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A Systematic Review of Experimental Work on Persuasive Social Robots

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Abstract

There is a growing body of work reporting on experimental work on social robotics (SR) used for persuasive purposes. We report a comprehensive review on persuasive social robotics research with the aim to better inform their design, by summarizing literature on factors impacting their persuasiveness. From 54 papers, we extracted the SR's design features evaluated in the studies and the evidence of their efficacy. We identified five main categories in the factors that were evaluated: modality, interaction, social character, context and persuasive strategies. Our literature review finds generally consistent effects for factors in modality, interaction and context, whereas more mixed results were shown for social character and persuasive strategies. This review further summarizes findings on interaction effects of multiple factors for the persuasiveness of social robots. Finally, based on the analysis of the papers reviewed, suggestions for factor expression design and evaluation, and the potential for using qualitative methods and more longer-term studies are discussed.

Keywords Persuasion · Behaviour change · Human–robot interaction · Social robotics

1 Introduction

Social robotics (SR) has been identified as robots that are socially evocative, socially receptive, equipped with a social interface or sociable [8]. In contrast to physically assistive robots, SR support their users through social interactions. Thus far, SR have been considered for multiple application areas (e.g., healthcare, education, commercial services [16]) and roles (e.g., servants, assistants, collaborators). For some time now, the field of Human-Robot Interaction (HRI) has studied the persuasive nature of social interactions with robots [70]. More recent research suggests that the act of persuasion is an inseparable component of the interaction between humans and a social robot, similar to human-human interaction (HHI) [74]. Several studies have argued for the benefits of social robot persuasion in creating effective, engaging and meaningful social robotic assistance [25,37,74]. Beyond these benefits, understanding social robot persuasion also helps avoiding any ethical and psychological damage from unintentional persuasion effects [74]. To date, persuasion by social robots has been explored and evaluated in a multitude of application scenarios, such as promoting a healthy lifestyle [6,39], facilitating learning activities [85,89], and increasing environmental awareness [82] (see Table 4).

Many experimental studies have investigated which and how SR's design and behaviour can affect their persuasive power towards their human counterparts. A survey study in 2018 reviewed the persuasive effects of non-verbal interaction of SR. The survey provided an overview of, and evaluated non-verbal robot communication design with regards to the robots' kinesics, proxemics, haptics and chronemics, and evaluated the persuasive effects in their ability to shift cognitive framing, elicit emotional responses, trigger specific behavioural responses, and improve task performance [66]. Another survey from the same year investigated current developments in social robot personality research [62]. While both reviews present an overview of the present, and a vision on future persuasive social robot design, the current scope of experimental work in the field extends beyond non-verbal interaction and personality. In order to reflect on current developments and to support further persuasive SR design, we provide an overview on the body of work regarding persuasive SR research. Specifically, we explore how persuasion through SR has been studied, the persuasive factors that have been evaluated, as well as their effects on persuasiveness.

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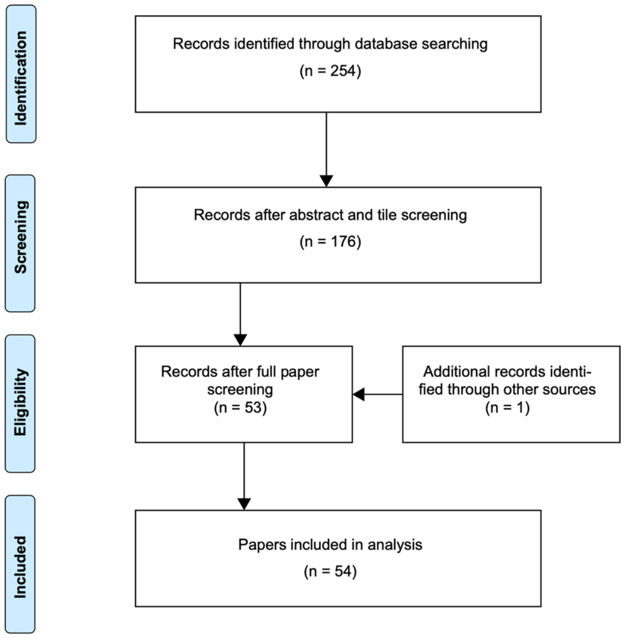

Fig. 1 PRISMA flow diagram [53] for the selection of papers reviewed

The topic of persuasion has been extensively studied in HHI, with many theoretical frameworks proposed to understand such processes:, e.g., theory of planned behaviour [3], self-determination theory [64], and the elaboration likelihood model [58]. Similarly, in the domain of human-technology interaction, theories have been developed for eliciting compliance from users [15]. Summarizing, there is a broad theoretical basis on which designers of persuasive technology in general, and social robots specifically, can build their designs. Notwithstanding this theoretical basis, however, researchers are actively exploring the effectiveness of theory-based persuasion techniques in the domain of social robotics. This review attempts to bring together this body of work, with the aim of identifying factors that have been "tried and proven" in the design of persuasive social robotics.

One could challenge the need for studying the psychology of persuasion in HRI, because an extensive body of work already exists on persuasion in the field of HHI. However, HRI is fundamentally different from HHI, since robots lack the ability to be persuaded themselves, and humans' perception of robots as non-humans influences their attitude and behavior towards the latter. Finally, interaction with social robots concerns a cognitive process of both social interaction and interaction with an artefact [31]. Due to this duality, theories from HHI or HCI are not necessarily sufficient to explain the phenomena surrounding persuasion in HRI and a need to develop, hence the need for theoretical investigation of persuasion specifically in the domain of HRI.

In the remainder of this paper, we detail the methods we used in collecting and analyzing the body of knowledge that was reviewed in this study. We present a detailed analysis of the reviewed papers that were clustered in five categories. Finally, we discuss the implications of the current paper on future SR research and design.

2 Method

This review focuses on persuasive factors in SR design and their evaluation. The review procedure follows the guidelines proposed by the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) statement. PRISMA was designed to help systematic reviewers transparently report why the review was done, what the authors did, and what they found [53].The PRISMA statement provides a checklist addressing the introduction, methods, results and discussion sections of a systematic review report, and a flow diagram that depicts the flow of information through the different phases of a systematic review, visualizing the number of records identified, included and excluded (see Fig. 1).

2.1 Search Strategy

A query was conducted on the ACM, IEEE, and Scopus databases on August 19, 2019. The search query used was: *(TITLE (robo*) AND TITLE-ABS-KEY (persua* OR "behaviour change" OR "behavior change" OR coaching OR "behaviour modification" OR "applied behaviour analysis"))*. The query resulted in 254 papers. After title, abstract and full paper screening (see Fig. 1), we manually added one additional paper that satisfied the inclusion criteria, but that was not found using the search query. 54 papers reporting on a total of 60 studies were included for further analysis according to the criteria listed in Table 1.

Given our aim to summarize the research on social robots persuading human participants, we collected studies that evaluate social robots' persuasive effects through user studies. Therefore, we included research involving human participants in experiments where the social robot functioned as a social actor in the interaction and mediated the persuasion. We excluded papers that investigated technical aspects of robotic design, such as user adaptation [23], user-related cognition [56], control systems [57], etc. Other papers that were excluded focused on design methodology [14], design cases of robot platforms [60,61], application issues regarding deployment [59], user perceptions [11,88], tasks [35,80], and ethical issues [30].

2.2 Method of Analysis

Data were extracted based on the categories shown in Table 2. The factors evaluated by each study are addressed as persuasive factors in the review. For example, one study evaluated

Table 1 Inclusion and exclusion criteria

Inclusion criteria	Exclusion criteria
Exploring persuasive factors and strategies in social robotics	Does not provide the evaluation of the design/strategies with user
Including user-involved evaluation on persuasiveness of the SR	Does not focus on persuasive effects of SR
Study reported in English language	Robot that acts as a tool for telepresence
	Position paper
	Review paper
	Book or book chapter

Table 2 Data extracted from the studies

Meta-data	Persuasive factor design and evaluation
Author	Persuasive factor
Title	Factor expression (how the factor is presented in the interaction)
Country (based on source of participants)	
Year of publication	Experiment design
Application field	Participants
Robot platform deployed	Measurements and results
Study type (Lab, field, etc.)	Factor interaction results
Technology presentation (Using Wizard-of-Oz, illustrations, products, etc.)	

the effect of SR showing politeness on persuasion by comparing participants' responses to a SR with/without polite cues [32]. For this study, we registered "politeness" as the persuasive factor evaluated. As most persuasive factors by themselves are relatively abstract, the review also extracted a detailed description (factor expression) of how the persuasive factor is portrayed in the actual interaction. For example, in the case of evaluating politeness, researchers used eight different ways for expressing politeness (e.g., showing indirectness, expressing the goal as the subject's own wish or Socratic hints, etc) [32]. Beyond evaluating individual factors, 25 studies investigated how a social robot's persuasiveness is influenced by a combination of multiple factors. For example, two studies investigated how either verbal or non-verbal interaction, or a combination of both affected robot persuasiveness, and found that combining both verbal and non-verbal interaction resulted in higher compliance than for each of the factors used individually [6,10]. These "factor interactions" are presented in a dedicated section, investigating factor interactive effects and potential patterns for factor combinations. Finally, to avoid misinterpretation, terminology used to describe the factors follows the description provided by the authors of the papers we reviewed.

To map the current areas of research on persuasive social robots, the extracted persuasive factors were clustered and organised into five categories through card sorting. Three researchers (first author with two other non-authors, with research backgrounds of design and/or social robotics) were provided with the persuasive factors and their expressions extracted from the studies in this review. The researchers first clustered the factors individually, then integrated their clusters into a commonly agreed structure through discussion. The card sorting analysis was conducted according to the standard procedure proposed by Spencer & Garrett [75]. This analysis identified five categories of factors evaluated in persuasive social robotics research: modality, interaction, social character, persuasive strategies and context.

