: Playing Mastermind game. Experimental and main study	First study: + Gesture, speech and eye LED pattern were adequate to express confidence and surprise Second study: + Participants enjoyed playing Mastermind game with the robot + NAO has an entertainment value + Behavioral pattern adds to the entertainment value (more laughter)
	Kennedy et al. [25]	28 participants (11 males, mean age 7.9 years)	Guided discovery learning task. Experimental study	= No significant difference between virtual and physical robot for learning, maybe due to the short exposure time + The behavior of the robot might have more impact than the embodiment. + The children spent significantly more time looking at the real robot than the virtual robot, leading to more social engagement
	Ros et al. [26]	84 participants (unknown gender, aged 9–11 years)	Motivation in a learning activity. Experimental study	+ A motivational support (in the study, the conditions with the robot and the condition with the virtual agent) had a positive impact on healthy habit change + The conditions using the robot had an effect on the self-assigned goals. More children achieved their goals in the robot system condition + Children in robot groups had an improved behavior towards healthy habits, according to the parents
	Jochum et al. [27]	56 participants (26 males, 27 females and 3 non-response, aged 18–74 years)	Using the robot in a theatre play. Experimental study	+ Participants (members of the audience), perceived the robot as alive, lively, responsive, kind, pleasant, nice, competent, knowledgeable, intelligent and responsible + The play was perceived as engaging, entertaining and realistic, even though there were some technological problems
Matching personalities	Aly and Tapus [28]	21 participants (14 males, aged 21–30 years)	human–robot interaction about restaurants in New-York. Experimental study	+ Necessary to have matching personalities for a more appropriate interaction + Adapted mixed robot's behavior is more engaging and natural than adapted speech only robot's behavior
	Dang and Tapus [29]	17 participants (16 males, aged 23–36 years)	NAO coaching in a stress game (Operation board game). Experimental study	+ Participants preferred performing the task with the robot = Robot did not influence performance – Matching personalities does not always enhance performance
	Bechade et al. [30]	37 participants (23 males, mean age 25.1 years)	Emotion recognition game and a more humorous interaction (telling jokes). Experimental study	+ Positive mental states are related to more social engagement – Negative mental states are related to lower social engagement + Only extraversion was related with self-confident mental state

Table 1 (continued)

Theme	Author	Sample	Design	Findings on NAO[a]
Communication	Pelikan and Broth [31]	13 participants (8 males, unknown age, university students)	human–robot conversation (turns-at-talk). Experimental study	+ Participants adapted very well to the robot = Taking the organization of human–human interaction into account may be essential since human–robot interactions are based on human–human interaction signals
	Behrens et al. [32]	First study: 80 respondents (unknown gender and age) Second study: 6 participants (5 males, students, unknown age)	First study: Online questionnaire on robot's voice gender. Preliminary study Second study: Live interaction with the robot on sharing personal information. Experimental study	First study: + Male voice robot was reported as more trustworthy Second study: = Robot's voice gender seemed irrelevant in this study – Programming opportunities, ability to modify dialog functions and error states limited the second study with the NAO
	Tahir et al. [33]	First study: 20 participants (16 males, mean age 25 years) Second study: 20 participants (17 males, mean age 23 years)	First study: Recognition of the robot's speech. Experimental study Second study: Social mediation. Experimental study	First study: + Gesture helps clarify an audio message Second study: + Sociofeedback is appreciated by the participants
	Baddoura and Venture [34]	40 participants (26 males, mean age 23.5 years)	Real social interaction with the robot. Experimental study	+ Familiarity resulted in more response from the participants to the practical action (handing the questionnaire) + Appreciation increased response to the social actions (greeting and goodbye) + Adequate response to the practical action resulted in more responses to the social actions
	van Dijk et al. [35]	19 participants (9 males, mean age 67 years)	Effectiveness of human–robot communication. Experimental study	+ Iconic gestures had a positive effect on recall – In this study, gaze did not have a significant effect on recall

[a]+: positive finding, =: neutral finding, –: negative finding

explain this phenomenon by the contrast effect, a concept well known in social psychology [36]. In short, it refers to the fact that if one develops a positive attitude towards the object of attitude (in this case, the interaction with the robot), negative experiences will influence the person more, since it contrasts with the initial attitude. Therefore, if the errors occur at the beginning of the interaction, the attitude is not totally formed, and the robot can recover from this initial negative assumption. Also, [13] assessed the effects of the NAO being an in-group or an out-group member on the participants' perception about the robot. To do so, they assigned the participants to different groups (i.e., blue or green group). In the in-group condition (blue team), participants were told the NAO was part of their team, whereas in the green group, the robot was not part of the team, but still present in the activity. Results showed that the participants perceived the NAO more positively and were more willing to interact with it when it was an in-group member than when it was not. In another study, using the Prisoner's Dilemma and the Ultimatum Game, [14] found that participants cooperated more with the human than with the robot. The human was also perceived as more open and agreeable. However, they explain this result with the fact that even if they did not want neither of the agents (robot or human) to display emotions, they had no control over nonverbal body language of the human agent. Also, when the robot (and the human) used the Tit for Tat (TfT) technique (cooperate in first round, then copy what the other person chose for the next rounds), they were perceived as more extroverted and agreeable. In [15], they examined how human build rapport with a robot. They observed that the participants engaged in positive social behaviors such as thanking and complimenting the robot, which enhanced the rapport-building. Finally, the two last studies [16, 17] show that human tend to perceive the robot as trustworthy and are willing to follow their lead when facing an ambiguous decision.

