A Systematic Review of Attitudes, Anxiety, Acceptance, and Trust Towards Social Robots

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Abstract

As social robots become more common, there is a need to understand how people perceive and interact with such technology. This systematic review seeks to estimate people's attitudes toward, trust in, anxiety associated with, and acceptance of social robots; as well as factors that are associated with these beliefs. Ninety-seven studies were identified with a combined sample of over 13,000 participants and a standardized score was computed for each in order to represent the valence (positive, negative, or neutral) and magnitude (on a scale from 1 to − 1) of people's beliefs about robots. Potential moderating factors such as the robots' domain of application and design, the type of exposure to the robot, and the characteristics of potential users were also investigated. The findings suggest that people generally have positive attitudes towards social robots and are willing to interact with them. This finding may challenge some of the existing doubt surrounding the adoption of robotics in social domains of application but more research is needed to fully understand the factors that influence attitudes.

Keywords Attitudes toward technology · Social robots · Systematic review · Human–robot interaction

1 Introduction

According to a widely-reported large-scale survey [1], a substantial proportion of EU citizens have negative attitudes toward the use of robots within healthcare and other fields that are traditionally dominated by humans. There have also been suggestions of a growing anxiety among the public that automation, enabled by robotics, will lead to a significant loss of jobs [2, 3]. As we will explore in this article, attitudes toward robots appear mixed, likely depend on the setting and question asked, and in some cases are somewhat divorced from reality (e.g., there is evidence that attitudes are based on science-fiction, rather than objective reality; [4]). While atti-

tudes do not consistently predict behaviour, they are thought to influence people's behavioural intentions [5] and therefore may predict the uptake and use of robots alongside other variables such as anxiety, trust, and intention to use and engage with robots. An improved understanding of people's attitudes toward robots should therefore help to inform future research, development, and deployment of robotics in various domains of public and private life.

The present review focuses on social robots, due to their increasing use in various settings such as healthcare, entertainment, and customer service [6–8]. While the idea of robots that can interact socially with people has been around for some time, their use has been relatively limited and less widespread in comparison to, for example, manufacturing robots [9, 10]. Nevertheless, social robots garner attention from the media and general public alike, and have sparked debate about their potential impact on society [11, 12]. We define a social robot as a physically embodied artificial agent (i.e., something that has a physical structure that mimics the behaviour, appearance, or movement of a living being—usually a human, but could also be an animal or plant) that: (a) has features that enable humans to perceive the agent as a social entity (e.g., eyes); (b) is capable of interacting with humans via a social interface [13]; and (c) can communicate verbal and/or non-verbal information to humans (see Supple-

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mentary Materials 2). In short, a social robot is an embodied system that can be perceived as a social entity and is capable of communicating with the user [14].

To date, no systematic review has investigated and synthesised the current evidence on people's attitudes toward, trust in, anxiety associated with, and acceptance of social robots. Evidence suggest that all of these beliefs can predict the use of social robots [15, 16], and reflect the same broad construct [17–20], which is people's perception or evaluation of robots.

1.1 Attitudes Toward Social Robots

Current evidence on people's attitudes toward social robots reveals a somewhat ambiguous picture that makes it difficult to say whether people, in general, have a negative or positive view of social robots. This is, at least to some extent, likely to be due to the variety of contexts in which social robots are employed. People generally agree that, while working alongside robots is not out of the question, robots should not entirely replace humans in jobs that require substantial social skills (e.g., nursing; [21]). At the same time, some studies have found positive attitudes toward robots performing jobs that demand more social skills [1, 21]. These inconsistencies merit further investigation.

In addition to providing an overall assessment of the current evidence of people's attitudes toward robots, where possible, the present review will also look at three distinct components of attitude—cognition, affect, and behaviour [22]. Cognitive attitudes reflect people's thoughts—or cognitive evaluations—about the attitude object (e.g., that robots are useful). Affective attitudes reflect the individual's feelings or emotions toward the attitude object (e.g., whether they feel warm toward social robots). Finally, behavioural attitudes reflect people's observable or self-reported behaviours toward an attitude object (e.g., the extent to which they approach and interact with a social robot). Differentiating between the various components of attitude may provide more insight into people's attitudes toward social robots, and potentially account for some of the mixed findings identified in the literature to date (e.g., people may have positive cognitive attitudes, believing that social robots are worthwhile, but have negative affective attitudes, to the extent that they feel uneasy when they think about interacting with a robot).

1.2 Anxiety About Social Robots

A number of studies provide evidence that anxiety, alongside attitudes, predicts intentions to use social robots and the quality of people's interaction with social robots [23–25]. Anxiety toward robots is often measured using self-report measures, such as the Robot Anxiety Scale (RAS; [25]) or direct observation of behaviour during human–robot interaction (HRI). Despite the potential importance of anxiety in shaping how

people interact with robots, current evidence presents a mixed picture as to how anxious people are about social robots. For example, Nomura, Shintani, Fujii, and Hokabe [26] found that both anxiety and attitudes can affect how people behave during HRI in similar ways, while de Graaf and Allouch [27] found that participants interacting with a robot showed a change in their anxiety but not their attitudes. Therefore, the present review sought to integrate the evidence on anxiety to date, as well as identify factors that might account for the variable estimates in individual studies.

1.3 Trust in Social Robots

Trust has also been recognised as a factor that, at least in part, predicts not only the quality of HRI but also how willing people are to use social robots for certain tasks [28]. Trust is likely to be particularly important in relation to social robots, especially in healthcare, where trust has been associated with patient satisfaction and therapeutic effectiveness [29]. So far, reviews have focused on the impact of trust in robots on human–robot interaction, showing that the main factors influencing trust relate to aspects of the robot (e.g., the robot's design and performance) while environmental factors play a more moderate role in how much people trust robots [30]. However, the impact of trust in relation to social robots specifically has not been reviewed [31].

1.4 Acceptance of Social Robots

Acceptance is generally defined as the intention to use, and in some cases, as the actual use of robots [15, 32, 33]. Compared to anxiety and trust, there is considerably more evidence on the extent to which people accept social robots, particularly in the healthcare and elderly care domains. Acceptance of robots in healthcare has been found to be mixed and can vary considerably depending on the function and appearance of the robot [34]. Despite the potential that social robots have to alleviate the ever-growing demands on healthcare professionals [34, 35], low levels of acceptance can prove detrimental to the development and utilisation of such technology [34, 36]. Therefore, a broader understanding of the extent to which social robots are accepted in healthcare and other settings; along with factors that are associated with acceptance is needed.