3 Results

3.1 Meta-Data Results

Studies on persuasive social robotic research first emerged in 2005 and started to appear consistently in literature from 2008 (see Fig. 2). Table 3 provides an overview of the methods, experimental settings, sample sizes and application fields for all studies included. Primary locations for conducting persuasive robotic research are the United States (24%), the Netherlands (20%) and Japan (17%). Widely used robotic platforms for these studies are NAO, Pepper, iCat, Socibot and ATR's robovie-mR2 (see Fig. 3), while Table 5 provides an overview for the studies, year of publication and frequency of use for all included robotic platforms.

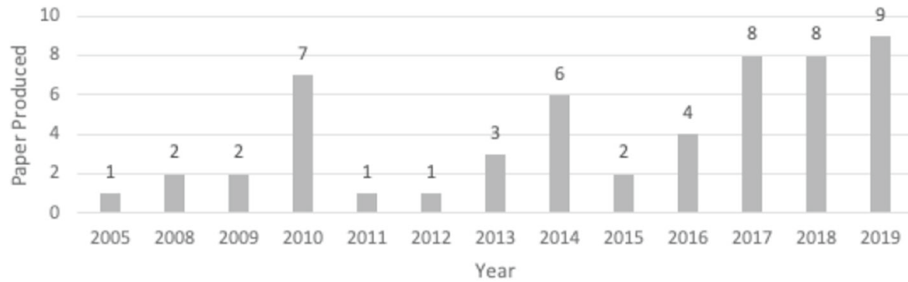

Fig. 2 Papers by publication year

To present, most persuasive social robotic research has focused on evaluating factors for persuasiveness outside any particular application area or societal context. Rather, persuasion effectiveness is studied in the context of abstract laboratory tasks such as desert/Mars survival games [46], mundane or repetitive tasks (copying formulas, image recognition) [54,72] and fictional tasks, such as making a drink for an alien [21]. 64% of the research was done in such an artificial context. while 36% of the studies were situated in a certain application field and scenario of use as shown in Table 4.

Among all the studies extracted from the survey, sessions in which participants had live interactions with a robot are the most prominent way of evaluating persuasive factors. These studies were mostly (87%) done in a lab environment with a Wizard-of-Oz approach, and typically lasted between 30 minutes and two hours. Other study types include field studies (12%) and online surveys (2%). Among the field studies, two particular studies assessed long-term robotic persuasion over the course of six weeks [39] and six months [49].

Studies primarily use quantitative measures for data collection. They mostly collected data regarding compliance (indicated by actual behavior change (an objective act of compliance), or through self-reported persuasion) and theoretical components related to the evaluated persuasive factor. For example, a study evaluating credibility measured (1) participant's compliance to the robot's suggestion and (2) trustworthiness of the robot, a factor impacting persuasiveness as indicated by theoretical reference [21]. Qualitative data were collected to interpret the quantitative data and to gain insights [2,87]. Bio measurements were also incorporated in one study, with respiration rate, heart rate, blinking rate, and skin conductance as indicators for stress level during negotiation with a robot [13].

Table 3 Meta-data on the included studies (total number (n) might differ in each section due to some papers including multiple experiments)

Method	% n = 54
Quantitative	94% (51)
Qualitative	2% (1)
Mixed (Quantitative & Qualitative)	4% (2)
Experimental setting	**% n = 60**
Lab	87% (52)
Field	12% (7)
Online survey	2% (1)
Sample size	**% n = 60**
Under 20	53% (32)
20 to 50	33% (20)
50 to 100	8% (5)
Over 100	6% (3)
Application field	**% n = 54**
General (nonspecific field)	63% (34)
Environmental Sustainability	11% (6)
Healthcare	11% (6)
Service	7% (4)
Education	4% (2)
Automotive	2% (1)
Sports	2% (1)

3.2 Evaluated Persuasive Factors

To clearly present the data from the survey, the extracted persuasive factors were clustered and organised into five categories through card sorting analysis. The analysis identified the following five categories of factors addressed in the design of persuasive social robotics research:

1. **Modality** aspects of the social robotics' presence.
2. **Interaction** robotic interactive functionalities.
3. **Social Character** human or non-human character traits.
4. **Persuasive strategy** persuasive strategy application in social robots.
5. **Context** contextual factors impacting persuasiveness of human-robot interaction.

Based on the results presented, the presence of social robots can elicit stronger compliance compared to some other persuasive embodiments like pamphlets, phones and non-social robotics. Studies in section of social robot interactions shows that a more interactive robot that equips various ver-

Fig. 3 Most-used social robotic platforms (from left to right: NAO. Pepper, iCat, robovie-mR2, SociBot)

Table 4 Specific application fields and target groups addressed by social robotic persuasion research

Application field	Target participant group
Environmental Sustainability	Tourists [82]
	General group [27–29,52, 84]
Service	Consumer [34,38,45,54]
Education	Young students (Age 6–17) [85]
	Students [89]
Healthcare	Patient [78]
	Children (Diet) [6]
	Elderly (Fall Prevention Education) [49]
	Elderly (Assistant) [32]
	Obese Patients [39]
	Rehabilitation Patient (Physiotherapy) [87]
Automotive	Driver [86]
Sports	General Group [68]

bal and non-verbal interactive cues, generally gains higher persuasiveness. Several persuasive strategies from the HHI domain like peer pressure, compatibility, foot-in-the-door technique and reciprocity are also found to be applicable in persuasive HRI. Contextual factors like task difficulty, cultural background and social influences have been found to influence participants' attitude and behaviour. Factors regarding a robot's social character were widely explored, however results are not aligned. Similarly, several studies confirmed that persuasive factors do interact. However, in part due to the lack of replication studies on some factors combinations, current results are not strong enough to convincingly confirm the interactive effect of particular factor combinations.

With the intent to provide an clearer view for the status of social robotic persuasive research, the sections below show:

1. An overview of the factors evaluated and their effectiveness in eliciting compliance within the section.
2. A table presenting the following information from the reviewed studies: the robotic platform that was used, the factor they evaluated, the means through which the factor was expressed, the measures that were recorded, and the results found.

Comparing the studies, we observed that some authors use different terminology to describe identical factors and use the same terms to describe different factor expressions. For example, two studies both reported on the effect of social speech, however one study varied the presence of the speech function itself (by not using a verbal cue in the control condition) [84], the other one investigated the effect of emotions in speech feedback by comparing emotional speech and emotionless speech between experiment conditions [82]. To disentangle such term collisions, studies were clustered based on the factor expression that was compared between experimental conditions, also with regards to the measurements used in the experiments, to check if they align with the term and expression.

3.2.1 Modality

The studies in the modality category investigated the persuasive effect of the presence of social robot, compared to other forms of persuasive agents (i.e., non-social robots, pamphlets, desktop PC, kiosk, virtual agents and human) (see Table 6). In line with media equation theory [55] and a previous survey study on different types of agent presence [43], the studies in the current survey have provided ample evidence that the presence of SR can lead to positive compliance to persuasive communications. Generally, when compared to other means of persuasion, SR have been shown to have a stronger influence [28,38,49,84,86]. Findings are mixed, however, when comparing SR to virtual agents [70,79,82,89] or human persuaders [34,86] (see Fig. 4).

Apart from presence, the SR's modality design is also discussed. One notable study explored the persuasive effects of SR with a hybrid modality named "docking". Their specific platform consists of a physical robot and a virtual agent with the same appearance on a handheld device. The handheld device can be docked into the physical robot. When the physical robot is not around, the user can continue interacting with the virtual robot on the portable device. The system used the same agent image across devices and inherited conversational and usage histories to create a more ubiquitous

Table 5 Number of studies and year of publication per robot type

Social robot	Number of studies applied	References	Publication
NAO	16	[1,6,7,17,25,26,33, 45,46,48,67,68,70, 76,77,81,83]	2011–2019
iCat	6	[27–29,52,63,84]	2008–2014
ATR's robovie-mR2	5	[38,54,72,73,78]	2008–2013
SociBot	5	[18–22]	2017–2019
Pepper	2	[13,87]	2018–2019
CHRIS	2	[40,41]	2016–2019
AIDA	1	[86]	2014
Autom	1	[39]	2008
ChairBot	1	[2]	2008
Churi-Chan	1	[82]	2019
Dinsow Mini	1	[49]	2019
Lego mindstorm robots	1	[4]	2013
Mobile Dexterous Social (MDS) robot	1	[74]	2009
MugBot	1	[69]	2017
Olivia	1	[37]	1997
ROBOMO	1	[89]	2017
Robopec Reeti	1	[32]	2016
Robovie-R3	1	[79]	2013
RS Media robot	1	[85]	2010
Sam	1	[65]	2019
Sota	1	[71]	2016
Wakamaru	1	[10]	2012

persuasive agent. The study compared the persuasive power of the robot with/without the handheld device [78]. Even though the docking design was not shown to be more persuasive, the study suggests that the research of persuasive SR modalities extends beyond the robot's presence. With further technology advances, it is important to explore more aspects of social robots' modality (e.g., form factor, ways of presence) and explore their influence on the persuasiveness of the SR.

3.2.2 Interaction

This section includes research that explores the presence of robotic interactive capabilities like speech, gesture, gaze, etc. Such factors reflect the interactivity of the social robots (see Table 7). Higher levels of interactivity can be achieved by equipping the robot with more interactive cues or by increasing the interactivity of each cue. Generally, robots equipped with interactive cues have been shown to be more persuasive, except for gestures, which only showed marginal effects (see Fig. 5).

3.2.3 Social Character

A number of studies have evaluated the impact of SR's social characters on persuasiveness. So far, widely explored factors include agency level, sociability, gender, trustworthiness, rapport building, and the robot's communication styles. Individual studies also investigated the effect of showing politeness, goodwill, acknowledgement, and the robot being a teammate (see Fig. 6 and Table 8).

As general trends, studies show that higher sociability [27,28,52,84] and providing negative feedback [27–29,52] can lead to higher compliance. Studies also found that robots whispering and touching humans could elicit compliance by building up rapport with the user [54,72,73]. Trustworthiness is widely explored with various expressions. Though results have not been replicated, showing facial trustworthiness [21], providing practical knowledge and implementing rhetorical capabilities [4] have been shown to be effective for persuasion.