3.2.2 Social Engagement

Ten studies (552 participants) investigated the social engagement in human–robot interactions. First, three studies were conducted to observe children-robot interaction. Two studies observed young children in a pretend play (or role play) and a playing game interaction with the NAO robot [18, 19]. In the first one, the authors observed that the children recognised the gender of the robot and adapted their behavior according to gender-based social rules. In line with this finding, concerning proxemics, they observed that children in general did not change their distance between them and the robot or decreased it when facing a male gender robot. However, when they were facing a female gender robot, boys significantly increased their distance between them and the robot. This finding indicates that: (1) children can recognize the gender identity of a robot and, (2) they interact with them considering gender-based social norms (gender separation). In addition, [20], who conducted a similar study on proxemics between children and robots, observed that younger children tend to stay further from the robot. Although, in their subsequent study, [19] observed that younger children are not able to identify correctly the gender of the robot, but they prefer to interact with a same-gender robot. Contrarily, older children recognised the gender of the robot. According to them, the matching gender was not important to children, although some mood variations were observed, being lower in opposite-gender condition than in the same-gender condition. Interestingly, children had more positive reactions when interacting with a female robot, regardless of their own gender. In two other Australian experimental studies, children were playing a snakes and ladders game and vocabulary learning with the robot [21, 22]. The aim of the studies was to assess the social engagement of the children with the robot concerning eye-gaze, gestures towards robot, etc. in a long-term interaction. Results show that the children's social engagement was consistent throughout the sessions and that positive emotional feedback from the robot enhanced social engagement and learning. Also, duration of verbal responses increased, whereas facial expressions decreased over the sessions. Then, an experimental study conducted with adults evaluated their social engagement in the form of helping behavior induced by mimicry [23]. Their study is based on the chameleon effect, which triggers when someone mimics behaviors, postures or mannerisms of someone else [37]. This effect was shown to increase the mimicker's likability. In this study [23], mimicry from the robot should enhance the helping behavior of the participant because of this increase in likability. The authors noted that a high mimicry rate (83%) increases likability of the robot, and therefore generates a positive impression of the robot. Also, the authors observed that the increased likability resulting from the high mimicry rate promoted willingness to help the NAO (form of social engagement) when the participants were explicitly asked to do so. Another study assessed the entertainment value of the NAO robot with adult participants playing the game Mastermind with the robot [24]. The authors observed that the behavioral pattern displayed by the robot resulted in more laughter, which effectively indicates an entertainment value of the robot. Two studies examined the engagement of children in learning activities. In [25], they observed that the embodiment (physical or virtual) did not impact their learning. They mention that it could be explained by the novelty effect, since the interactions lasted a short time. Although, they advanced that children spent more time looking at the physical robot than at the virtual robot, suggesting more social engagement. In their study, [26] use a physical and a virtual robot to teach children on healthy habits. They conclude that having a motivational agent (either physical or virtual robot) enhances healthy habit change. What the physical robot added was that the children achieved more their goals when interacting with this type of embodiment. Finally, [27] used the NAO robot in a theatre play as an actor in a care scenario. They wanted to see how the audience would respond. Interestingly, the play was perceived as engaging, entertaining and realistic, even though there were some technical problems. The robot was perceived as alive, responsive, kind, pleasant, intelligent and more.

3.2.3 Matching Personalities

Three studies (75 participants) evaluated the importance of matching personalities in the interactions between a human and a robot. Results show that a robot that matches the participant's personality is essential for an appropriate interaction (e.g., extrovert robot for extrovert participant) and that a robot that adapts to the personality of the participant seems more engaging and natural than a robot that does not [28]. In an experimental study where the authors exposed participants to a stressing game and were coached by a robot with different personalities, the performance was not always increased when the participant was coached by a robot with a matching personality [29]. Finally, another study included other personality factors than extroversion and introversion, namely openness and neuroticism [30]. Results show that the mental state of the participant seemed to be in relation with the behavior the participants adopted during the interaction. In fact, positive mental states were related with more social engagement (longer duration of speech, laughter, short reaction time), whereas negative states were related with less social engagement (lack of laughter, negative speech and failure in the game). More work must thus be done to understand better the effects of personality in human–robot interactions.

3.2.4 Communication

Finally, one last important facet of social interaction concerns general aspects of communication, assessed by five studies (198 participants). It is known that when interacting with a robot, humans tend to use the same signals as in human–human interactions [31]. In this first study, the authors observed human–robot interactions and saw that participants tended to adapt to the robot's need and capabilities, but this was sometimes difficult probably because of the lack of transparency in the robot's verbal cues. Another study aimed to assess the influence of the robot's gender [32]. When questioning participants in a preliminary study, results showed that people characterised the male voice as more trustworthy and were more willing to share personal information him. Although, when testing this fact experimentally, the robot's gender seemed to be irrelevant because firstly, participants shared information equally with both robot's genders. Secondly, some participants did not distinguish the robot's gender (identify the wrong gender or describe the robot as genderless). More studies need to be done on how the gender of the robot affects human–robot interactions. Then, a study investigated the importance of sociofeedback given by the robot through audio messages and gestures [33]. In fact, it was found that audio messages are essential in delivering a sociofeedback, but gestures help to increase the clarity of the feedback, which is appreciated by the participants. Another study [35] concluded that iconic gesture is an important component of the communication, and in this study, on recall. Finally, the last study compared the participants' responses to social actions (e.g., greeting and goodbye) and practical actions (e.g., handing the questionnaire) made by the robot [34]. The outcomes of the study were that practical actions were more responded when participants felt familiarity, the social actions were intensified when robot's sociability was higher, and that the more practical actions were adequately responded by the participants, the more they responded to social actions.

3.3 Affectivity

Nine studies (291 participants) assessed the affectivity value of the NAO robot. To be an effective SAR, it is essential for the robot to be able to perceive and express emotions [3]. Also, according to the same authors, empathy, or the capacity to demonstrate that one's feelings are understood or shared, is a necessary capacity for a robot to have, since it is crucial to social interactions (Table 2).

3.3.1 Emotion Expression

Since the NAO robot cannot express emotions through facial expression, unless with changing colors eye LED, one might think that this is an obstacle to emotion expression for this robot. Nonetheless, six studies (254 participants) assessed the NAO robot's emotional expression capabilities through affective bodily expressions. In the first two studies, the authors implemented affective bodily expressions [38, 39]. Cohen, Looije and Neerincx [38] assessed the recognition rate, meaning that the robot (NAO or iCat) expressed an emotion (e.g. sad, happy, fear) and the child had to recognize it. Then, they compared the recognition rates of the NAO, which expressed emotions through postures, and of the iCat robot, which used facial expression. Results show that in general, recognition rates were significantly higher for the iCat than for the NAO, but when comparing each emotion separately, there is no significant difference between the two recognition rates, which shows that both robots can express emotions and that facial expression is

Table 2 Selected studies in affectivity

Theme	Author	Sample	Design	Findings on NAO[a]
Emotion expression	Cohen et al. [38]	First study: 8 participants (5 males, mean age 24.6 years) Second study: 14 participants (5 males, mean age 8.64 years)	First study: Signal-detection task of emotion expressions. Pilot study Second study: Emotion identification task. Experimental study, within-subject design.	First study: + NAO could perform the five implemented affective bodily expressions Second study: + No overall significant difference of recognition accuracy between iCat and NAO + Emotions expressed in a context are easier to recognize + Children would choose the NAO over the iCat because it is perceived as more friendly and trustworthy
	Read and Belpaeme [39]	28 participants (11 males, mean age 30.5 years)	A three-task experiment (labelling, discriminating and identifying). Experimental study	= Females had higher mean affective rating than males
	Xu et al. [40]	36 participants (25 males, mean age 26.6 years)	Imitation game. Experimental study	+ Contagion effect of mood + In easy game condition, participant's mood was influenced by the robot's mood (positive robot mood = positive participant mood) + In difficult game condition, negative robot mood improved the performance in the game (as expected)
	Andreasson et al. [41]	64 participants (32 males, aged 20–30 years)	Emotion communication through touch to the robot. Experimental study	+ Females tended to touch the NAO for a longer duration, to touch more locations and to use more varied ways to touch the robot for every emotion + Sadness was the emotion conveyed for the longest time (independent of gender) + Participants touch more various locations when expressing love (independent of gender) – More tactile sensors are needed
	Beck et al. [42]	24 participants (11 males, mean age 12 years)	Children's perception of robot's emotions. Experimental study	+ Children can identify emotions displayed by a robot. Absence of facial expression was not an obstacle to this goal + Overall, emotion interpretation is similar between children and adults, apart from the anger emotion, which was less recognized by children