2 What Factors Influence People's Attitudes Toward Robots?

Several factors are likely to be associated with people's attitudes toward, trust in, acceptance of, and anxiety toward social robots. For example, people's beliefs may differ as a function of whether they have recently been exposed to social

robots (e.g., studies that provide direct HRI may report different attitudes to studies where participants do not interact with a robot), the intended domain of application (e.g., companionship and domestic assistance, education, or healthcare), and the design of the robot (e.g., humanoid or anthropomorphic). We expand on these potential factors below.

2.1 Type of Exposure to Robots

The way that people think about robots might be affected by whether they are given the opportunity to interact with a robot, directly or indirectly, prior to their attitudes being measured. Studies generally provide participants with at least one of three types of exposure to robots (i.e., HRI):

No HRI Participants were not asked to interact, view, or imagine a social robot or robots (e.g., participants were only asked about their attitudes toward social robots in general; [37]);

Indirect HRI Participants observed a direct interaction or were shown (or asked to imagine) a representation of the social robot or robots (e.g., participants read an illustrated description of a NAO robot; [38]);

Direct HRI Participants interacted with a social robot that was physically present at the same time and place as them (e.g., participants took part in a mock-interview with a Geminoid HI-2 robot; [39]).

2.2 Domain of Application

Evidence suggests that people's attitudes toward robots may, to some extent, depend on the domain in which the robot is (or is intended to be) used [40, 41]. For the purposes of this review, we identified six broad domains of application:

Companion Robotics and Domestic Assistance Robots designed specifically and exclusively to interact socially with humans for a prolonged period of time and to provide companionship (e.g., a study investigates attitudes towards the robots NAO and Darwin; [42]); or robots that are designed to help with domestic chores, as well as provide social interaction (e.g., a study investigating the evaluation of a socially assistive robot in a smart home setting; [43]);

Education Robots Designed to assist educators with teaching and social interaction with students (e.g., a study investigating how students evaluate the use of NAO to teach English lessons; [44]).

Healthcare Robots designed to help patients, doctors or healthcare providers (e.g., a study investigating the attitudes and preferences of staff, residents, and relatives of residents in a retirement village towards a health-care robot; [2]).

Paediatric Care Robots that are used in healthcare but specifically designed to assist children and the healthcare providers who treat them (e.g., an evaluation of physiotherapists' acceptance of assistive robots as a therapeutic aid for children in rehabilitation; [45]).

HRI Robots that are designed primarily to interact with people, with any additional functionality (e.g., providing care) being secondary. For example, playing games or having a conversation (e.g., a study examining the effect of group size on people's attitudes and behaviours toward robots as interaction partners; [46]).

General Application The study does not specify or imply an application domain for the robot or robots being investigated. (e.g., a study investigating the effectiveness of exhibitions of robots as a means of shaping people's beliefs about robots; [47]).

2.3 Design of Robot

Design features of robots, such as the degree of human-likeness, are likely to influence people's attitudes towards robots [31, 48]; however, this influence has not been quantified or reviewed comprehensively so far. The present review therefore categorised each of the robots studied into one of three broad categories:

Humanoid A robot that resembles a human body (e.g., the humanoid robot NAO; [49]).

Anthropomorphic A robot that imitates some parts of the human body and can be subject to anthropomorphisation by the user (e.g., a robot with a human-like face; [50]).

Non-humanoid A robot that resembles any other living organism except for a human or does not imitate a living organism (e.g., Aibo, a robot that resembles a dog; [51]).

2.4 Geographical Location

The cultural background and nationality of users may contribute to the variability in people's attitudes toward [52], trust in [20], and acceptance of [53] social robots. The present review therefore compares the geographical locations (i.e., countries) in which the studies took place as an approximation of participants' cultural backgrounds. Enough data was available to compare eight geographical locations: Australia, France, Germany, Italy, Japan, the Netherlands, New Zealand, South Korea, Taiwan, and the United States of America (USA).

2.5 Sample Characteristics

Attitudes towards robots also likely vary according to demographic factors such as users' age and gender [48]. For example, men generally tend to have more positive attitudes

towards robots than women [40]. Similarly, young adults tend to have more positive attitudes toward robots than elderly adults and are more willing to make use of robots [40]. Therefore, the present review investigates whether participants age and gender are associated with their beliefs about robots. In addition, some studies have reported that previous experience with and long-term exposure to robots also affects people's attitudes [54] which is why the present review also attempted to investigate this factor.

3 The Present Review

The present review expands on earlier efforts to understand people's beliefs about social robots (e.g. [31, 34, 41, 55]) by taking a broad approach to the collection and synthesis of available literature in order to provide an overview, of not only people's attitudes toward social robots, but also other beliefs which are relevant to the uptake of robotics such as acceptance, anxiety and trust. The review sought to include studies focusing on any type of social robot and a wide variety of domains where they might be used. In addition, we also present a series of analyses that go beyond previous systematic reviews. Specifically, we have developed a novel method for standardising the measures of participants' beliefs about robots in each of the primary studies. This approach enabled us to estimate people's attitudes toward robots, across the available evidence, weighing each estimate by the size of the sample in a manner similar, but not identical, to that of a conventional meta-analysis.[1] Additionally, by combining estimates of beliefs in specific areas (e.g., studies focusing on social robots in particular contexts), we were able to investigate the factors that are associated with people's attitudes toward robots.

4 Method

The review was pre-registered on PROSPERO (CRD42017057331).