Apart from the above-mentioned factors, some factor combinations also produced mixed results, e.g., the combination of gaze and gesture has both shown no interaction [26] as well as an interactive effect strengthening their persuasiveness [25].

Agency level refers to the robot's personality on a scale from machine-like to human-like. This factor was expressed in multiple ways over different studies but was not consistently shown to be effective in persuasion. One study found

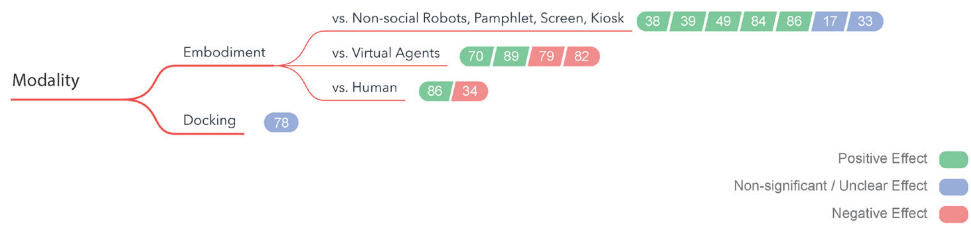

Fig. 4 Summarised results of persuasive effectiveness of social robot modality (numbers indicate the referred study, with colour code to show the general result of the study)

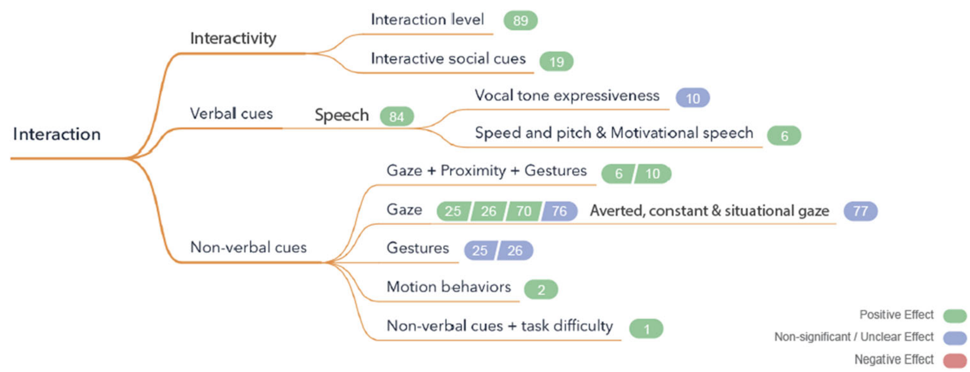

Fig. 5 Summarised results of persuasive effectiveness of social robot interaction (numbers indicate the referred study, with colour code to show the general result of the study)

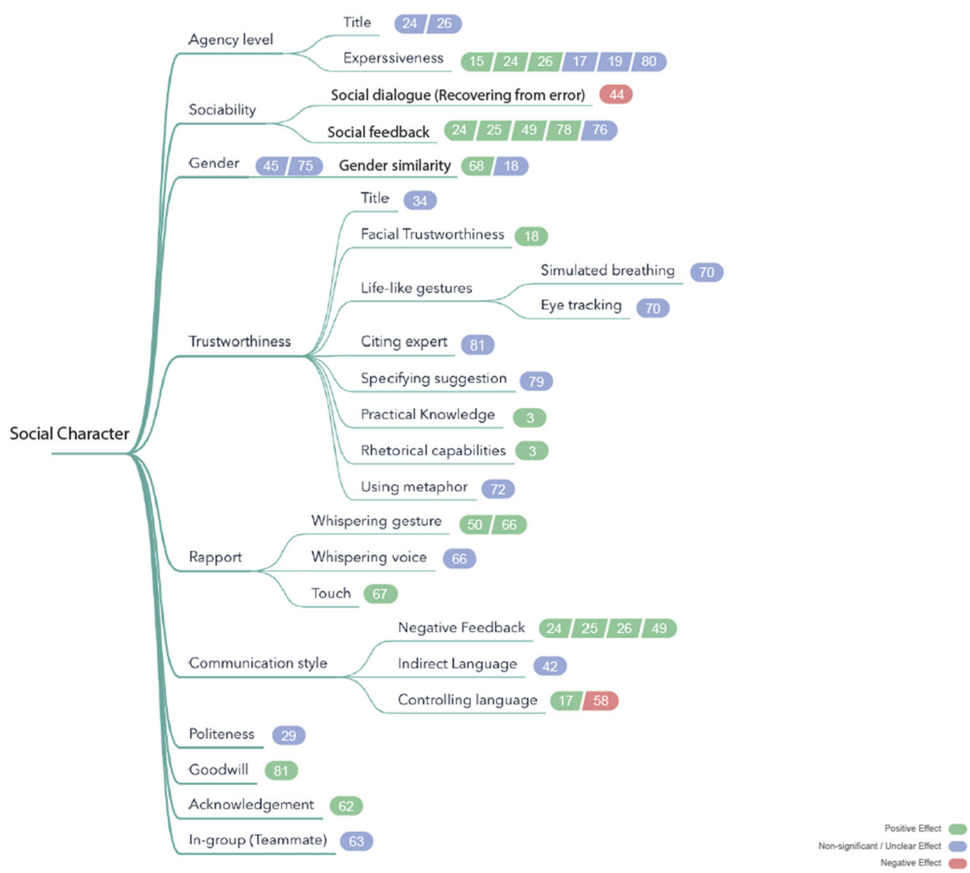

Fig. 6 Summarised results of persuasive effectiveness of social robot social character (numbers indicate the referred study, with colour code to show the general result of the study)

that higher agency level would lead to higher psychological reactance [22]. A study on gender differences showed that there is a positive cross gender effect on persuasion and that men show more gender related behaviors [74]. However this conclusion was not fully supported by any other experiment on the same factor [81].

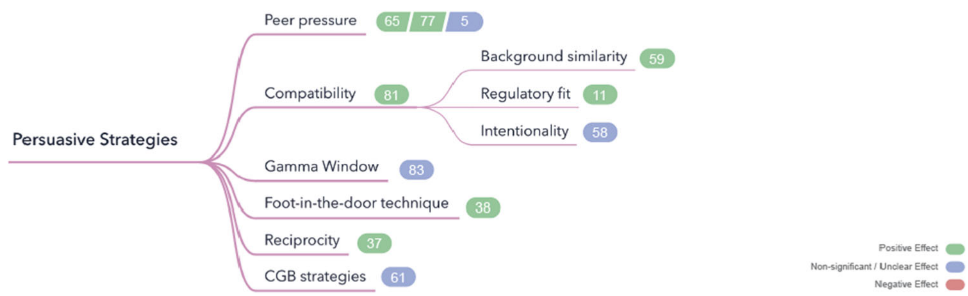

Fig. 7 Summarised results of persuasive effectiveness of social robot persuasive strategies (numbers indicate the referred study, with colour code to show the general result of the study)

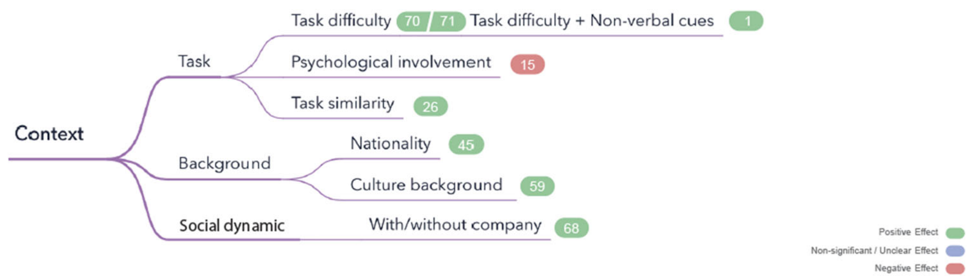

Fig. 8 Summarised results of persuasive effectiveness of social robot interaction context (numbers indicate the referred study, with colour code to show the general result of the study)

3.2.4 Persuasive Strategies

Factors discussed in this section concern persuasive strategies implemented through social robots. Such persuasive strategies derive from research in human-human communication, e.g., in the fields of social psychology or communication studies. The strategies evaluated include peer pressure, regulatory fit, similarity, timing (based on the theory of cognitive dissonance), foot-in-the-door technique, reciprocity and strategies from the CGBs collection (a collection of persuasive verbal messages using the following strategies: affect, authority, cooperative, criticise, deceit, direct, exclusive, liking, logical, threat [50]). Over half of the strategies evaluated were found to have marginal to significant positive effects on participants' compliance to the robot agent. Though there is a lack of replication studies, these results suggest a promising potential for applying persuasive strategies common in human-human interaction to the field of social robotics (see Fig. 7, Table 9).

3.2.5 Context

This section includes contextual factors that are not directly related to the SR, nor the participants, but are considered relevant to the human-robot interaction and persuasive outcomes (see Fig. 8, Table 10).

Tasks are usually a necessary part of a persuasive HRI evaluation session. The effects of task similarity, task difficulty and task relevance to the user have been investigated. The results show that when the task gets difficult, participants tend to follow the robot's advice more [1,76,77]. Having company during the interaction with a social robot has also been found to be relevant for a participant's compliance, and the effect varies between genders. In particular, female participants change their behavior when interacting with a persuasive robot when accompanied by another person, in contrast to a situation in which they interact with the robot individually [74]. Finally, cultural background was also found to be a relevant factor in the persuasiveness of SR [48,65].

3.3 Persuasive Factor Interactions

It is common for a social robot in a human-robot interaction to portray more than one of the factors discussed in the previous section. A numbers of studies evaluated the effects on persuasion of multiple factors implemented simultaneously. Figure 9 presents an overview of the factor combinations evaluated and Table 11 presents further details with each evaluation. Since factors from across the five above sections were combined in the studies, we clustered similar combinations.