Table 2 (continued)

Theme	Author	Sample	Design	Findings on NAO[a]
	Rosenthal-von der Pütten et al. [43]	80 participants (30 males, mean age 24, 44 years)	Perception of the robot's emotion through human and robot nonverbal behavior. Experimen-tal study	+ Human and robot nonverbal behavior both increase perceived animacy of the robot, positive affect, self-disclosure, and the combination of the behaviors increase these characteristics even more (control < RNB < HNB < RNB + HNB) + When the NAO told its happy story, participants felt significantly more positive and less negative + Humanlike nonverbal behavior influenced positive affects of the participants after the positive story
Empathy	De Carolis et al. [3]	One participant (male, 73 years old)	Typical interaction scenario in an apartment. Case study	= Affective factors are essential to consider when modeling social interactions between a user and a robot – Avoiding repetition of the same behavior of the NAO in similar situations needs to be addressed
	De Carolis et al. [2]	18 participants (9 males, mean age 75.6 years)	First study: Evaluation of the robot's behavior. Experimental study Second study: Evaluate if the robot's behavior was empathic. Experimental study	First study: + Robot conveyed the intended empathic goals, which were recognized by the participants Second study: + Cognitive empathy was higher than affective empathy, regardless of age and gender – Avoiding repetition of the same behavior of the NAO in similar situations needs to be addressed
	Tielman et al. [44]	18 participants (9 males, mean age 8.89 years)	Quiz game. Experimental study	+ Children show more expressions and behave more positively with an affective robot + Affective robots increased empathy, but decreased acceptance and trust (–) + Non-affective robot was perceived as more trustworthy + Intelligibility of robot's voice is more important than emotion for children

[a]+: positive finding, =: neutral finding, –: negative finding

not an essential component of emotional expression. They also found that expressing the emotion in a context enhanced the recognition of that affective state. Furthermore, children mentioned that they preferred the NAO robot to the iCat, because the NAO seems to be perceived as more trustworthy and friendly. Also, in [42], they conclude that children can identify emotions displayed by a NAO robot correctly, and they add that there is no significant difference between them and adults apart from anger emotion. This emotion was less perceived by the children. The results of another study show that bodily expression of the robot's mood has a contagion effect on the participants, explicitly and implicitly. The robot's mood influenced the participants' performance in the difficult condition of an imitation game, a positive mood from the robot having a negative effect on performance because the participants were more entertained [40]. In addition, in a Swedish experimental study, participants had to communicate emotions to the robot through touch [41]. The results showed that males and females conveyed emotions to the robot differently from one another. Females tended to touch the NAO longer, to touch more locations and to use more varied ways to touch the robot for every emotion. However, the participants touched the robot longer when expressing sadness, regardless of the gender. Finally, in [43], they evaluated how humans perceived the robot's emotions through human nonverbal behavior (moving head, arms, torso) and robotic-specific nonverbal behavior (changes in eyes color). They conclude that both nonverbal behaviors increase the perceived animacy of the robot, positive affect and self-disclosure. They also add that combining these behaviors increase these characteristics even more. Thus, when the NAO told its happy story, participants felt more positive and less negative.

3.3.2 Empathy

Three studies (37 participants) evaluated the role of empathy of the NAO robot interaction with participants. Considering affective factors is essential when investigating social interactions between a robot and a human [3]. In an experimental study, [2] assessed the robot's empathic behavior and the participants' perception of the robot's empathy. In this study, the robot correctly realised the intended empathic goal, since it was recognized by the participants. Thus, the robot's cognitive empathy (understanding of the participant's emotion) was higher than its affective empathy (feel the participant's emotion), regardless of age and gender. In the last study in this category, [44] used a quiz game to assess the children's perception of an affective and a non-affective NAO robot. While the affective robot enhanced positive expression, behavior and empathy perceived by the children, the non-affective robot was perceived as more trustworthy. Although, the affective robot was preferred by the children because of its bodily expression of emotions and its adaptability to the children.

3.4 Intervention

Thirteen studies (519 participants) investigated the use of a NAO robot as a therapist. The robot was used as an interviewer, in evaluation/recommendations, and in physical interventions (Table 3).

3.4.1 Interviewer

Three studies (32 participants) assessed the interviewer value of the NAO robot. The first study compared the NAO robot to a human interviewer to conduct an employment interview [45]. Results showed no significant difference between the human and the robot interviewers, which suggests that the NAO robot is a conceivable interviewer. Then, a pilot study introduced a NAO robot in a working environment [46]. The robot had to motivate the workers to get up of their chair and to follow the robot in doing a routine. The authors observed that the employees rarely rejected the request from the robot and almost always performed the routine. Also, they noted that the robot helped breaking the hierarchical boundaries. In another study, a NAO robot was programmed to conduct a motivational interview [47]. Motivational interview is a psychological intervention that enhances behavior changes. In this study, the robot had to encourage physical activity among the participants. The main positive outcomes were that the participants enjoyed their interaction with the robot and liked the neutrality of the robot. Participants felt unhurried since the robot did not interrupt them, and more comfortable since the robot did not judge them. Some participants even pointed out that the interview had an impact on their behavioral change.

3.4.2 Evaluation and Recommendations

Three studies (215 participants) evaluated the potential of the NAO robot as a therapist. In an experimental study with children of 9.5 years old (in average) having cancer, the authors used a robot as a psychologist assistant [48]. The robot participated in a therapy with a psychologist for children having cancer and they were compared to a control group having a conventional therapy with a psychologist only. The study's results show that using a robot as a psychologist decreased anxiety, depression and anger significantly when compared to the control group having the traditional psychotherapy. Authors advance that the robot, just like peers, increase the children's self-esteem and make them feel more supported than with an adult. Also, the authors conclude that a humanoid robot was useful to calm the children by teaching them about their illness and