4.1 Systematic Literature Search

In order to identify studies that measured people's attitudes toward, trust in, acceptance of, and/or anxiety toward social robots, the following databases were searched between January and February, 2018 and repeatedly searched in Jan-

uary 2019: PsycINFO and PsycARTICLES (Ovid), IEEE Xplore, ProQuest, and Google Scholar. A separate search was conducted for each of the four measures of interest in each database (except Google Scholar) using the search terms: "[attitud*/accept*/trust*/anxi*] AND (robot* OR "human–robot interaction" OR "assistive robot" OR "social robot") AND participant". A slightly different approach was used for Google Scholar as it was found that the combination of the above search terms did not generate as relevant results as the phrase: "[attitude/acceptance/trust/anxiety] AND robot AND participant". Only articles from the first ten pages of results for each of the four searches conducted in Google scholar were considered in order to ensure that the search was manageable. In order to identify further grey literature, publication lists of relevant research laboratories were also searched (a full list of the laboratories can be found in the review's protocol on PROSPERO). No limitations on publication date were specified for any of the databases. The references of the identified papers were added to and managed via EndNote where duplicates were removed prior to screening the research articles. Figure 1 shows the number of articles that were identified as well as the number of articles that were included and excluded at each stage of the screening process.

### 4.2 Screening and Selection of Relevant Papers

The search results were screened by a member of the research team in two stages and guided by a priori inclusion and exclusion criteria. Any uncertainty as to whether a paper should be included or not was resolved through discussion with the research team.

First, the titles and abstracts of the retrieved research articles were screened in order to identify potentially relevant studies that satisfied our inclusion criteria. At this stage studies that clearly did not measure people's attitudes, trust, acceptance, or anxiety toward social robots were excluded. For example, technical papers detailing the development of sensors for social robots were removed. Literature reviews, meta-analyses, editorials, newspaper articles, and other forms of popular media were also excluded at this stage as we were only interested in original empirical studies.

Second, the full-text of the identified papers were considered. Where the full-text was not available, the authors of the paper were contacted or the articles were obtained via an interlibrary loan request. Since our research questions focused on social robots exclusively, we used a pre-specified definition checklist (see Supplementary Materials 2) in order to decide whether an article was relevant or not. For example, papers investigating attitudes toward industrial robots were not included unless they also measured attitudes toward social robots. No limitations were placed on the design of the primary studies and studies with randomised and non-

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[1] A traditional meta-analysis was not viable since traditional effect size metrics cannot be used to describe the average level of a given variable (e.g., the valence of people's attitudes); only the extent to which it is influenced by a manipulation (e.g., effect size Cohen's d) or is related to another measure (e.g., effect size r).

Fig. 1 PRISMA diagram showing the flow of studies through the review
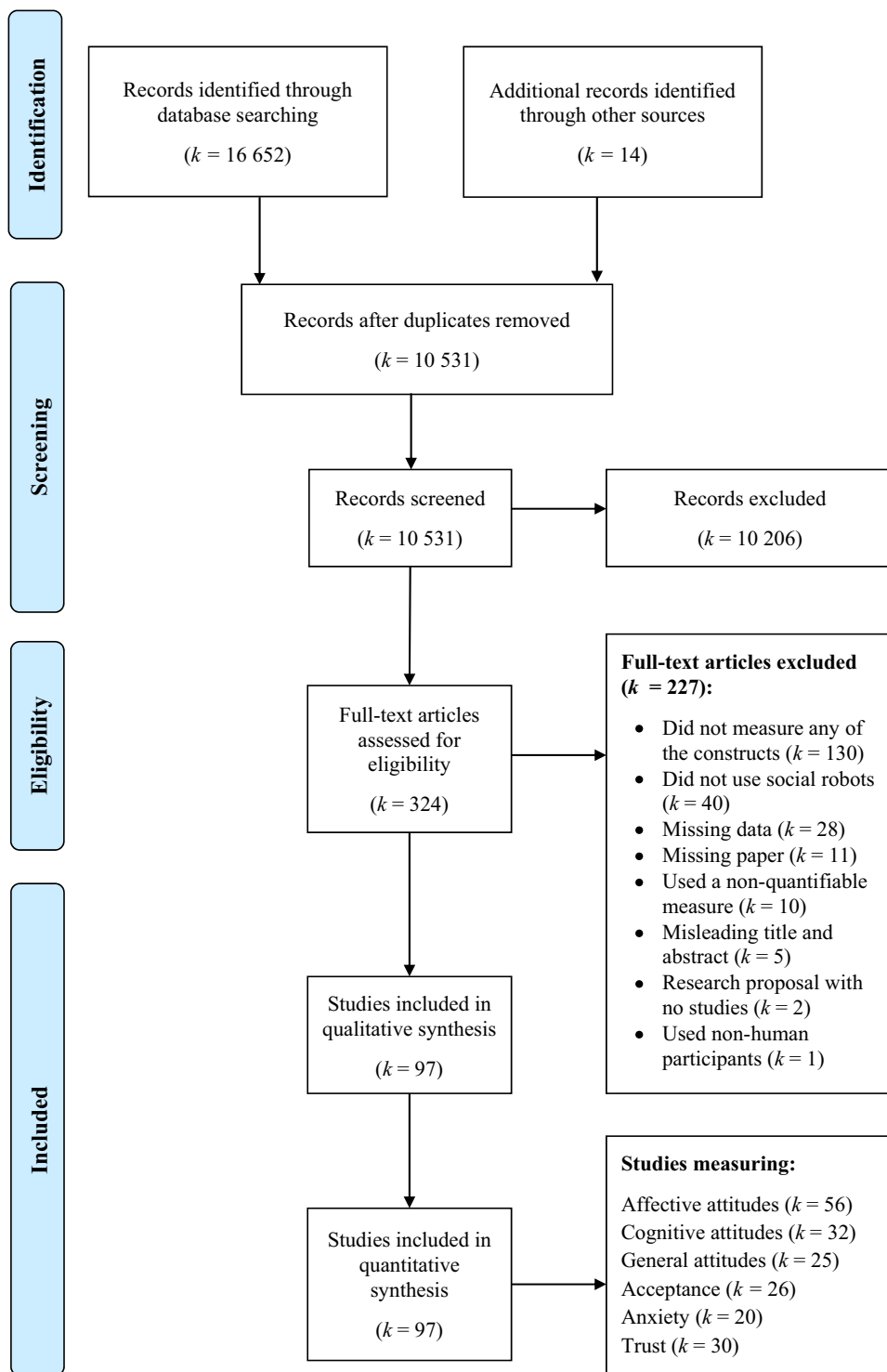
randomised field and lab experiments, questionnaires and surveys, interviews, pilot studies, and thesis were all included if they met the other inclusion criteria. The flow of papers through the review is detailed in Fig. 1.