Studies generally show that the identified factors interact when combined. Often, factors that are already effective individually would increase their efficacy when combined. Such results have been found repeatedly with the combinations of non-verbal cues and task difficulty [1,76], and negative and social feedback [27,28]. Some factors that are not effective individually can still boost the effect of other effective factors when combined, though this effect is not observed in all related studies. While combinations of gaze and task difficulty (effective individually) [77] and whispering gesture (effective individually) and small voice [54,72] do not show any difference in persuasive effects, the combination of gaze and gesture (effective individually) [25], and high controlling language (effective individually) and social agency

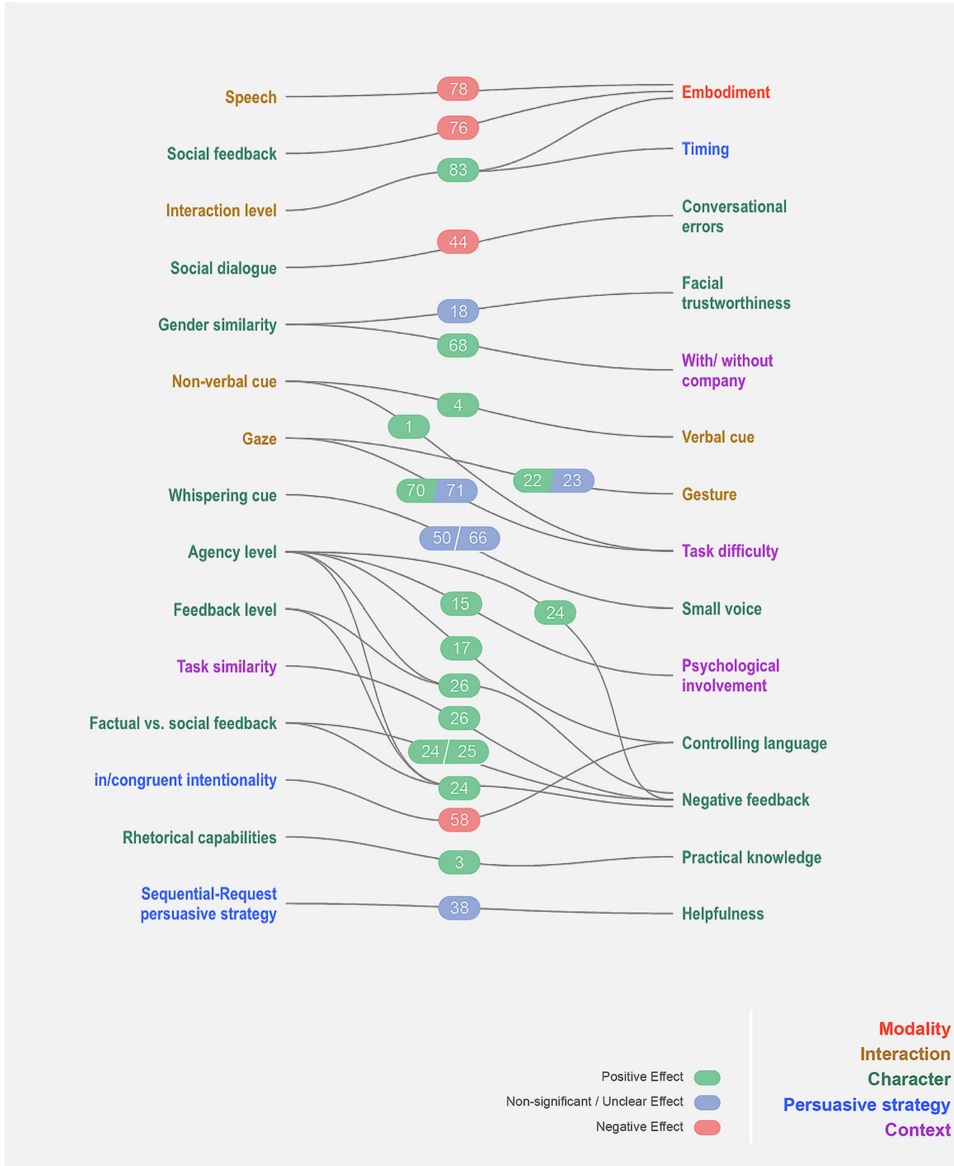

Fig. 9 Summarised results of persuasive effectiveness of factor combinations (numbers indicate the referred study, with lines connecting the factors evaluated as a combination in each study)

level [20], appear to have a stronger effect than individual factors.

4 Discussion

This survey on persuasive social robot research has identified a number of general trends in persuasion by social robot. Overall, persuasion studies involving the presence of a social robot have provided evidence for the persuasiveness of social robots. Social robots tend to be more persuasive with higher levels of interaction gained through deploying verbal and non-verbal cues. Also, contextual factors within human-robot interaction including specific tasks, backgrounds and social dynamics have been shown to be generally effective in eliciting compliance in participants.

While this review shows consistently positive effects on persuasion by factors related to modality, interaction and context, the choices of social character and persuasive strategies implemented in the robot have been found to produce mixed results. As a general, trend such studies are based on and are aimed at testing current theories from HHI or elements thereof. Studies with such intention aim to establish whether theories of human persuasion apply to the context of HRI. To this point, results are mixed, suggesting that HRI can gain from applying methods borrowed from HHI persuasion, but the effects are not the same as for human persuaders. One related insight for this phenomenon was captured within an interview from one of the evaluated studies, where a participant remarks: *"it is nice that the robot shows good will, but I'm just not sure if he (the robot) is sincere."* [87]. Other studies have shown that the cognition towards social robots is a complex process [9]. One of the ways for understanding how social robots persuade humans, is through synthesizing related works. As much as the variables were strictly controlled within the studies in this review, the variety of setups, measurements and analyses used amongst the reported experiments on identical factors make it difficult to synthesize this review's findings into a coherent narrative. Below we discuss ways in which future research can address these limitations.

4.1 Effects of Varied Factor Expressions

The factor expression refers to how a factor manifests itself in a robot's actions. In general, experiments are designed based on a particular theory (on persuasion) that typically only provides the researchers with an abstract concept of a factor description (e.g., 'credibility'). However, such abstract descriptions provide ample of room for different implementations (e.g., 'showing practical knowledge' [4], 'citing expert' [87], 'using metaphor' [78], 'title' [37], 'facial characteristics' [21], etc.). As the varied results have shown, these different implementations themselves might have a significant impact on the persuasive effect. In this review, studies have provided different levels of clarity on how the expression of the factors were designed. Some studies designed the expression based on previous research [7], some base their designs on theory [4], while other studies provide no clear description.

The influence of factor expression is exemplified in a series of experiments which examined whether a robot could elicit behavior change through peer pressure. Three experiments were all based on Asch's conformity experiment [5] and used similar experimental designs, including their measurements and tasks for participants. The earliest study in the series did not find a significant effect of peer pressure on persuasion [7]. However, the two later studies used different versions of the expression design with synchronized robot behavior [71] and a mixed group of human and robot peers [83], and both found the strategy of peer pressure to be effective in social robot persuasion.

Unlike the above-mentioned case, in most cases the experimental design of studies on similar factors are different from each other (especially the variety in measurements and tasks). Hence, we are unable to compare the effectiveness between different expressions for the same factor. However, the ability to do so is instrumental to discover the efficacy of certain theoretical factors, as well as the most suitable way to express them. For comparing different expressions of the same factor, we suggest the approach from a study on the influence of politeness on persuasiveness [32]. Before evaluating the persuasive effects of the polite robot, the study first investigated the different ways of expressing politeness using eight strategies (e.g., showing indirectness, expressing the goal as the subject's own wish or Socratic hints, etc). The evaluation of the eight strategies identified expressions that were more successful in expressing politeness, as well as the different levels of clarity in expressing politeness for each expression. Essentially, this approach checks the extent to which the implementation of the factor aligns with the intentions of the researchers (in this case showing politeness). Following this approach could eliminate the potential risk of failing manipulations (e.g., the robot not being perceived as polite). Beyond reducing risk in individual studies, the results of such evaluations can help to compare the designed expression across studies to identify opportunities for optimising the effect of a given factor.

Apart from evaluating the design of factor expressions, a theoretical common ground can also be adopted at an earlier stage when considering the design of factor expressions. For the case of equipping social robots with character traits, psychology research describes that personality is portrayed through someone's behaviors, cognition and emotions [24]. Different experiments can plan, design and measure the social robot interaction according to the dimensions indicated by such theory, thus resulting in increased comparability.

4.2 Mixed-Methods Research

Within the studies surveyed, the experimental hypotheses were not always supported by the results. Qualitative data can be very useful to provide such explanations. For example, one study hypothesised that a robot showing goodwill in the experiment would increase the robot's credibility and likability. While the results show the strategy indeed provided a good encouragement, the credibility and likability measures did not correlate with the objective measure of compliance [87]. Though showing goodwill has been shown to be effective in eliciting compliance, the hypothesized explanation for that effect was not proven, and thus the hypothesized mechanism for the factor's effect remained not validated. However, a follow up interview in the same study revealed that the participants had doubts about the intentions behind the robot's behaviour, which is an issue that was not covered by the theoretical framework on which the study was based. Similarly, in studies measuring the interactive effects of multiple combined factors, the quantitative measurements used currently can only reflect on the complex phenomenon as a whole, but do not provide a deeper understanding of the mechanism behind such effects.

As illustrated by the above cases, HRI interaction remains a complicated process that extends beyond the realm of HHI and HCI theories that are referenced in the reviewed research. We thus recommend a mixed methods approach, where qualitative research methods can help in gaining a better understanding of how social robots gain persuasive power towards their human counterparts. Furthermore, the current focus on behavioural and self-report data can be complemented with physiological data (e.g. respiration rate, heart rate, blinking rate, and skin conductance). Such data has proven to facilitate a better understanding of effects studied in SR persuasive research [13].