Table 3 Selected studies in intervention

Theme	Author	Sample	Design	Findings on NAO[a]
Interviewer	Ahmad et al. [45]	8 participants (6 males, aged 20–30 years)	Employment interview done by NAO or human. Comparative study	+ No statistically significant difference between the human and the robot interviewers, suggesting that the NAO has a potential as an interviewer
	Brandstetter et al. [46]	4 participants (unknown gender and age, but they were all employees)	Motivational robot at work. Pilot study	+ Employees enjoyed having the robot around and performing the routines + NAO helped to break hierarchical barriers by its presence and interactions, since the group members were "forced" to participate in the ridiculous tasks – Technical challenges like path finding, face recognition and battery usage are still to address
	da Silva et al. [47]	20 participants (3 males, aged 18 and above)	Robotic motivational interview. Experimental study	+ Discussing with the robot about their behavior motivated the participants + Enjoyed interactions and found the robot easy to use + They liked the neutrality of the robot – More sophisticated speech recognition and branching logic are needed to allow the robot to summarize what participants said to make suggestions, etc
Evaluation and recommendations	Alemi et al. [48]	11 children (1 boy, mean age 9.5 years) diagnosed with cancer	Social robot-assisted therapy. Empirical study	+ Social robot-assisted therapy had significant decreases in anxiety, depression and anger when compared with the control group (traditional therapy)
	Edwards et al. [49]	86 participants (28 males, mean age 21.76 years)	Medical interview simulation. Experimental study	+ Both physicians were found to be credible and to produce positive affects = The human physician was although rated higher in both spheres (credibility and positive affects). Perceived social presence, which was higher for human physician, mediated these relationships
	Lee et al. [50]	118 participants (66 males, aged 18–59 years)	Stress level assessment and recommendations. Experimental study	+ There are rules of politeness in human–robot interaction too = Necessary to adapt the politeness level to the users, because high level of politeness does not always enhance compliance

Table 3 (continued)

Theme	Author	Sample	Design	Findings on NAO[a]
Medical and physical interventions	López Recio et al. [51]	13 participants (unknown gender, geriatric patients)	Modeling movements for the inpatients in physiotherapy. Experimental study	+ When the robot was slower than the patient, some of them slowed down to match the speed of the NAO, which improved the movements' quality – Some patients did not reach the correct distance of some movements because of the robot's physical limitations + There was more mimicking with the physical NAO than with a virtual robot
	Carrillo et al. [52]	9 participants (children patients, unknown gender, unknown age) and 4 physiotherapists (unknown gender, unknown age)	Paediatric rehabilitation. Experimental study	+ Parents trusted the robot – Therapists had difficulties to trust the robot, probably because of the short time they were exposed to the robot + The system developed in the study was strongly accepted
	Looije et al. [53]	17 diabetic participants (unknown gender, mean age 8.24 years)	Returning hospital visits activities. Experimental study	+ The children had a positive experience with the robot throughout the sessions + They built a relationship with the robot, had a small gain in knowledge, had mood and openness improvements and increased their self-management + The children thought the robot made their visit to the hospital more positive
	Pulido et al. [54]	First study: 117 healthy children (64 males, mean age 7.9 years) Second study: 3 participants with upper-limb motor impairments (3 males, mean age 7,67 years)	Both studies: Paediatric rehabilitation. Experimental study	First study: + The children perceived the robot positively and accepted it well. They liked interacting with the robot and would be willing to pursue physiotherapy treatment with it Second study: + Children said they had a good time with the robot and would like to do more sessions with it – They thought it talked too much + Therapists and physicians thought it was a useful tool for diagnosis

Table 3 (continued)

Theme	Author	Sample	Design	Findings on NAO[a]
	van den Heuvel et al. [55]	Children: 17 participants (10 males, aged 31 months to 18 years) Professionals: 7 participants (unknown gender, aged 26–63 years)	Rehabilitation, pilot study	+ Achievement of goals of children was enhanced by the ZORA-based intervention + The most promising applications of the ZORA-based interventions are movement skills, communication skills and cognitive skills, according to the professionals – Improvement and development are still needed
	van den Heuvel et al. [56]	Children: 33 participants (22 males, aged 3–18 years) Professionals: 12 participants (unknown gender, aged 25–63 years)	Rehabilitation, experimental study	+ Achievement of goals of children was enhanced by the ZORA-based intervention, especially movement and communication skills + Professionals think that the most promising role is the motivator role, but it also has a role of rewarder and instructor + Children liked playing with ZORA and professionals appreciated working with ZORA
	Niemelä and Melkas [57]	40 participants (unknown gender, unknown age)	Geriatric rehabilitation, pilot study	– Using the robot requires specific resources like knowledge, skills, time and organizational infrastructure = Knowing the customers' needs in advance is essential when planning to use the robot + Participants viewed the robot as cute and sympathetic – Although, there were problems with people with vision earing impairments

[a]+: positive finding, =: neutral finding, –: negative finding

methods to relax and to take control of their situation. In another study, the robot was used to do a medical interview simulation and was compared with a human physician [49]. Albeit both human and robot were significantly credible on credibility scale, the human physician was rated higher in credibility than the robot and had a greater positive impact on the patients. Although, this relationship between credibility and physician (human or robot) was mediated by the perceived social presence of the physician, which was higher for the human. Thus, using a NAO robot in combination with traditional physician in a medical interview might be a great avenue in the health service system. In the last study, the NAO robot was used to assess the stress level of the participants using a low to high level of politeness [50]. Then the robot made recommendations on how to reduce the participant's stress. Results of the study show that the robot needs to adapt its politeness level to the different users, because a high level of politeness is not always appropriate, and does not always have positive effects on the user's compliance to the robot's recommendations on how to reduce the user's stress. The authors conclude by saying they believe that human-like robots might be a great avenue in the healthcare service because they might be perceived as more acceptable helpers than other technologies.

3.4.3 Medical and Physical Interventions

Seven studies (272 participants) used the NAO robot and three studies (109 participants) as a rehabilitation assistant. The robot had to assist a physiotherapist by showing the movements to the patients. The main findings were that the robot enhanced the quality of the movements of the patients, more than a virtual robot, probably because of its physical presence [51]. In addition, the robot adapted the speed of the movement to the patient, which made the patients pay more attention to the movements performed by the robot. When the NAO performed a movement slowly, patients also adapted to the pace of the robot, which improved the quality of their movements. Two main issues were noted in the studies. First, due to the robot's physical limitation, some movements were not correctly modeled by the robot (i.e. the optimal distance for some movements was not reached by the robot, so by the patients too). Also, there were some trust issues from the therapists concerning the advices given by the robot in the other study, but the authors mentioned that it was probably due to the therapists' short exposure time to the robot [52]. Nevertheless, the robot was well accepted by the patients, the therapists and the parents for the study with children [58]. In a similar study concerning paediatric rehabilitation, [54] achieved similar results, saying that the robot was well accepted by the children. The professionals also agreed that it would be an interesting tool to use in rehabilitation. Three studies [55–57] used the ZORA robot as a rehabilitation assistant. The first two studies focused on children with physical disabilities. The robot was used in rehabilitation sessions, taking the professional role of instructor, demonstrator, etc. The authors wanted to see if a robot-based intervention would help in achieving goals in four domains: movement skills, communication skills, cognitive skills and attention skills [55, 56]. The professionals (physiotherapists, speech language therapists and others) were present in the session. The main outcome of these studies is that the robot enhanced achievement of goals, especially in the movement and communication skills. Also, using the robot allowed the professionals to concentrate all their attention on the observation of the patient, which they appreciated. The last study was also a pilot study to incorporate a ZORA robot in a geriatric rehabilitation hospital and in two service care homes [57]. Participants mainly mentioned that using a robot requires many adjustments and resources like knowledge, skills, time and organizational infrastructures. Also, when planning to use the robot, participants pointed out the necessity to know what the customers' needs are in advance. Nevertheless, participants enjoyed the robot and thought it was cute and sympathetic. Although, there were problems with people that had vision or hearing impairments (e.g., small robot size, quiet voice, no lip-reading possible). Finally, one study used the NAO robot with children diagnosed with diabetes [53]. The NAO assisted in the weekly appointments and educated them on diabetes. The results showed that the children appreciated their interactions with the robot and that it made their visit more positive.