4.3 Data Extraction

The information from the primary studies was extracted by a member of the research team and 10% of the papers were second-coded by a different member of the team, with a comparison showing that 93% inter-rater agreement was

reached. Any disagreements or inconsistencies between the two coders were resolved through discussion.

We first extracted bibliographic information from the articles, this included the date of publication, the country where the research was conducted, the sample size and demographics of the sample (i.e., mean age, gender, and cultural or ethnic background), the domain of application, the design of the study, and the name, design, and capabilities of the social robot. The type of outcome (categorised as general attitudes, affective attitudes, cognitive attitudes, behavioural attitudes, trust, anxiety, or acceptance) and details of the measures used to assess each outcome (e.g., the NARS) were identified and extracted next.[2]

The methodological quality of the primary studies (i.e., risk of bias) was assessed using the tool described in Supplementary Materials 3. As with the other characteristics, a member of the research team carried out the quality assessment and a different member of the team second-coded 10% of the studies. There was moderate inter-rater agreement between the two coders, Cohen's $k = .554$, 95% CI [0.43, 0.68], $p < .001$. The average difference in the quality scores between the two coders was 0.20 points ($SD = 0.18$) for the overall methodological quality and 0.40 points ($SD = 0.16$) for the separate criteria with a maximum possible difference of 3 points. As before, disagreements were resolved via discussion.

4.4 Calculating and Interpreting Rescaled and "Standardised" Outcomes

The present review sought to quantify the valence of people's attitudes toward robots and compare this between different contexts, methods, and samples. As such, traditional effect size metrics used in meta-analyses (i.e., r and d) were not appropriate for answering our primary research question. We therefore needed a way to estimate the extent to which studies provided evidence that people have positive, neutral, or negative attitudes toward social robots. This was achieved by comparing the average value on the measure of attitude across the sample with the value of the same measure that would reflect a 'neutral' attitude (i.e., one that was neither positive nor negative). For example, if a participant completed a Likert scale measuring attitudes toward robots on a 1–5 scale, then a score of 3 would indicate that this participant has a neutral attitude toward robots.

In order to perform this normalisation, we calculated a pseudo-standardised sample mean ($\bar{x}_s$) and standard devia-

tion (s_s) for each study. To calculate the pseudo-standardised scores, the mean, standard deviation, and the minimum and maximum values of each measure (i.e., scale) were identified, as well as whether the measure indicated a positive or negative outcome (e.g., whether higher values indicated a negative or a positive attitude toward robots). If a measure had multiple subscales (e.g., the NARS), then we sought to extract data separately for each subscale. Missing data was requested from authors via email or via a direct request on Research-Gate. Where the missing data was not obtained within 2 weeks, the papers were excluded. If articles contained multiple measures and the key statistical data was available for at least one of the measures, then the paper was included with the available data. Once all relevant data had been extracted, the following formula was used to calculate the standardised scores where $\bar{x}_s$ and s_s denote the standardised sample mean and standard deviation and $\bar{x}$ and s denote the sample mean and standard deviation extracted from each study.[3]

$$\bar{x}_s = \frac{\bar{x} - \mathrm{MR}}{x_{max} - x_{min}} \times 2$$

$$s_s = \frac{s}{x_{\max} - x_{\min}} \times 2$$

Following this, an average weighted mean ($\bar{x}_w$) was calculated for each outcome. For studies that had multiple measures or subscales that assessed the same outcome (e.g., affective attitudes), the $\bar{x}_s$ and s_s for those measures were averaged. As such, each study only contributed a single $\bar{x}_s$ and s_s for a given outcome (i.e., general attitudes, affective attitudes, cognitive attitudes, behavioural attitudes, trust, anxiety, and/or acceptance). In the following formula, the mean is weighted by w_i which denotes the sample size for each study and $\sum w_i$ is the sum of all study samples for a particular outcome. We also calculated the variance ($s^2_{\bar{x}_w}$) of each weighted mean where k is the number of studies for each outcome, as well as the SD ($s_{\bar{x}_w}$), SE ($\sigma_{\bar{x}_w}$), and 95% Confidence Intervals where t_c is the critical t value for a two-tailed probability at $p < .05$.

$$\bar{x}_w = \frac{\sum_{i=1}^{n}(\bar{x}_s \times w_i)}{\sum_{i=1}^{n} w_i}$$

$$s^2_{\bar{x}_w} = \frac{\sum_{i=1}^{n}\left(w_i \times (\bar{x}_s - \bar{x}_w)^2\right)}{\frac{\sum_{i=1}^{n} w_i \times (k-1)}{k}}$$

$$s_{\bar{x}_w} = \sqrt{s^2}$$

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[2] Measures of acceptance typically overlapped with behavioural attitudes (i.e., reflected people's observable or self-reported behaviours and/or intentions to use robots). Therefore, behavioural attitudes were omitted as an outcome and instead we examined evidence on the acceptance of social robots, which was easier to identify.

[3] Note that *MR* is the numerical value for each scale that indicates a neutral attitude. If a scale measured negative attitudes, then $\bar{x}$ was reversed prior to calculating $\bar{x}_s$ by adding the maximum (x_{max}) and minimum (x_{min}) possible values of each scale and taking away the $\bar{x}$ (e.g., for a 1–5 scale with a mean of 2, the reversed score would be (1 + 5) − 2 = 4.

$$\sigma_{\bar{x}_w} = \frac{s}{\sqrt{\frac{\sum w_i}{k}}}$$

$$95\% CI_{\bar{x}_w} \approx [\bar{x}_w \pm t_c \times \sigma]$$

Taken together, $\bar{x}_s$ and s_s can be interpreted as a sample mean and standard deviation on a scale of -1 (indicating an extremely negative outcome) to $+1$ (indicating an extremely positive outcome). Since all possible values of $\bar{x}_s$ and $\bar{x}_w$ fall within a scale with an absolute maximum and minimum values, we propose that the computed means can be interpreted in a manner that is comparable, but not identical, to that conventionally applied to Pearson's r. Specifically, we propose that the midpoint between neutral attitudes and the two extremes of negative and positive attitudes (i.e., $\bar{x} \geq \pm 0.50$) is interpreted as a large-sized (or *substantial*) positive or negative attitude, $\bar{x} \geq \pm 0.30$ as a medium-sized (or *moderate*) positive or negative attitude, and $\bar{x} \geq \pm 0.10$ as a small-sized (or *slight*) positive or negative attitude.