4.3 Long-Term Studies and Field Evaluations

As mentioned in section 3, the majority of experiments reviewed are single session lab experiments, potentially involving the novelty effect that is well known to influence participants in the field of human robot interaction [44]. However, related research has shown that the novelty effect wears off quickly and users show changes in attitude [42]. To produce sustainable social robotic persuasive strategies, future studies should make an effort to address potential novelty effects by (1) planning repeated interaction sessions with the same participants, (2) adding an introduction session before the experiment to familiarise participants with the novel elements.

The preference for lab studies in the reviewed literature bears another risk, where the setting potentially influences participants' behaviour (generally known as the Hawthorne effect [51]). For example, beyond the presence of experimenters, one of the reviewed studies has shown that having company can also modify participants behaviour for robot persuasion [74]. Given the different context, transferring these results into the field might prove difficult. A series of studies investigating the persuasive effect of whispering cues evaluated the same strategy in the field [54], and further validated the findings in the lab [72]. Such a cross-contextual triangulation can yield better understanding of the design of persuasion robots suitable for a real-world deployment.

4.4 Limitations

In this paper, we have limited ourselves to a review of the 'tried and proven'. Many of the studies we have reviewed are grounded in theoretical frameworks on persuasion, but are not easily mapped onto a single, overarching perspective grounded in theory. In limiting our work to review these studies, and by grouping them based on design choices, we cannot provide a comprehensive overview of the areas of persuasive design currently under explored by the field. However, we do provide an overview of design choices that have been found to be effective in the field of persuasive SR.

5 Conclusions

We presented a survey on the research performed on persuasive social robotic factors from 2005 to 2019 to inform further persuasive social robotic research and design. From the studies reviewed, we identified and presented current findings of persuasive social robotic research in areas of modality, interaction, social character, persuasive strategies and context. Based on this review, we have found that the presence of a social robot can elicit stronger compliance compared to some other media like pamphlets, phones and non-social robotics. Furthermore, studies on social robot interactions show that a more interactive robot, equipped with a range of verbal and non-verbal interactive cues, generally gains higher persuasiveness. Several persuasive strategies in HHI domain like peer pressure, compatibility, foot-in-the-door technique and reciprocity have been found to be applicable in persuasive HRI. Finally, contextual factors like task difficulty, culture background and social influences are also found to influence participant attitude and behaviour.

Factors regarding a robot's social character were widely explored but have resulted in less consistent results. Similarly, studies have confirmed that persuasive factors do interact. However, partly due to the lack of replication studies on similar factor combinations, there is as yet not strong enough evidence regarding the interactive effect of combining two or more of these factors.

Finally, based on our review of the studies in the current paper, we wish to draw the attention of researchers to (1) the design and evaluation of persuasive factor expression for optimising the factor's effect, (2) incorporating qualitative research methods for further results interpretation, and (3) striving for long-term and field evaluations to eliminate novelty and observer effects.

Declarations

Data availability The authors declare that the data supporting the findings of this study are available within the article and its supplementary information files.

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

Appendix 1: Tables

See Tables 6, 7, 8, 9, 10 and 11.

Table 6 Overview of study results of social robotic persuasion through modality, showing the robotic platform that was used, the factor evaluated, the means through which the factor was expressed, the measures that were recorded, and the results found. * effect (+ for effective, − for not effective)

Reference	Robot platform	Factor	Factor expression	Measures	Results
[17]	NAO	Embodiment	NAO, Roomba iRobot, and a server box	• Task performance	± No statistical difference was found on task performances
[34]	Sketch Material	Embodiment	Human, humanoid robot & information kiosk	• Following suggestion	− Human condition was significantly more persuasive than robot condition
				• Source credibility	
[79]	Robovie-R3	Embodiment	Robot versus Virtual agent	• Task performance	− Overall, a virtual agent was more influential on the user than a robot in situations where maintenance of motivation was needed
[70]	A robot developed by NTT	Embodiment	Robot versus Virtual agent	• Following suggestion	+ Robot presence condition is significantly higher in suggestion adoption than agents and no recommendation
[49]	Dinsow Mini	Embodiment	With/ Without Robot presence	• Number of exercises	+ The robot group showed a faster statistically significant improvement in knowledge mean score at the 3rd month
				• TUG	+ The robot group showed a statistically significant higher number of exercises at 3rd and 6th month. Moreover, the intervention group showed a statistically significant increment number of exercises over time
				•BBS	+ The robot group revealed statistically significant improvement in both TUG and BBS at 6th month after the intervention was performed
				•Knowledge on fall prevention	
[89]	ROBOMO	Embodiment	Robot versus Mascot (static image with voice)	• Following suggestion	+ Participant find the text easier when a robot interfered than a mascot. + results show a higher score on participant's attitude when the robot interferes than the mascot

Table 6 continued

Reference	Robot platform	Factor	Factor expression	Measures	Results
[39]	Autom	Embodiment	Social robot versus Stand-alone computer versus paper log	• Following request of recording diet	+ Participants with a robot used their system significantly longer with average 50.6 days, than a computer (36.2 days on average) and a paper log (26.7 days on average)
[84]	iCat	Embodiment	Computer versus Social robot presence	• Amount of energy saved after feedback	+ The social agent group consumed less energy than participants who received feedback from the computer
[82]	Churi-Chan	Embodiment	Robot versus Virtual agent	• Personal factors on behavioural intention • Consumers' acceptance of the intervention • Pro-environmental behavioral intention	− The intervention will be particularly effective if it was provided by virtual assistant with social feedback
[38]	ATR's robovie-mR2	Presence	Robot versus digital signage	• Following suggestion	+ Robot presence elicit higher transition rate when they recommend customer to visit certain area + Robot presence elicit high recommendation purchase rate when they recommend for certain product
[86]	AIDA	Embodiment	Robot versus Phone versus Human	• Adhere to safety suggestions	+ The adherence in the robot presence condition is significantly higher than that of phone or human
[33]	NAO	Anthropomorphism & perceived authority	NAO versus Roomba	• Following suggestion • Following request	± No significant difference was found upon all measures
[78]	ATR's robovie-mR2	Using Metaphor & Docking	Combination of phone (Virtual robot agent) and Robot	• Source Credibility • Relational Communication Scale • Self-evaluated questions indicate the effect of persuasion	± No significant difference was found upon all measures

Table 7 Overview of study results of social robotic persuasion through interaction, showing the robotic platform that was used, the factor evaluated, the means through which the factor was expressed, the measures that were recorded, and the results found. * effect (+ for effective, − for not effective)

References	Robot platform	Factor	Factor expression	Measures	Results
[19]	SociBot	Interactive social cues	Social cues include:	• Compliance	+ Negative cognitions were found to be lower when the robot has more interactive social cues
			1. Mimicry of head movement.	• Psychological reactance	+ Liking on persuasive robot increased with the increment of the number of interactive social cues
			2. Proper timing of praise	• Liking rate of the robot	+ Robot with social praise enhances trusting beliefs towards the agent
				• Trusting beliefs	
[89]	ROBOMO	Interaction level	Comparing dynamic and static robot	• Following suggestion	+ Higher interaction level leads to better compliance to robot's suggestion, higher score for mood and regard the tasks to be easier
				• Mood	
				• Attitude	
				• Convenience metric (evaluate the difficulty of the test)	
[84]	iCat	Speech	Presence of speech	• Amount of energy saved after feedback	+ Participants who received speech feedback consumed less energy than participants who received visual feedback
[1]	NAO	Nonverbal cues +	Directive gestures: looking, pointing at the suggested answer	• Recall accuracy	+ The presence of non-verbal behaviour elicit nonsignificant compliance in easy task conditions and significant compliance in both difficult task conditions
		1. Task difficulty (memorization load)		• Completion time	
		2. Task difficulty (interruption)			
[70]	A robot developed by NTT	Gaze	Gaze at participant	• Following suggestion	+ Presence of gaze elicit higher compliance
[77]	NAO	Gaze	1. Averted gaze (might suggest lying)	• Task performance	± No significant difference found in compliance to different types of gaze

Table 7 continued

References	Robot platform	Factor	Factor expression	Measures	Results
			2. Constant gaze (might suggest aggression and dominance)		
			3. Situational gaze (only used in a disagreement)		
[76]	NAO	Gaze	When asking for the participant's answer, the robot would look directly at the participant (direct gaze). If Eye Gaze was Off, the robot would look at the monitor displaying the shell game (averted gaze).	• Trust the robot's opinion	+ Participants take less time to answer when gaze in present
				• Changed their answer • Task accuracy • Time taken	
[26]	NAO	Gaze	Gaze at participant	•Attitude change that indicates persuasion	+ Participant in gaze condition have significant different opinions about the character in the story + Gaze can make robots become more persuasive and the effect is stronger when the robot uses gestures
		Gesture	Simulated gesture from a story telling actor	•Attitude change that indicates persuasion	± No significant difference found in attitude change
[25]	NAO	Gaze	Gaze at participant	• Attitude change that indicates persuasion	+ Participant in gaze condition have significant different opinions about the character in the story+ Gaze can make robots become more persuasive and the effect is stronger when the robot uses gestures
		Gestures	Simulated gesture from a story telling actor	• Attitude change that indicates persuasion	± No significant difference found in attitude change
[6]	NAO	Verbal cue	1. Speed and pitch	• Fix higher goals	+ Participants fix higher goals with presence of verbal cues
			2. Motivational speech		Verbal cues were found to be more effective than non-verbal cues

Table 7 continued

References	Robot platform	Factor	Factor expression	Measures	Results
		Non-verbal cue (Body)	Gaze, proximity (With or without a desk between participant and robot) and gesture (animated speech gestures)	• Fix higher goal s	+ Participants fix higher goals with presence of non-verbal cues
[10]	Wakamaru	Vocal cues	Vocal tone, expression	• Change choice	± No significant difference found in compliance to presence of verbal cues
				• Perceptions of the robot's persuasiveness	± Participants do not regard either robot to be more persuasive
				• Intelligence	
				• Participants' assertiveness	
		Bodily cues	Proximity, gaze, gestures	• Change choice	+ Participants' compliance with the robot's suggestions were higher when the robot employed nonverbal cues than they did when it did not use any nonverbal cues
				• Perceptions of the robot's persuasiveness	± Participants do not regard either robot to be more persuasive
				• Intelligence	
				• Participants' assertiveness	
[2]	ChairBot	Motion behaviors	Using four kinds of moving pattern to recruit participant for a chess game at an exhibition	• Following and participate	+ The ChairBot successfully recruited participants with each motion behaviour. people were most likely to sit on the chair in response to forward back at the table robot strategy, while for all the other measures highest success was associated with approach person outside table robot strategy. Results shows that minimal motion behaviours in chairbots can persuade people