3.5 Assisted Teaching

Another field of application of SAR that has been explored is robot-assisted teaching. Ten studies (401 participants) assessed the utility and effects of a NAO robot in this type of environment. Particularly, the robot was used as a teaching-assistant in schools, for sign language learning and as a trainer-assistant (Table 4).

3.5.1 Schools

Seven studies (206 participants) used the robot in a classroom. The participants were all aged between 9 and 12 years old. NAO would be a great avenue to assist teaching in the future because it uses multi-modal interaction that meets all three sensorial modalities essential in learning, namely auditory, visual and kinaesthetic [58]. Also, the children think that using a robot to assist teaching is a positive idea. According to [59], children as young as six years-old are adequately cognitively developed to be able to interact with a NAO robot. In one of the studies, children specifically appreciated the fact that the NAO robot was programmed to adapt to their emotions (understand children's feelings and

Table 4 Selected studies in assisted teaching

Theme	Author	Sample	Design	Findings on NAO[a]
Schools	Majgaard and Brogaard Bertel [58]	34 participants (22 children aged 9–10 years old, unknown gender, and 12 upper secondary students, unknown gender)	Assisted teaching. Preliminary experimental study	+ NAO robot enriches the learning using multi-modal interaction (auditory, visual and kinaesthetic interaction)
	Arias-Aguilar et al. [59]	12 participants (unknown gender, aged 5 to 12 years)	Program of behavior modification (Applied Behavior Analysis method). Experimental study	+ 6 years-old children are developed enough cognitively to interact adequately with the NAO (5 years-old children if assisted)
	Ahmad et al. [60]	12 participants (4 males, 10–12 years	Robotic motivational interview. Experimental study	+ Discussing with the robot about their behavior motivated the participants + Enjoyed interactions and found the robot easy to use + They liked the neutrality of the robot – More sophisticated speech recognition and branching logic are needed to allow the robot to summarize what participants said to make suggestions, etc
	Deshmukh et al. [61]	31 participants (15 males, mean age 12.40 years)	Map-based treasure-hunt application activity. Experimental study	+ NAO was perceived as more friendly, pleasant and empathic than the EMYS robot, probably due to its capacity to produce expressive behaviors with its hands
	Kazemi and Stedman-Falls [62]	First study: 5 participants (1 male, mean age 26.7 years) Second study: 4 participants (no male, mean age 22.75 years old)	Both studies: Patient simulation. Experimental study	First study: + Similar performance with robot and actor when trained to conduct PS preference assessment Second study: + Similar performance with robot and actor + Skills acquired with robots could be extended to working with actual children + Robot was rated favorably, which provides support for the social validity of using NAO as patient simulator
	Alemi et al. [63]	46 participants (no male, aged between 12 and 13)	Robotics assisted language learning. Experimen-tal study	+ The use of a robot helped to reduce anxiety, so the students were able to learn better + Students had fun in the robot-assisted class, which made the students enjoy the class more + The robot making mistakes reassured the students and they were less afraid of making mistakes themselves + When their names were called out by the robot, students focused more on the robot than on the judgement of the class + Students liked having a robot in class and considered it helped them to learn English

Table 4 (continued)

Theme	Author	Sample	Design	Findings on NAO[a]
	Chandra et al. [64]	First study: 25 participants (unknown gender, aged 7–9 years) Second study: 37 participants (19 males, mean age 8.4 years)	Both studies: Children teaching to a robot. Experimen-tal study	First study: + Improvements were measured for almost all the children; the others had the same scores (no negative effect) Second study: + Improvements were found in the personal-ised-learning and in the continuous-learn-ing conditions, but not in the non-learning condition Both studies: + Significant writing improvement when they were in robot learning condition than in non-learning + The children liked to be the robot's tutors + Acting like a teacher influenced the way the children evaluated themselves
Sign-language	Köse et al. [65]	First study (no acquaintance of TSL): Adults group: 16 participants (all male, mean age 28.2 years) Children group: 23 participants (7 males, mean age 10.04 years) Second study (acquaintance of TSL): Group 1: 21 hearing-impaired children (10 males, mean age 8.71 years) Group 2: 10 children (five males, mean age 11.8 years)	Sign language interaction game. Pilot study (first study) and experimental study (second study)	= When videos are presented, physical appearance did not matter + Physical robot improves sign recognition compared to video robot (or virtual robot) = Sign language knowledge improves the performance with the physical robot, but not with the virtual robot
	Köse et al. [66]	113 participants: 40 adults (16 males) without acquaintance with sign language 12 adults (1 male) with sign language acquaintance 25 teenagers (9 males, 13-19 years) 20 participants (11 males, 18-37 years) from web-based survey 16 pre-school children (10 males)	Sign language learning session. Experimen-tal study	+ Words taught by the physical robot were significantly better recognized by the par-ticipants, especially children = Sign language knowledge affects perfor-mance (capacity to discriminate similar signs) = Effects of age and gender are not clear, more studies needed – Physical limit of the robot since it only has 3 fingers
Trainer-assistant	Ros et al. [67]	12 participants (7 males, mean age 8 years)	Robot assisted dancing activity. Experimen-tal study	+ Creativity support (i.e. dancing), active participation and not only following orders enhance involvement – Involvement decreased over the sessions – Problems with feedback from the robot, repeated itself or did not adapt to the children

[a]+: positive finding, =: neutral finding, –: negative finding

share its own emotions), memory (e.g., remembering name or previous performance) and personality (being introvert or extravert according to the child's personality) [60]. In addition, when the NAO robot is compared to another robot (in this case, EMYS robot), children perceive the NAO as more friendly, pleasant and empathic, probably due to its capacity to express emotions through body language [61]. Although, the three papers mention some limitations in the usability of the NAO robot in schools. Mainly, the robot would have to follow the learning rhythm of the children, because they do not learn at the same pace, and to not make fast moves or quick responses so the children do not get scared of the robot. Furthermore, one of the greatest challenges would be to address the technological difficulties that could be experienced in a long-term children-robot interaction. Another study used the NAO robot in a robotic-assisted language learning class [63]. The authors wanted to see how the robot could reduce the anxiety of learning a new language. They conclude that the robot helped to reduce the participants' anxiety, enabling them to learn better. The students were reassured by the mistakes the robot would make (intentionally), were less anxious when their name was called out and had more fun in the class. Concerning academic education of adults, an experimental study exploited the NAO robot to perform a patient simulation [62]. The participants had to perform a common behavioral procedure with the patient (NAO or human). Results showed that the performance of the participants were similar when facing a robot or a human actor. In addition, the learnings the participants made could be generalized to working with real children. Finally, an interesting article [64] used the robot in a reversed teaching experimental study. They used the NAO to act like a child that learns how to write, and the children had to teach it how to write letters. They observed that the children improved their own writing when the robot was learning than when it was not. They also pointed out that children liked being the robot's tutor and it had positive impact on their self-evaluation.