4.5 Calculating and Interpreting Weighted Means, Standard Error, and 95% Confidence Intervals

In order to investigate whether categorical factors (e.g., type of HRI, domain of application, and robot design) are associated with people's attitudes toward social robots, we computed an average weighted mean ($\bar{x}_m$) for each level of each moderator (e.g., a weighted mean for all studies with no HRI, a weighted mean for all studies with indirect HRI, and a weighted mean for all studies with direct HRI). We excluded any studies where the outcome was measured using two or more different types of exposure to the robot, or for different robots that had different application areas, or where the outcome was measured for different robots that had different designs or no design was specified. Unlike $\bar{x}_w$, the $\bar{x}_m$ was weighted by the reported sample variance (s_s^2) in each study (in other words, we applied inverse-variance weighting instead of frequency weighting). We also calculated the variance ($s_{\bar{x}_m}^2$) of each weighted mean, as well as the SD ($s_{\bar{x}_m}$), SE ($\sigma_{\bar{x}_w}$), and 95% Confidence Intervals where t_c is the critical t value for a two-tailed probability at $p < .05$.

$$\bar{x}_m = \frac{\sum_{i=1}^{n} (x_s/s_s^2)}{\sum_{i=1}^{n} (1/s_s^2)}$$

$$s_{\bar{x}_m}^2 = \frac{1}{\sum_{i=1}^{n} (1/s_s^2)}$$

$$s_{\bar{x}_m} = \sqrt{s^2}$$

$$\sigma_{\bar{x}_m} = \frac{s}{\sqrt{k}}$$

$$95\% CI_{\bar{x}_m} \approx [\bar{x}_m \pm t_c \times \sigma]$$

Table 1 reports the weighed means, standard deviations, and 95% CIs for each level of each moderator. Larger positive and negative values of $\bar{x}_m$ indicate a more positive or negative outcome respectively. An overlap between confidence intervals indicates that there is insufficient evidence to conclude that there is a difference in the outcomes between the groups as a function of a given factor. Conversely, no overlap between the confidence intervals indicates that there is a difference in the outcomes between the groups as a function of a particular factor.

5 Results

5.1 Description of Included Studies

Data on people's acceptance of, attitudes toward, anxiety associated with, and trust in social robots was obtained from $k = 97$ studies published between 2005 and early 2019 in scientific journals (52%) or in conference proceedings (45%), with only three studies coming from alternative sources. The majority of these studies were conducted in the USA (17%), Germany (13%), and Japan (11%). The average size of the sample in the included studies was $N = 135$ ($SD = 182$) and the majority of studies (68%) were published between 2014 and 2019.

5.2 Affective Attitudes

Attitudes toward social robots were most commonly assessed in terms of affective attitudes, with the majority of studies ($k = 56$, 58%) including at least one measure of affective attitudes (i.e., feelings or emotions toward social robots). Not surprisingly, given the popularity of the Negative Attitudes towards Robots Scale (NARS; [10]) in HRI research, seventeen studies (30%) used the full scale or subscales to measure participants' affective attitudes. We categorised both the NARS-S1 (interaction with robots) and NARS-S3 (emotions in interaction with robots) subscales as measures of affective attitudes, as the items enquire how people expect to feel when they interact with social robots. Other measures of affective attitudes included other validated scales (e.g., Godspeed Questionnaire Series—likability) and less-known self-report measures (e.g., semantic differential scales based on [56]). Twelve studies (21%) measured participants' affective attitudes toward social robots in general (e.g., [57]) or specific types of social robots (e.g., domestic robots; [37]), while the rest measured participants' attitudes toward specific social robots (e.g., NAO; [43]).

The average weighted mean for affective attitudes was $\bar{x}_w = 0.27$ (see Fig. 2), suggesting that people generally have slight (bordering on moderate) positive affective attitudes toward social robots. Eight studies (14%) found evidence

Table 1 Weighted means ($\bar{x}_m$), weighted standard deviations ($s_{\bar{x}_m}$), total sample size (N), number of studies (k), and weighted 95% Confidence Intervals for outcomes as a function of factors that might influence outcomes