Table 8 Overview of study results of social robotic persuasion through social character, showing the robotic platform that was used, general category of the factors, the factor evaluated, the means through which the factor was expressed, the measures that were recorded, and the results found. * effect (+ for effective, − for not effective)

References	Robot platform	Category	Factor	Factor expression	Measures	Results
[29]	iCat	Agency level	High versus Low-agency	In the high agency condition, robot was introduced as "robot that has a mind of its own"	• Amount of energy saved after feedback	± No significant difference found in compliance
[27]	iCat		High versus Low-agency	In the high agency condition, robot was introduced as "a robot that has a mind of its own"	• Amount of energy saved after feedback	± No significant difference found in compliance
[86]	AIDA		Expressiveness	With/ Without Head movement, voice/touch interaction	• Adhere to safety suggestions	+ both robot conditions gain adherence significantly higher than that of phone or human ± no difference found between expressive versus Non-expressive robot condition
[20]	SociBot		Social agency level	In the high social agency (HSA) condition, the Socibot can express verbal and nonverbal cues through the movement of its head, eyes and mouth.	• Perceived Threat to Autonomy (PTA) • Psychological Reactance • Response to Advice and Recommendations (RAR)	± Participants showed no significant difference in psychological reactance and compliance
[22]	SociBot		Level of social agency	High agency level is expressed through tone of voice, facial expression and head movement	• Following suggestions • Psychological reactance • Negative cognition	± No significant difference found in compliance − High agency level leads to higher reactance than medium agency level, but both lower in reactance than low agency condition
[18]	SociBot		Level of social agency	In the high social agency (HSA) condition, the Socibot can express verbal and nonverbal cues through the movement of its head, eyes and mouth	• Change decision	+ Participants who received social feedback consumed less electricity than participants who received factual feedback

Table 8 continued

References	Robot platform	Category	Factor	Factor expression	Measures	Results
					• Psychological reactance • Threat to autonomy	
[27]	iCat		Level of social agency	The robot is either introduced as a "advanced electronic device" (low agency) or "Victor, a robot with a mind of its own" (high agency), provides feedback by single script for a certain type of feedback (low agency) or a script with six synonymous variations (high agency).	• Amount of energy saved after feedback	+ Participants who received social feedback consumed less electricity than participants who received factual feedback
[27]	iCat		Low, Medium & High level of feedback	1.feedback level "low", e.g., a sad face or a smiling face. 2. iCat illuminated little lights at the top of its ears 3. the iCat uttered a negative or positive word ("Terrible!" or "Fantastic!")	• Amount of energy saved after feedback	+ High-level feedback leads to high compliance than that of Low and Medium-level feedback
[29]	iCat		Low, Medium& High level of feedback	1. Feedback level "low", e.g., a sad face or a smiling face 2. iCat illuminated little lights at the top of its ears 3. the iCat uttered a negative or positive word ("Terrible!" or "Fantastic!")	• Amount of energy saved after feedback	+ High-level feedback leads to high compliance than that of Low and Medium-level feedback
[47]	NAO	Sociability	Social dialogue(remedy for conversational errors)	Using a ice-breaker conversation	• Following suggestions	- The interaction between error and ice-breaker conditions approached a trend showing that the negative effect of errors tends to be worse after the ice-breaker

Table 8 continued

References	Robot platform	Category	Factor	Factor expression	Measures	Results
[82]	Churi-Chan		Social feedback	With/without emotional expressions in the dialogue. • Consumers' acceptance of the intervention • Pro-environmental behavioral intention	• Personal factors on behavioral intention	± Presence of social feedback was not found to be effective in persuasive outcome
[28]	iCat		Factual versus Social feedback	Feedback with social speech compared to a graphical factual feedback from screen	• Amount of energy saved after feedback	+ Social feedback has a higher impact on behaviour than factual feedback
[27]	iCat		Factual versus Social feedback	Feedback with social speech compared to a graphical factual feedback from screen	• Amount of energy saved after feedback	+ Participants who received social feedback consumed less electricity than that of factual feedback
[27]	iCat		Factual versus social feedback	Factual feedback: energy meter. Social feedback: robot's facial expressions, led lights and utterance of a word	• Amount of energy saved after feedback	+ Participants who received social feedback consumed less electricity than that of factual feedback
[52]	iCat		Factual versus Social feedback	Feedback with social speech compared to a graphical factual feedback from screen.	• Amount of energy saved after feedback	+ Participants who received social feedback consumed less than that of factual feedback
[84]	iCat		Feedback type	Factual feedback: energy meter Evaluative feedback: computer would give feedback by changing the background color Social feedback: speech from iCat while it displayed emotional expressions consistent with the given feedback	• Amount of energy saved after feedback	+ Participants who received social feedback than that of either factual feedback or evaluative feedback

Table 8 continued

References	Robot platform	Category	Factor	Factor expression	Measures	Results
[21]	SociBot	Gender	Gender Similarity	Match / mismatch gender with robot and participant	• Participants obeyed the advises	± No difference in trusting belief and behaviour
					• Trusting beliefs	+ Similar gender with robot and participant leads to lower psychological reactance
					• Psychology reactance	
[48]	NAO		Gender	Voice and name to express gender	• Donation amount	+ Female robot received more donation
					• Trust	
					• Credibility	
					• Engagement	
[81]	NAO		Gender	Gendered name, voice and accessories	• Persuasive discourse inventory questionnaire	± No difference was found based on the robot's gender
						+ Women rated the robot as more persuasive than men
[74]	Mobile Dexterous Social (MDS) robot		Gender & similarity	Using voice to express gender, also manipulating gender match between participant and robot.	• Donation amount	+ Subjects donated more often to the female robot than the male robot. Men primarily prefer donating to female robot
					• Trust	+ Men rated the female robot as more credible than the male robot, while women rated the male robot as more credible than the female robot
					• Credibility	+ Men tended to report that the female robot was more trustworthy than the male robot. Women, conversely, reported that the male robot was slightly more trustworthy than the female robot
					• Engagement	+ Men are predominantly affected by the change in robot gender
						+ Men reported significantly more engagement with the female robot, while women showed no preference. Female robot is more engaging than the male robot, and women tend to report being more engaged than men

Table 8 continued

References	Robot platform	Category	Factor	Factor expression	Measures	Results
[4]	Lego mind-storm robots	Trustworthiness	Rhetorical capabilities (on perceived expertise)	Expressing goodwill, prior experience, metaphors, organisation, fluency in voice interactions	• Following suggestions	+ The participants chose to visit landmarks described by robots using high rhetorical ability 57% of the time, compared to 43% for landmarks described by the robots using low rhetorical ability
					• Competency	+ Robots with high rhetorical ability were rated more competent, more persuasive, and more sociable
					• Persuasiveness	± Rhetorical ability had no effect on participants' ratings of the robot's trustworthiness
					• Sociability	
					• Trustworthiness	
[4]	Lego mind-storm robots		Practical knowledge	Showing practical knowledge with script.	• Following suggestions	+ Participants chose landmarks that were described with all possible information more frequently than they chose landmarks that were described with only some information
					• Competency	+ Participants rated robots with high practical knowledge to be more competent, more persuasive, more trustworthy, and marginally more sociable
					• Persuasiveness	
					• Sociability	
					• Trustworthiness	
[87]	Peppper		Expertise	Citing expertise or those of the information source	• Amount of exercise	± No significant difference found in compliance
					• Exercise duration	
					• Exercise speed	
[78]	ATR's robovie-mR2		Using Metaphor	Using metaphor to describe participant's health condition	• Source credibility	± No significant difference found in compliance
					• Relational communication scale	

Table 8 continued

References	Robot platform	Category	Factor	Factor expression	Measures	Results
					• Self-evaluated questions indicate the effect of persuasion	
[37]	Olivia		Role	Introduced as expert or novice	• Following suggestions	± No significant difference found in compliance
					• Cooperation intention	
					• Credibility	
					• Intelligence	
[85]	RS Media robot		Credibility	Robot gives participant a suggestion and give different levels of specification for the reason	• Following suggestions	± No significant difference found in compliance
					• Level of certainty	
					• Robot credibility	
[21]	SociBot		Facial trustworthiness	Different facial characteristics and expression based on Facial Action Coding System (FACS).	• Participants obeyed the advises	+ A trustworthy face would elicit higher trusting beliefs and trusting behaviours
					• Trusting beliefs	+ A trustworthy face cause lower psychology reactance specifically measures of feeling of anger
					• Psychology reactance	
[76]	NAO		Eye tracking (Life-like body gestures)	Using life-like body gestures to express credibility.	• Asked the robot for help	± No significant difference found in compliance
					• Changed their answer	
					• Task accuracy	
					• Time taken	
[76]	NAO		Simulated breathing (Life-like body gestures)	Using life-like body gestures to express credibility.	• Asked the robot for help	± No significant difference found in compliance
					• Changed their answer	