3.5.2 Sign-Language

Two studies (183 participants) examined the NAO robot's potential in teaching sign language. Both studies compared participants with and without sign language acquaintance. The two researches come to the same conclusion that sign language knowledge influences the performance [65, 66]. Effectively, if one already has experience in sign language, one might be able to recognize the signs faster and more accurately than the participant that has no knowledge in this language. In addition, if the robot's movements are not precise enough, the participant with anterior experience would be able to differentiate the target words from other words that look alike when signed but have different meanings. Also, the two studies noted that physically embodied robots are way more effective than virtual robots. The effect of sign language acquaintance is important when interacting with the physical robot, whereas this effect is not present when confronted to a virtual robot, since the performance of each group (with and without sign language acquaintance) had similar performances with the virtual robot. The main limit in the usability of the robot in this field of research might be its limited physical capacities, since it only has four fingers.

3.5.3 Trainer-Assistant

Finally, the last study (12 participants) evaluated the effectiveness of a dancing activity among hospitalised children [67]. The robot had to demonstrate the movements and the child had to imitate them. The authors concluded that the robot enhanced participation and involvement of the child, probably because of the creativity and active participation the activity required, instead of following instructions only. Although, the study noted a decreased of involvement over the sessions. Long-term studies will be necessary to assess the effect of long-term interaction with robot teaching assistants.

3.6 Mild Cognitive Impairment and Dementia

Five studies (185 participants) used the NAO robot with participants with mild cognitive impairment or dementia. Two studies focused on intervention among elderly with dementia or with mild cognitive impairment. The two other studies were more interested in the interaction between elderly and the robot (its acceptability) (Table 5).

3.6.1 Robot-Assisted Intervention

Three studies (128) used the NAO robot in interventions with participants with dementia or mild cognitive impairment. The first study used a memory training program to assess cognitive functions, e.g. episodic memory, verbal long-term memory, short-term memory, visual attention, etc. as main outcome measure [68]. They also measured anxiety and depression symptoms. According to them, the NAO increased the participants' attention during the task and decreased depressive symptoms. The second study focusing on therapy for elderly with dementia is a comparative study involving the NAO robot, the Paro and a dog [69]. In this study, the NAO was compared to the Paro robot, but not with the dog. Interesting results concerning the NAO were that it decreased apathy, delusions and irritability. When compared to the Paro, there is no significant difference between them. The two studies conclude that a robot-assisted approach would be a great avenue as a non-pharmacological intervention, since it enhances engagement from the users and

Table 5 Selected studies in Mild cognitive impairment and dementia

Theme	Author	Sample	Design	Findings on NAO[a]
Robot-assisted intervention	Pino et al. [68]	21 participants (11 males, mean age 73.45 years)	Memory training program. Experimental study	+ Robot assisted training increases participants' attention and decreases depressive symptoms – Would be interesting if the NAO could be totally autonomous once it is switched on and if it could respond to voice command and look like it has it own needs
	Valentí Soler et al. [69]	Phase 1: 101 participants with dementia (13 males, mean age 84.7 years) Phase 2: Did not involve NAO robot	Phase 1: Supervised group therapy (cognitive, musical and physical) with Paro, NAO or TAU. Randomised controlled trial	Phase 1: + Decreased apathy in NAO and Paro groups – Increased delusions in the NAO group – Increased irritability in both robot groups = Decrease in scores on the MMSE, but not the sMMSE,in the NAO group + There were no significant differences between NAO and Paro groups
	Johnson et al. [70]	6 participants (2 males, mean age 70 years)	KSERA (Knowledgeable SErvice Robots for Aging) system. Experimental study	+ People accepted and used more the KSERA system when interacting with a robot + Participant perceived the robot as harmless, trustworthy, and comforting. They did not perceive the system KSERA as a risk and thought it was a source of savings
Interactions and acceptability	Tsardoulias et al. [71]	8 participants (older than 65 years)	Focus group. Pilot study	= RApps must motivate the users by following simple steps without needing to memorize things like passwords, being personalized to the user and communicating clearly (i.e. being able to recognize what the user says and to have a clear voice so the elderly can hear them)
	Sarabia et al. [72]	49 participants (17 males, aged 18–100 years). 7 were diagnosed with dementia	Trials with the robot, one or two interactions. Experimental study	+ Participants enjoyed interacting with the robot – Age and dementia influenced the interaction with the robot, but not the gender – Audio transmission was lagged and noisy, and the robot was not responsive enough according to the participants

[a]+: positive finding, =: neutral finding, –: negative finding

improves global neuropsychiatric symptoms when a robot is included in therapy sessions. Even if this robot represents a good alternative to pharmacological treatments, some studies are evaluating the use of a NAO robot to perform a medication sorting task to help people that need to take multiple medications (see [73]). In another study among elderly participants, [70] included the NAO robot in the KSERA system (Knowledgeable SErvice Robots for Aging). This system is an intelligent apartment containing captors and intelligent devices to help elder people to live longer in their home, independently. Although this study did not imply patients with dementia or mild cognitive impairments, it is interesting because of the possible avenue concerning this population. In the study, participants accepted and used the KSERA system more when interacting with a NAO. It was perceived as harmless, trustworthy, and comforting. The NAO robot seems like a good agent to connect the elderly with the KSERA system and with the external world.

3.6.2 Interactions and Acceptability

The two other studies (57 participants) focused on how the robot was useful and how the elderly perceived it. In the first Greek pilot study, they conducted a focus group where participants experimented the Email-Handler and Cognitive exercise RApps (see [71] for more information). The results of the focus group indicate that the robot must be as simple to use as possible for elderly with dementia or mild cognitive impairment, so nothing that requires memory like passwords or complicated commands. It must be clear enough for them to understand the robot. Nevertheless, participants enjoyed their time with the robot and found it easy to use. Finally, an experimental study (49 participants) observed the subjects interacting with the NAO [72]. Most of the participants enjoyed their interaction with the robot. Also, interestingly, they pointed out that age and dementia, but not the gender, influenced negatively the interaction between the user and the robot.