	Affective attitudes					Cognitive attitudes					General attitudes				
	$\bar{x}_m$	$s_{\bar{x}_m}$	N	k	95%CI$_{\bar{x}_m}$ [LL, UL]	$\bar{x}_m$	$s_{\bar{x}_m}$	N	k	95%CI$_{\bar{x}_m}$ [LL, UL]	$\bar{x}_m$	$s_{\bar{x}_m}$	N	k	95%CI$_{\bar{x}_m}$ [LL, UL]
Type of HRI															
No HRI	0.40	0.08	4544	13	[0.35, 0.44]	0.35	0.09	4535	11	[0.29, 0.41]	−0.10	0.04	1854	6	[−0.14, −0.05]
Indirect HRI	0.09	0.16	1063	7	[−0.05, 0.24]	0.37	0.26	558	4	[−0.05, 0.78]	0.22	0.06	1544	8	[0.16, 0.27]
Direct HRI	0.34	0.05	1807	26	[0.32, 0.36]	−0.13	0.08	1192	12	[−0.19, −0.08]	−0.14	0.09	838	8	[−0.22, −0.07]
Area of robot application															
Companionship and domestic	0.45	0.13	703	4	[0.23, 0.66]	–	–	674	2	–	–	–	384	2	–
Education	0.23	0.21	832	4	[−0.11, 0.57]	0.59	0.12	652	3	[0.28, 0.90]	–	–	375	2	–
General application	0.13	0.07	4171	15	[0.09, 0.17]	0.07	0.08	4160	10	[0.02, 0.13]	−0.09	0.11	2389	7	[−0.20, 0.01]
Healthcare	0.58	0.07	563	7	[0.51, 0.65]	0.09	0.25	282	4	[−0.30, 0.48]	−0.02	0.04	660	6	[−0.06, 0.02]
HRI	0.34	0.07	1351	22	[0.31, 0.37]	0.12	0.11	845	10	[0.04, 0.20]	−0.06	0.14	562	7	[−0.19, 0.06]
Paediatric care	0.36	0.30	235	3	[−0.37, 1.10]	–	–	188	2	–	–	–	172	1	–
Design of robot															
Anthropomorphic	0.24	0.17	286	6	[0.07, 0.42]	0.24	0.24	141	3	[−0.36, 0.84]	–	–	57	1	–
Humanoid	0.34	0.05	1253	26	[0.32, 0.35]	0.10	0.07	1040	15	[0.06, 0.13]	−0.18	0.09	625	9	[−0.25, −0.11]
Non-humanoid	0.33	0.17	856	5	[0.11, 0.55]	–	–	467	1	–	–	–	41	1	–
Geographical location															
Australia	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
France	0.58	0.12	232	3	[0.28, 0.88]	0.35	0.11	313	5	[0.21, 0.48]	–	–	–	–	–
Germany	0.22	0.12	668	10	[0.13, 0.30]	–	–	145	2	–	0.04	0.19	532	3	[−0.44, 0.52]
Italy	0.57	0.17	156	5	[0.36, 0.79]	–	–	80	1	–	–	–	18	1	–
Japan	0.21	0.13	1613	8	[0.10, 0.31]	0.05	0.07	1331	5	[−0.04, 0.14]	–	–	–	–	–
Netherlands	0.31	0.18	327	3	[−0.13, 0.74]	0.01	0.26	327	3	[−0.64, 0.65]	−0.09	0.10	386	3	[−0.35, 0.17]
New Zealand	–	–	–	–	–	–	–	–	–	–	0.23	0.07	220	3	[0.07, 0.40]
South Korea	0.43	0.21	350	3	[−0.08, 0.95]	–	–	270	2	–	–	–	–	–	–
Taiwan	–	–	226	1	–	–	–	–	–	–	–	–	578	2	–
USA	0.05	0.19	979	5	[−0.19, 0.29]	0.04	0.28	961	3	[−0.66, 0.74]	−0.10	0.04	2400	10	[−0.13, −0.07]

Table 1 continued

	Acceptance					Anxiety					Trust				
	$\bar{x}_m$	$s_{\bar{x}_m}$	N	k	$95\%CI_{\bar{x}_m}$ [LL, UL]	$\bar{x}_m$	$s_{\bar{x}_m}$	N	k	$95\%CI_{\bar{x}_m}$ [LL, UL]	$\bar{x}_m$	$s_{\bar{x}_m}$	N	k	$95\%CI_{\bar{x}_m}$ [LL, UL]
Type of HRI															
No HRI	0.42	0.20	2168	4	[0.10, 0.74]	0.10	0.20	933	4	[−0.22, 0.41]	–	–	24	1	–
Indirect HRI	−0.14	0.20	608	6	[−0.35, 0.08]	0.03	0.19	394	4	[−0.27, 0.33]	−0.06	0.15	574	6	[−0.22, 0.09]
Direct HRI	0.03	0.15	671	10	[−0.08, 0.14]	0.65	0.08	314	9	[0.59, 0.71]	0.18	0.06	895	20	[0.16, 0.21]
Area of robot application															
Companionship and domestic	–	–	–	1	–	–	–	215	2	–	–	–	29	2	–
Education	0.35	0.02	1152	4	[0.32, 0.38]	0.34	0.14	543	3	[−0.02, 0.69]	–	–	18	1	–
General application	0.07	0.19	1526	6	[−0.13, 0.27]	–	–	2	1	–	−0.04	0.08	282	6	[−0.13, 0.04]
Healthcare	0.02	0.28	260	4	[−0.42, 0.46]	0.36	0.22	100	4	[0.01, 0.71]	0.09	0.16	256	5	[−0.11, 0.29]
HRI	−0.02	0.15	913	8	[−0.15, 0.10]	0.05	0.13	760	8	[−0.05, 0.16]	0.32	0.08	884	13	[0.27, 0.37]
Paediatric care	–	–	88	2	–	–	–	80	1	–	–	–	88	2	–
Design of robot															
Anthropomorphic	−0.08	0.30	195	3	[−0.83, 0.67]	0.26	0.19	153	4	[−0.03, 0.56]	0.25	0.14	327	6	[0.10, 0.40]
Humanoid	0.34	0.02	1037	12	[0.33, 0.35]	0.62	0.07	571	10	[0.57, 0.67]	0.14	0.06	919	18	[0.11, 0.17]
Non-humanoid	–	–	182	2	–	–	–	83	2	–	–	–	150	2	–
Geographical location															
Australia	–	–	8	1	–	–	–	–	–	–	0.11	0.23	108	3	[−0.45, 0.67]
France	–	–	36	2	–	–	–	11	1	–	–	–	60	2	–
Germany	0.03	0.16	967	8	[−0.11, 0.17]	0.04	0.18	712	4	[−0.24, 0.32]	0.31	0.22	106	3	[−0.25, 0.87]
Italy	–	–	80	1	–	0.57	0.22	123	3	[0.02, 1.12]	–	–	103	2	–
Japan	–	–	24	1	–	−0.01	0.20	376	3	[−0.52, 0.50]	–	–	87	1	–
Netherlands	–	–	60	1	–	0.03	0.23	327	3	[−0.53, 0.59]	–	–	237	2	–
New Zealand	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
South Korea	–	–	290	2	–	–	–	–	–	–	–	–	60	1	–
Taiwan	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
USA	–	–	177	1	–	–	–	–	–	–	−0.08	0.08	130	5	[−0.18, 0.03]

that people held negative affective attitudes toward social robots (i.e., $\bar{x}_w < 0$) and only 16 studies (29%) had a mean of $\bar{x}_s > \pm 0.50$, signifying that people held substantially positive or negative affective attitudes.

5.3 Cognitive Attitudes

Thirty-two studies (33%) included at least one measure of cognitive attitudes (i.e., people's cognitive evaluations or thoughts about social robots). The NARS, or more specifically the NARS-S2 subscale (reflecting beliefs about the social influence of robots), was the most commonly used measure ($k = 17$, 53%). Subscales of questionnaires relating to specific models such as the Almere Model of robot acceptance [15] and Unified Theory of Acceptance and Use of Technology (UTAUT; [33]) were also used to measure cognitive attitudes [58–60].