Table 8 continued

References	Robot platform	Category	Factor	Factor expression	Measures	Results
					• Task accuracy • Time taken	
[72]	ATR's robovie-mR2	Rapport	Whispering Gesture	Hold both hands in front of its own moth and ask participant to approach.	• Number of equations written • Time spent on the task	+ Whispering gesture leads to significantly more tasks done and longer task time
[72]	ATR's robovie-mR2		Small Voice	Whispering volume	• Number of equations written • Time spent on the task	± No significant difference found in compliance
[54]	ATR's robovie-mR2		Whispering Cue	Includes a whispering gesture and speech request.	• Number of equations written • Time spent on the task • Enjoyment for the task • Enjoyment for the robot	+ Whispering cue leads to higher compliance
[54]	ATR's robovie-mR2		Whispering cue with normal voice	Includes a whispering gesture and speech request, and deliver the content using normal volume of voice.	• Following suggestions	+ Whispering behaviour leads to more people printing the coupons
[73]	ATR's robovie-mR2		Touch	Robot to human touch/ Human to robot touch on the hand	• Number of tasks finished • Time spent on the task • Perceived friendliness of the robot	+ Robot's touch achieved significantly better both with task performed and time spent than no touch and human touching robot
[29]	iCat	Communication Style	Negative feedback	Giving positive or negative feedback based on participant's fulfilment of the task goal.	• Amount of energy saved after feedback	+ Negative feedback leads to higher compliance than that of positive feedback

Table 8 continued

References	Robot platform	Category	Factor	Factor expression	Measures	Results
[29]	iCat		Negative feedback	Giving positive or negative feedback based on participant's fulfilment of the task goal	• Amount of energy saved after feedback	+ Negative social feedback leads to higher energy conservation
[28]	iCat		Negative feedback	Giving positive or negative feedback based on participant's fulfilment of the task goal	• Amount of energy saved after feedback	+ Negative feedback leads to higher energy conservation
[27]	iCat		Negative feedback	Giving positive or negative feedback based on participant's fulfilment of the task goal	• Amount of energy saved after feedback	+ Negative feedback leads to high compliance than that of positive feedback
[27]	iCat		Negative feedback	Giving positive or negative feedback based on participant's fulfilment of the task goal	• Amount of energy saved after feedback	+ Negative feedback leads to higher energy conservation that that of positive feedback
[52]	iCat		Negative feedback	Giving positive or negative feedback based on participant's fulfilment of the task goal	• Amount of energy saved after feedback	+ Negative feedback leads to higher energy conservation that that of positive feedback
[52]	iCat		Negative feedback	Giving positive or negative feedbac k based on participant's fulfilment of the task goal	• Amount of energy saved after feedback	+ Negative feedback leads to higher energy conservation that that of positive feedback
[45]	NAO		Indirect language	Differed in the directness of the speech. A sample of the speech is presented: Direct form: "Why should you try Pepsi? Pepsi has a delicious flavor and has been objectively tested. In blind tasting, people preferred Pepsi" Indirect form: "What soda should you try? Maybe a soda with good flavor. In blind tasting, the participants preferred this brand without knowing it"	• Attitude change	± Participant's attitudes towards the presented product did not differ regarding the type of language employed by the robotic agent

Table 8 continued

References	Robot platform	Category	Factor	Factor expression	Measures	Results
[20]	SociBot		Controlling Language	High Controlling Language (HCL) used explicit or direct verbs (e.g., "You must serve the other beverage to the alien", "Dare change your mind?", "You have to.", 'You need to...')	• Perceived Threat to Autonomy (PTA)	+ Participants showed higher compliance with high controlling language
				Low Controlling Language (LCL) used less imperative and less derisive language in conveying the advice (e.g., 'Would you mind serving the other beverage to the alien?', 'Perhaps', "You may want to.", 'Maybe you need to...').	• Psychological Reactance	– Participants showed higher scores of anger with high controlling language
					• Response to Advice and Recommendations (RAR)	
[63]	iCat		High & low threatening language	Tone of voice. Difference between "you could"and "you have to"	• Feeling of anger	– Participants experienced more psychological reactance when receiving high-threatening advice
					• Negative thoughts	– High-threatening advice led to higher restoration
					• Perceived threat-to-autonomy	
					• Perceived intentionality	
					• Negative evaluations of the agent	
					• Restoration thoughts	
					• Restoration behavior	

Table 8 continued

References	Robot platform	Category	Factor	Factor expression	Measures	Results
[32]	Robopec Reeti		Politeness	Politeness and the compared conditions are expressed in total eight ways: These categories are: (A) direct commands, (B) indirect suggestions, (C) requests, (D) actions expressed as the tutor's goals, (E) actions as shared goals, (F) questions, (G) suggestions of student goals, and (H) Socratic hints.	• Politeness	± Significant differences were found between the different wordings for the perceived politeness, but not for the perceived persuasiveness
					• Persuasive	
[87]	Pepper		Goodwill	Caring about/taking an interest in the receiver, displaying understanding/empathy for their ideas/feelings.	• Amount of exercise	+ Showing goodwill elicit significantly higher compliance
					• Exercise duration	
					• Exercise speed	
[68]	NAO		Acknowledgement	Verbally acknowledge participants performance with speech "you're doing it right".	• Physical performance	+ Showing acknowledgement leads to higher physical performance
[69]	Mugbot		In-group	Whether the robot and participant are on the same team or neutral.	• Big request	– The manipulation of the robot's group membership was not strong enough for participants to notice and explicitly report feeling more like a group with the robot
					• Small request	+ Participants were more likely to adhere to the robot plea in the robot In-group condition than Neutral
					• Following the robot's medical advice	
					• Anthropomorphism of Robot and Researcher	
					• Participant emotions and attitudes toward the robot	

Table 9 Overview of study results of social robotic persuasion through persuasive strategies, showing the robotic platform that was used, the factor evaluated, the means through which the factor was expressed, the measures that were recorded, and the results found * effect (+ for effective, − for not effective)

Reference	Robot Platform	Factor	Factor Expression	Measures	Results
[7]	NAO	Peer pressure	A recreation of Asch Conformity experiment. Four robots would say a wrong answer one by one with participant answering last in the group	• Number of misled answers compared to baseline group	± No significant difference found upon measures used
[71]	Sota	Peer pressure with synchronisation	Participant answering quizzes with six robot contestants and one robot MC, the robot contestants would give their answer one-by-one/ in synchronisation	• Number of misled answers compared to baseline group	+ Robot synchronised behaviour created higher pressure for participants
				• Feeling of pressure from the robots	+ Synchronised behaviour leads to higher rate of mislead answers by the robots
[83]	NAO	Peer pressure	Participants answering quizzes with one robot and a group of human actors.	• Number of misled answers compared to baseline group	+ A robot dissenter (Having different answer with the rest of the group) have a strong leading effect on participants when its answer is correct
[13]	Peppper	Regulatory Fit	Different matching types between participant and the robot based on regulatory focus theory[10]. Expressed by body movements and speed of speech	• Purchasing behaviour	+ Chronic promotion focus participants are easily persuaded by the matching state of robot, prevention did not show such result
				• Physical condition (Stress level)	
[63]	iCat	In/congruent intentionality	Having the same goals or not. Specifically, energy saving or cleaning	• Feeling of anger	± No significant difference found upon measures used
				• Negative thoughts	
				• Perceived threat-to-autonomy	
				• Perceived intentionality	
				• Negative evaluations of the agent	
				• Restoration thoughts	
				• Restoration behaviour	

Table 9 continued

Reference	Robot Platform	Factor	Factor Expression	Measures	Results
[65]	Sam	Aligning with participants background	Different countries have different level of individualism or collectivism, the robot asks about the origin of the person and use either individualism or collectivism scripts	• Pictures labelled	+ Culturally matched participants help the robot longer than mismatched participants
[87]	Peppper	Compatibility	Emphasising similarity between the receiver and the source. Asking and agreeing with participants statements	• Amount of exercise	+ Robot that has similar opinions with the participants is considered to be higher with goodwill
				• Exercise duration	
				• Exercise speed	
[89]	ROBOMO	Timing (Based on cognitive dissonance)	When the student makes mistake, robot provide a suggestion before /during gamma window[33].	• Following suggestion	+ Participants regard the exercise to be easier when message is delivered during gamma window
				• Mood	+ Participants have better attitude towards the robot when message is delivered during gamma window
				• Attitude - Participants complied more with request to redo when the message is delivered before gamma window	
				• Convenience metric (evaluate the difficulty of the test)	
[41]	CHRIS	Sequential-Request persuasive strategy (Foot-in-the-door)	Asking a small request first, when participant complied, the robot would ask a bigger request.	• Task performance	+ Foot-in-the-door strategy leads to significantly higher (72%) rate of compliance
				• Perceived credibility	± Robot's perceived performance and credibility were not found to be a predictor for compliance

Table 9 continued

Reference	Robot Platform	Factor	Factor Expression	Measures	Results
[40]	CHRIS	Reciprocity	Giving versus Not giving help first, then ask for help.	• Task performance	+ Participants in the helpful robot condition were more likely to comply with the robot's request
				• Competence	
				• Warmth	
				• Trustworthiness	
[67]	NAO	CGBs strategies	Content-driven factors to persuasiveness have previously been categorised and studied by social psychologists as CGBs, investigating how people adjust their message to persuade or gain compliance from others[47]. Using persuasive verbal message that using following strategies: affect, authority, cooperative, criticise, deceit, direct, exclusive, liking, logical, threat	• Following suggestion	± Any individual strategies were not found to be more persuasive than one another
				• Self-claimed compliance	+ The Affect strategy had the most unanimous response and the largest number of participants (51%) that claimed to use information provided by the robot
				• Persuasiveness	+ The affect strategy had the highest percentage of participants using the exact robot suggestion (16%) and highest guessing within 10% (27%)
				• Trustworthiness	+ The Logical strategy had the second-best unanimous response, participants using the exact same guess (13%), and estimates within 10% of the suggested (19%)

Table 10 Overview of study results of social robotic persuasion through context, showing the robotic platform that was used, the factor the evaluated, the means through which the factor was expressed, the measures that were recorded, and the results found * effect (+ for effective, − for not effective)