3.7 Autism and Intellectual Disability

Seven of the collected studies (81 participants) assessed the utility of the NAO robot with participants diagnosed with autism spectrum disorder (ASD) or an intellectual disability (ID). All the studies on ASD concerned children, and one of them also assessed adults with ASD. One final study compared the effects of the NAO robot between ASD and ID participants (Table 6).

3.7.1 Autism

Six studies (70 participants) assessed the social engagement among ASD participants with the NAO robot. A first study used a motor imitation task to see how children with autism would respond. Results were variable and the authors suggested that there might exist subgroups of children with autism that would behave differently to the robot [74]. Indeed, more recently, [75] proposed three subgroups with different behavioral response to the robot in their first study. In this second one, they compared how participants from each group behaved when interacting with the robot. Children from the first group had more difficulty to focus their attention on the robot. The second and third groups did not switch their attention from the robot to another stimulus in the environment. The child from the third group was the only one to interact with the robot (wave back at it). Also, [78] experimented a joint attention task among ASD children. The authors observed that when both human and robot agents used cues like pointing, gazing or giving vocal instructions, the children's performance to the task increased. Albeit, pointing was the most engaging cue, more than gaze and vocal instructions. Two other studies concluded that the robot facilitated social engagement of ASD children. In the first one [76], the social engagement was reflected by an increase in the frequency of eye contact, its duration and the frequency of verbal initiation. In the second research [77], the NAO robot assisted music therapy sessions for 6 weeks. Over the weeks, the authors observed that the children increasingly imitated the robot, while the therapist's prompts decreased. Then, only one study (32 participants) compared ASD children with typical development (TD) ones [79]. In the NAO robot condition, both groups had lower performances in a joint attention elicitation task than in the human condition, although ASD children had an even lower score than TD ones. The authors proposed that the NAO robot was less engaging than the human partner. It was the only study to achieve a more negative outcome from the NAO robot. All the other studies observed that ASD children showed interest in the robot. The NAO robot represents a good avenue for future intervention programs, since it could be used as an example to imitate or to do modeling training for ASD children to practice social interaction (i.e., eye contact; [76]).

3.7.2 Intellectual Disability

Finally, only one study (11 participants) included adult participants with intellectual disability or ASD. In the study, the authors used interaction activities and a Bingo Musical activity, executed by the NAO, with participants diagnosed with ASD or ID [80]. According to the results, patients with ID do not interact the same way ASD participants do. In fact, participants with ID showed lower engagement toward the robot and they had more difficulty to follow the instructions given by a robot than by a human, whereas the opposite effect is seen with ASD participants. The main utility of the

Table 6 Selected studies in Autism and Intellectual disability

Theme	Author	Sample	Design	Findings on NAO[a]
Autism	Tapus et al. [74]	5 children with autism diagnosis and one with elements of autism (mean age 4.2 years, all boys)	2 intervention sessions per day for 4 weeks, 5 to 10 min length	= Since the results were mixed and children did not react the same to the robot, the authors suggest that there might be a subgroup of children with autism that HRI would be beneficial – The robot was only able to imitate gross arm movements and it was not fast enough to assure a perfect contingency
	Chevalier et al. [75]	First study: 6 autistic children (mean age 10.9 year) and 7 autistic adults (mean age 26.1 years) Second study: 4 children (3 boys) with ASD	First study: Evaluation of the participants' profiles Second study: First interaction with NAO and dancing Preliminary experiment	First study: + 3 groups with different behavioral responses: (1) overreliance on proprioceptive input and hyporeactivity to visual cues, (2) reliance on visual and proprioceptive input, (3) weak proprioceptive integration and strong visual dependency Second study: – People from group (1) switched their attention and had smaller duration of gaze towards robot + Groups (2) and (3) were more focused on the robot + The child in group (3) was the only one to wave back at the robot
	Chung [76]	14 children with ASD (aged 9–11 years, all males)	Robotic intervention program. Stratified random sampling, single-group-repeated-measure experiment	+ Interaction with robots facilitates social engagement (frequency and duration of eye contact, frequency of verbal initiation) of ASD children + Robotic intervention increased eye contacts with a human tutor + Since NAO robot can make eye contact, it is a model for children with ASD to learn eye contact by modeling learning
	Beer et al. [77]	4 children diagnosed with ASD	Robot assisted music therapy. Case study	+ Over the weeks, the children increasingly imitated the robot while the therapist's prompts decreased
	David et al. [78]	5 participants (4 males, aged 3–5 years)	Joint attention task. Experimental study	+ Using cues (pointing, gaze orientation, vocal instructions) increases the performances in the JA task + Pointing was an important engaging cue, more than gaze orientation and vocal instructions
	Anzalone et al. [79]	32 participants: 16 children with ASD (13 males, mean age 9.25 years) and 16 typical development children (9 males, mean age 8.06 years)	Joint attention induction task. Experimental study	– Significant decrease in performance when interacting with the NAO robot = Significant differences in patterns of behavior between ASD and TD groups

Table 6 (continued)

Theme	Author	Sample	Design	Findings on NAO[a]
Intellectual disability	Shukla et al. [80]	First study: 6 participants (1 male, mean age 50.23 years) Second study: 5 participants (no male, unknown age)	First study: Interaction activities with individuals with ID. Case study Second study: Bingo Musical activity. Case study	First study: = Patients with different levels of ID do not behave the same with the robot = Patients with higher disability show lower engagement toward the robot + Interactive activities generate higher attention from users that non-interactive activities – Individuals with ID had more difficulty to follow instructions given by a robot than by a human, whereas the opposite is shown in the literature for individuals with ASD Second study: + Caregivers' task's subjective workload is decreased when using robots, mostly affecting mental demand and effort required of the caregiver = Caregivers need adaptation to know how to deal with the time the robots enable them to save

[a]+: positive finding, =: neutral finding, –: negative finding

NAO concerning ID participants would be to decrease the workload of the caregivers. Indeed, using NAO robot lowers the mental demand and effort required to the caregivers to take care of the participant.

4 Discussion

Robotics evolved at an incredible speed, and the NAO robot is one of the most popular models. A great variety of studies have been done on this subject. The aim of the present survey is to bring together as many articles as possible investigating the utility of the NAO robot. Since the growing literature on the subject might be overwhelming, this study helps in knowing at what point we are in using the NAO robot as a SAR. In order to differentiate the different roles of the robot, six categories of usability were created subjectively by the authors, namely social interactions, affectivity, intervention, assisted teaching, mild cognitive impairment/dementia, and autism/intellectual deficiency.

In the first category, social interactions, it was shown that understanding the factors involved in the interactions between a human and a robot is crucial. The NAO robot can be used as an advertiser to influence people by communicating through different kind of speech (direct and indirect). In addition, enhancing social engagement of a robot is a very important part of the interactions, since it allows the users to be more comfortable with the robot and increases likability and positive attitude towards the robot. Also, the personality seems to be an important variable in the human–robot interactions, especially extroversion. The studies show that matching personalities might improve the relationship with a robot, although this effect is still unclear, and more studies are needed to be done. The communication process and perceptions of the robot are essential when investigating the social interactions between a human and a robot.