The average weighted mean for cognitive attitudes was $\bar{x}_w = 0.24$, indicating that, in general, people had slightly positive cognitive evaluations about social robots and their use (see Fig. 3). The majority of studies (72%) found evidence for positive cognitive attitudes with one study, [61], providing evidence for neutral cognitive attitudes ($\bar{x}_s \approx 0$).

5.4 General Attitudes

Twenty-five studies (26%) measured attitudes toward social robots in a general way—i.e., overall evaluations of the extent to which social robots are 'good' or 'bad' and/or measures that combined affective and cognitive evaluations. General attitudes were almost exclusively measured via self-report with the exception of three studies (12%) that used the Implicit Association Test (IAT). The aggregated data (see Fig. 4) indicated an average weighted mean of $\bar{x}_w = 0.07$, which suggests that people's general attitudes toward social robots tended to be neutral (bordering on slightly positive). Thirteen studies (55%) provided evidence of positive general attitudes (i.e., $\bar{x}_w > 0$) toward social robots while the rest provided evidence for negative attitudes, with one study reporting neutral attitudes (i.e., $\bar{x}_w = 0$).

5.5 Acceptance

Twenty-six of the included studies (27%) measured acceptance in terms of people's intentions to use social robots, actual use of specific social robots or social robots in general, or people's willingness to interact with social robots. The average weighted mean for this outcome ($\bar{x}_w = 0.24$) indicated that, in general, people accept social robots but only slightly so. However, acceptance of social robots varied considerably (see Fig. 5) and 42% of studies suggested that people did not accept robots (i.e., $\bar{x}_w < 0$).
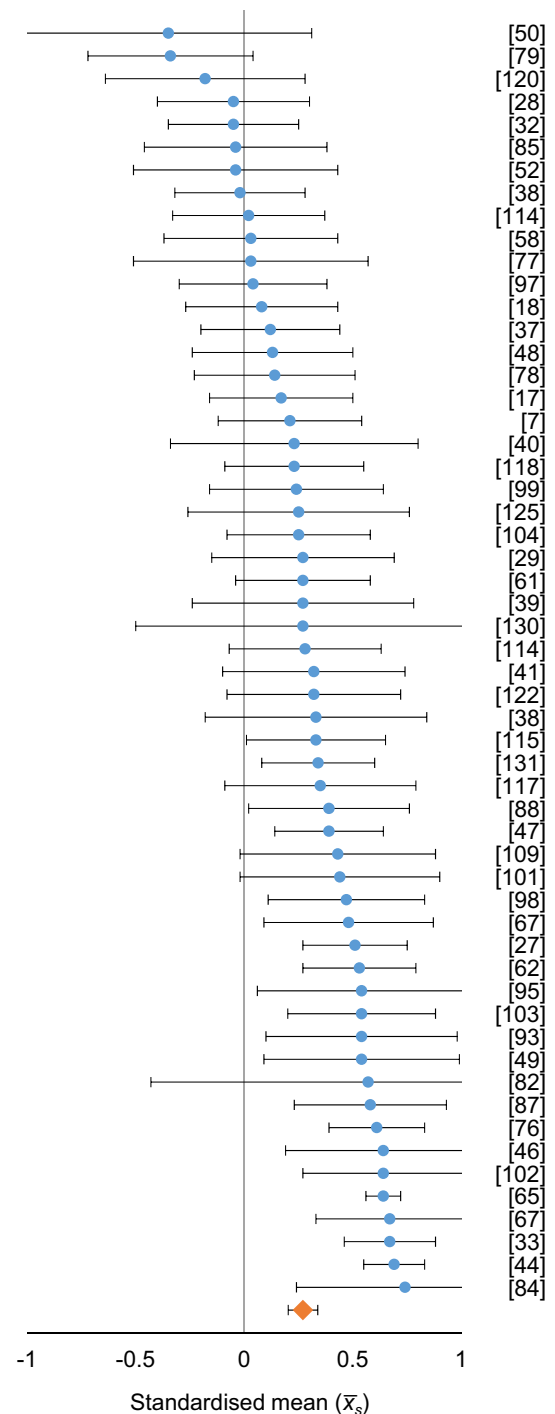
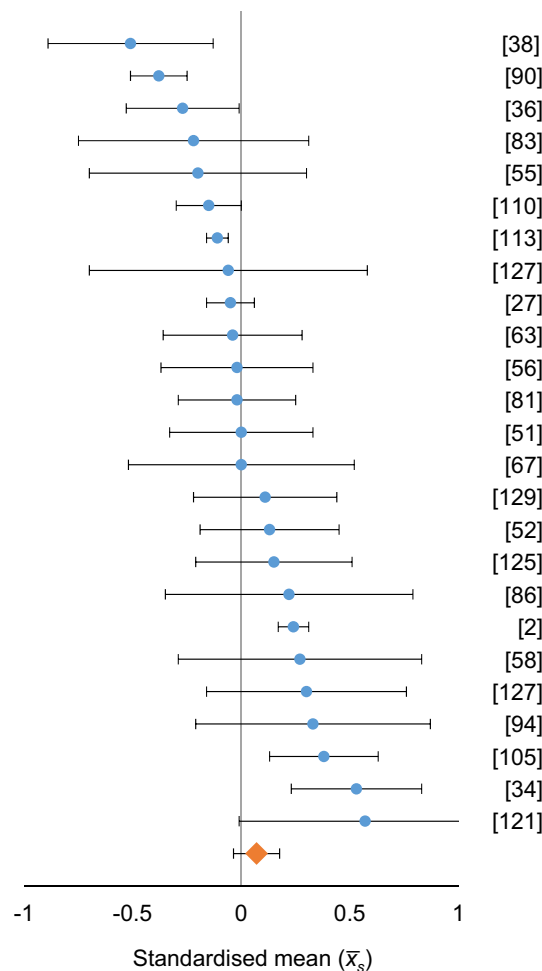**Fig. 2** Plot of pseudo-standardised means ($\bar{x}_s$) for studies measuring affective attitudes toward social robots. Error bars of the blue data points represent the standard deviation (s_s) of the mean. The orange data point represents the average weighted mean ($\bar{x}_w$) for affective attitudes and the error bars represent $95\% CI_{\bar{x}_w}$