References	Robot platform	Factor	Factor expression	Measures	Results
[77]	NAO	Task difficulty	By changing the speed of cup shifting in a cup and ball guessing game, participant will work together with a robot to finish the task	• Asked the robot for help	+ Participants are more likely to change their answer to the robot's as cup movement speed (task difficulty) increases
				• Changed their answer	+ Participants ask for Nao's opinion more often as the speed of cup movement (task difficulty) increased
				• Time taken	
[76]	NAO	Task difficulty	By changing the speed of cup shifting in a cup and ball guessing game, participant will work together with a robot to finish the task.	• Trusting behavior	+ Participants more likely to trust the robot on hard trials than medium trials
[1]	NAO	Task difficulty (memorisation load)	By adding memorisation load/ interruption	• Recall accuracy	+ NVB makes it easier to memorise and finish the task
		Task difficulty (interruption)		• completion time	+ NVB makes task marginally easier with interruption
		+ Nonverbal cues		• recall accuracy	+ The presence of non-verbal behaviour elicits non-significant compliance in easy task conditions and significant compliance in both difficult task conditions
[18]	SociBot	Psychological involvement	Relevancy of the task to the user. Making a healthy drink for participant themselves or for an alien	• Change decision	− Higher psychological involvement cases participant's higher psychological reactance
				• Psychological reactance	
				• Threat to autonomy	

Table 10 continued

References	Robot platform	Factor	Factor expression	Measures	Results
[29]	iCat	High versus Low task similarity	Used with positive/ negative feedback type	• Amount of energy saved after feedback	+ More similar tasks led to an increase of the persuasive effect of negative feedback
[48]	NAO	Nationality/ Cultural background	Comparing people with / without culture background from Kazakhstan	• Donation Amount	+ Foreigners (Non-Kazakhstan) donate more to the robot
				• Trust • Credibility • Engagement	
[74]	Mobile Dexterous Social (MDS) robot	With/Without company	With/ without human companion(s) while interacting with social robot	• Donation Amount	+ Men donate significantly more often to the female robot whether alone or accompanied by other visitors + Women donated significantly more often to the female robot when accompanied, however when alone, they reversed their preference with donating marginally more often to the male robot
				• Trust • Credibility • Engagement	
[65]	Sam	Participants background	Different countries have different level of individualism or collectivism, the robot asks about the origin of the person and use either individualism or collectivism scripts	• Pictures labelled	+ Culturally matched participants helped the robot longer than mismatched participants

Table 11 Overview of study results of social robotic persuasion through factor interaction, showing the robotic platform that was used, the factor evaluated, the measures that were recorded, and the results found on single factors and factor interactions * effect (+ for effective, − for not effective)

References	Robot platform	Factor evaluated	Measures	Single factor effect	Factor interaction effects
[84]	iCat	Speech	• Amount of energy saved after feedback (The study is set in the conditions of 2 (feedback source: embodied agent versus computer) X 2(feedback presentation mode: verbally with speech versus colours on computer screen. Computer condition is shown with only a screen, embodiment condition is shown with iCat and a screen)	+	− For spoken feedback, it did not matter whether the feedback was given by the iCat or by the computer. - Feedback which combined the two social cues (the social agent and the use of speech), did not lead to lower energy consumption than feedback in which only one of these cues was present
		Embodiment		+	
[82]	Churi-Chan	Embodiment	• Personal factors on behavioral intention	−	− Feedback indicates that the intervention will be particularly effective if it was provided by virtual assistant with social feedback
			• Consumers' acceptance of the intervention		
			• Pro environmental behavioral intention		
		Social feedback		+	
[89]	ROBOMO	Mascot versus Robot	• Following suggestions	+	+ In regard to measure of convenience metric, effects of a persuasive message spoken during gamma window appeared stronger for dynamic than static interaction level of the motivational source, and stronger for a robot than the mascot
		Interaction level	• Mood		
			• Attitude		
			• Convenience metric (evaluate the difficulty of the test)		+ Regarding attitude, the effect of agency was stronger for a robot than a mascot
		Timing		+	For participants' performance, effects of agency were stronger when the message was told before gamma window than when the message was told during gamma window
[47]	NAO	Social dialogue	• Following suggestions	−	− The negative effect of errors tends to be worse after the ice-breaker (Social dialogue)

Table 11 continued

References	Robot platform	Factor evaluated	Measures	Single factor effect	Factor interaction effects
		Conversational errors		N/A	
[21]	SociBot	Facial trustworthiness	• Participants obeyed the advises	+	± People show more trusting behaviours toward a robot with facial characteristics they trust on humans, which does not seem to be affected by gender similarity
		Gender Similarity	• Trusting beliefs	+	
			• psychology reactance		
[74]	Mobile Dexterous Social (MDS) robot	Gender & similarity	• Donation amount	+	+ Men donate significantly more often to the female robot whether alone or accompanied by other visitors
			• trust		+ Women donated significantly more often to the female robot when accompanied, however when alone, they reversed their preference with donating marginally more often to the male robot
			• credibility		
			• engagement		
		With/without company		+	
[6]	NAO	Verbal cue	• Fix higher goals	+	+ Condition with both verbal and non-verbal cues scored higher in compliance than both individual cue presence conditions
		Non-verbal cue (Body)		+	
[26]	NAO	Gesture	• Persuasion	–	± No interactive effect found
		Gaze		+	
[25]	NAO	Gazing	• Attitude Change	+	+ Gesture combined with gaze would lead to highest compliance among all conditions
		Gesture		–	
[77]	NAO	Gaze	• Task performance	–	± No interactive effect found
		Task difficulty		+	
[1]	NAO	Nonverbal cues + Task difficulty(memorisation load)	• Recall accuracy	+	+ Presence of non-verbal behavior makes task marginally easier in both task difficulty conditions
		Nonverbal cues + Task difficulty(interruption)	• completion time	+	
[76]	NAO	Gaze	• Asked the robot for help	+	+ Participants more likely to trust the robot's opinion when it gazed at them on the hardest trials, but less likely to trust the robot on all easier difficulties

Table 11 continued

References	Robot platform	Factor evaluated	Measures	Single factor effect	Factor interaction effects
			• changed their answer		+ Participants more likely to ask the robot for help with Eye Gaze for hard trials, but less likely for medium trials
			• task accuracy		+ Participants more likely to choose the correct answer on easier trials when the robot looked at them, but less likely to choose the correct answer on harder trials when the robot looked at them
			• time taken		+ Participants finishes the task faster in gaze condition with difficult tasks, the difference does not show in easier tasks.
		Task difficulty		+	
[54]	ATR's robovie-mR2	Whispering Cue	• Number of equations written	+	± No interactive effect found.
			• time spent on the task		
		Small Voice • Enjoyment for the task -			
			• Enjoyment for the robot		
[72]	ATR's robovie-mR2	Whispering Gesture	• Number of equations written	+	± No interactive effect found.
		Small Voice	• time spent on the task	–	
[29]	iCat	Negative feedback	• Amount of energy saved after feedback	+	+ Negative feedback given by a high agency level with high level of social feedback leads to the highest compliance among all conditions
		High versus Low agency		–	
		Low, Medium & High level of feedback		+	
[29]	iCat	High versus Low task similarity	• Amount of energy saved after feedback	+	+ More similar tasks led to an increase of the persuasive effect of negative feedback.
		Negative feedback		+	
[28]	iCat	Negative feedback	• Amount of energy saved after feedback	+	+ Negative feedback provided in a highly social manner leads to the highest compliance among all conditions.
		Factual versus Social feedback		+	
[27]	iCat	Factual versus Social feedback	• Amount of energy saved after feedback	+	+ Negative feedback given by a high agency level with high level of social feedback leads to the highest compliance among all conditions

Table 11 continued

References	Robot platform	Factor evaluated	Measures	Single factor effect	Factor interaction effects
		Negative feedback		+	
		High versus Low agency		–	
		Low, Medium & High level of feedback		+	
[27]	iCat	Negative feedback	• Amount of energy saved after feedback	+	+ Negative feedback provided in a highly social manner leads to the highest compliance among all conditions.
		Factual versus Social feedback		+	
[18]	SociBot	Level of social agency	• Change decision	+	+ High level of social agency and psychological involvement brings highest psychological reactance among all conditions.
		Psychological involvement	• psychological reactance	+	
			• Threat to autonomy		
[27]	iCat	Level of social agency	• Amount of energy saved after feedback	+	+ The greatest changes to conservation behaviour were achieved after negative feedback (compared to positive feedback), in particular at the highest feedback level (including speech). Such effect was strongest for the participants who received social feedback. However, such effect was stronger in the social feedback condition with low agency level compared to the social feedback condition with high agency
		Negative feedback		+	
[20]	SociBot	Controlling Language	• Perceived Threat to Autonomy (PTA) +	+ In low controlling language condition, the psychological reactance increased according to the level of social agency. This trend did not occur in the high controlling language condition	
		Psychological involvement	• Psychological Reactance	–	+ The feelings of anger in all three levels of social agency increased according to the levels of controlling language.
			• Response to Advice and Recommendations (RAR)		

Table 11 continued

References	Robot platform	Factor evaluated	Measures	Single factor effect	Factor interaction effects
[63]	iCat	High & low threatening language	• Feeling of anger	–	– When the robot gave high-threatening advice and expressed an incongruent goal, participants reported the highest level of anger
			• Negative thoughts		
			• Perceived threat-to-autonomy		
			• Perceived intentionality		
			• Negative evaluations of the agent		
			• Restoration thoughts		
			• Restoration behavior		
		in/congruent intentionality		–	
[4]	Lego Mindstorm robots	Rhetorical capabilities (on perceived expertise)	• Following suggestion	+	+ High rhetorical ability significantly improved participant compliance regardless to the level of practical knowledge
			• competency		+ In measures of competency and persuasiveness. Rhetorical ability improved perceptions of competency when practical knowledge was low, and not when it was high
			• Persuasiveness		
			• sociability		
			• trustworthiness		
		Practical knowledge		+	+ High practical knowledge with low rhetorical ability was not significantly different from low knowledge with high rhetorical ability in ratings of persuasiveness, indicating that rhetorical ability can make up for a lack of knowledge in the perceived persuasiveness of a robot
[41]	CHRIS	Sequential-Request persuasive strategy(Foot-in-the-door)	• Task performance	+	± No interactive effect found
			• perceived credibility		
		Helpfulness(supportive factor)		N/A	

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