In the affectivity category, the main outcome from the authors is that it is essential for a SAR in general to be an empathic device. Studies have shown that an empathic robot is well perceived by the participants because it can understand their emotions and express emotions through gestures. Effectively, since the NAO robot cannot use facial expression to express its emotions, authors show that using audio information and body gesture is enough for the participants to correctly recognise the conveyed emotions.

The intervention category shows a great avenue of the NAO robot. In fact, authors show that it has great potential in interviewing and in intervention, particularly in motivational therapy in the presented studies. Also, the robot was able to evaluate participants using tests and to make recommendations after classifying them in certain categories. Authors advance that SARs could have a great potential in healthcare system, since it is multifunctional and is perceived as more acceptable by people. In addition, the NAO was used to assist physical intervention by modeling the movements to the patients. Although the robot was useful to improve the quality of the movements done by the participants, the physical limitations of the robot are still an obstacle, since some movements were not optimally modeled by the NAO.

The studies in the category of assisted training all mention that using a NAO robot as a teacher or a coach is a great technology improvement, even though some obstacles are still in the way. In schools, students seem to appreciate the contact with the robot. Its efficacy in this field of application is mainly due to its multimodal interaction, since it uses the auditive, visual and kinaesthetic modalities when interacting with the students. There are some limits to the robot in assisted teaching, such as following the learning rhythm of the children, technical problems and physical limitations (more important in sign language teaching).

Using the robot in mild cognitive impairment and dementia patients is a promising avenue in future research. As [4] show in their review on SAR in elderly, they are widely experimented in this field of application. Although, there are not that many studies investigating usability of the NAO robot among this population. The studies presented show a positive impact of the NAO when interacting with people with dementia or mild cognitive impairment. It is easy to use, and it can either be a cognitive trainer or a companion.

Finally, the last category consisted of studies dedicated to the use of a NAO robot with participants having either ASD or ID. Using a NAO robot to improve social relations skills among this population is effective, since modeling learning. Nonetheless, studies' results vary concerning social engagement, since one says the robot enhances it, whereas another say it does not. More studies are needed to improve our knowledge on the effect of using a NAO robot with this population. Also, since the field of research is still new, studies are developing ways to use the robot to help in the diagnosis of ASD (see [81]).

4.1 Limitations

The first limitation of this literature review is the probability to have excluded or to have not found a relevant article on the subject. Even if the initial set of studies did not include that many studies (N = 139), there is a risk that some studies were not spotted or were excluded too quickly. Also, the fact that we did not have interrater agreement in our study selection process could be a limitation, even though all the authors validated the list.

Second, the categories that were made in this review are totally subjective, which might not be as representative as other possible categories. In addition, some studies could have been classified in more than one category, but the choice was made according to the main outcomes. Therefore, the reliability of the categories could be questioned.

Finally, even if methodological quality was not an exclusion criterion, some studies do not mention the sex or the age of the participants, which means that the results must be interpreted with caution. Also, some sample sizes were very small and limits the power of the analysis and the results of these studies.

4.2 Future Research

As mentioned before, SAR is an expending literature and it will continue to grow in the next years, because of all the technological advances that are made. In fact, more research needs to be done in all the field of applications explored in this review, since new progress is made every day concerning robots. Although, future studies must consider how the humans interact and perceive the robots, and how the robot can adapt to the people to create a personalized interaction. Also, as mentioned in [4], future studies should be more careful when choosing outcome measures, since performance or social interaction components such as laughter or duration of eye-gaze are not certainly relatable measures. Finally, the duration of almost all the studies are very limited, so it would be very interesting to investigate the effects of a cohabitation with a humanoid robot. Long-term studies are needed to assess such type of effects.

5 Conclusion

This study focused on one specific robot, the NAO robot. This robot is a SAR that is used in various contexts because of it's multifunctionality. Although its usability presents a positive avenue, there is still room for progress, whether concerning the methodological issues of the studies or the technological improvements that are to come. According to the studies presented in this review, the NAO robot has a great potential as a SAR because of its capability to be adaptative and multifunctional. The NAO seems to benefit to both the professionals that would use them and to the users who will interact with it.

Studying human–robot interaction is a complex field of research. Six categories were defined in the presented surveys: social interactions, affectivity, intervention, assisted teaching, mild cognitive impairment/dementia, and autism/intellectual disability. The NAO robot showed both strengths and weaknesses in these categories. First, social interactions are essential to be assessed to understand how human–robot interactions work. It was found that the attitude of the participants towards the robot is mainly positive, but this relation can be modified by the technical errors made by the robot. Also, reversely, the robot can influence the user's attitude in advertisement. Moreover, the effects of matching personalities are not clear in the presented results. It would be interesting to explore other dimensions of the personality than only extroversion and introversion, as Bechade, Dubuisson Duplessis, Sehili et Devillers (2015) tried to do. Second, affectivity is a key component in interactions between users and robots. The NAO robot is an effective platform to both perceive and express emotions accurately using bodily embodied expressions. In addition, it can be programmed to be an empathic robot. Third, as a therapy assistant, results show that the NAO reduced stress and anxiety in a psychological therapy. It is also effective in enhancing motivation among participants, but long-term studies are needed to clarify this effect. In physical therapy, the NAO is a great model for the participants to imitate, despite some physical limitations of the robot, which limit the movements it can do. Fourth, the robot was an efficient teacher or a coach assistant. Its greatest advantage is its use of multiple learning modalities (visual, auditive and kinaesthetic). However, disadvantages consisted of adapting to the rhythm of the children, technical issues and physical limitations. Fifth, with mild cognitive impairment and dementia patients, the NAO robot seems to be a good cognitive trainer and companion. Finally, concerning participants with ASD or ID, the NAO robot was very practical in improving social skills by modeling learning.

To conclude, the use of the NAO robot is very large and has a great potential, and research still needs to be done to better understand these constructs. We think that multidisciplinary teams can consider exploiting the robot for more advanced applications.

Appendix: List of the Reviewed Articles

Aagela, H., Holmes, V., Dhimish, M., & Wilson, D. (2017, March). Impact of video streaming quality on bandwidth in humanoid robot NAO connected to the cloud. In *Proceedings of the Second International Conference on Internet of things, Data and Cloud Computing* (pp. 1–8).

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Ahmad, M. I., Mubin, O., & Orlando, J. (2016b, November). Effect of Different Adaptations by a Robot on Children's Long-term Engagement: An Exploratory Study. In *Proceedings of the 13th International Conference on Advances in Computer Entertainment Technology* (pp. 1–6).

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Aly, A., & Tapus, A. (2015). Towards an intelligent system for generating an adapted verbal and nonverbal combined behavior in human–robot interaction. *Autonomous Robots*, *40*(2), 193–209. doi: 10.1007/s10514-015-9444-1

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