Two studies in particular should be mentioned as they are rather atypical as compared to the other studies measuring acceptance. First, Fridin and Belokopytov [62] reported an unusually small standard deviation (s_s) indicating very little
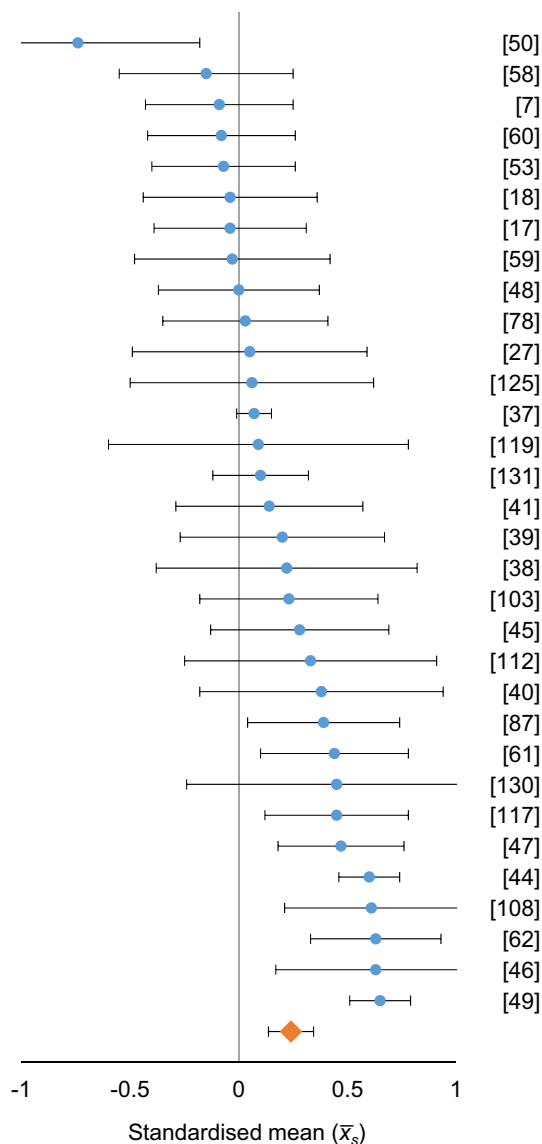
Fig. 3 Plot of pseudo-standardised means ($\bar{x}_s$) for studies measuring cognitive attitudes toward social robots. Error bars of the blue data points represent the standard deviation (s_s) of the mean. The orange data point represents the average weighted mean ($\bar{x}_w$) for cognitive attitudes and the error bars represent $95\% CI_{\bar{x}_w}$

Fig. 4 Plot of pseudo-standardised means ($\bar{x}_s$) for studies measuring general attitudes toward social robots. Error bars of the blue data points represent the standard deviation (s_s) of the mean. The orange data point represents the average weighted mean ($\bar{x}_w$) for general attitudes and the error bars represent $95\% CI_{\bar{x}_w}$

variation in participants' acceptance of social robots. This may be explained by the specific conditions and sample in this study. Participants were all preschool and elementary school teachers that attended a professional workshop on educational robotics where they were introduced to the capabilities of a NAO robot. This may explain why participants' views on robots aligned quite well. Second, Wu et al. [63] found strong evidence that participants did not accept robots ($\bar{x}_w = -0.99$) These negative beliefs may be explained by the finding that the participants who interacted with a social robot for a month in a Living Lab setting did not find the robot useful. Perceived usefulness has previously been iden-

tified as a factor that impacts participants' intention to use robots [33].

5.6 Anxiety

Twenty studies (21%) measured people's feelings of anxiety or nervousness evoked by social robots. Anxiety was predominantly assessed via the Robot Anxiety Scale (RAS; [25]) with ten studies (50%) having used some variation of the measure [37, 64, 65]. Other commonly used measures ($k = 5$, 25%) were the subscales of adapted questionnaires relating to specific models such as the Almere Model of robot acceptance [15] and Unified Theory of Acceptance and Use of Technology (UTAUT; [33]). All of the studies used self-report measures of anxiety with some studies measuring either anxiety toward specific social robots or toward social robots in general.
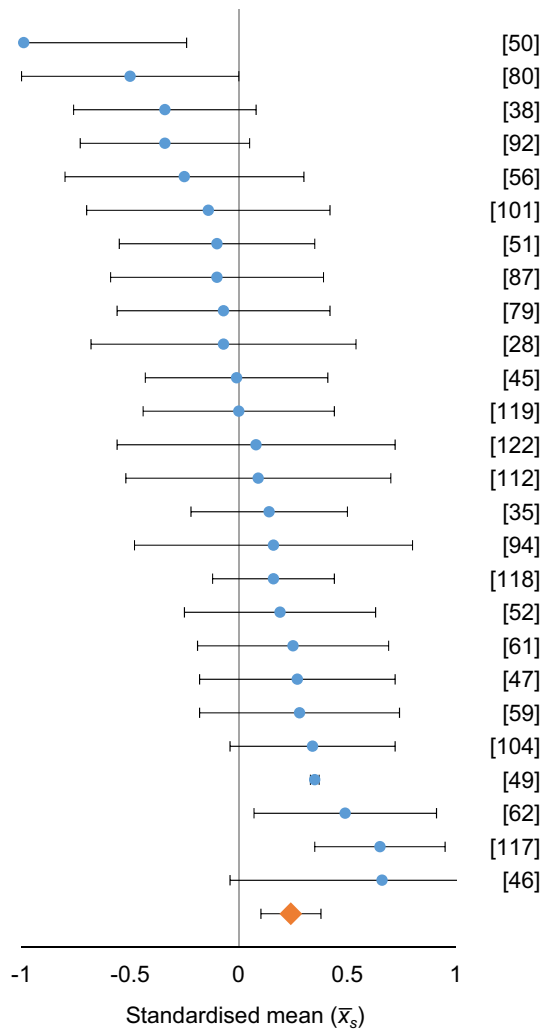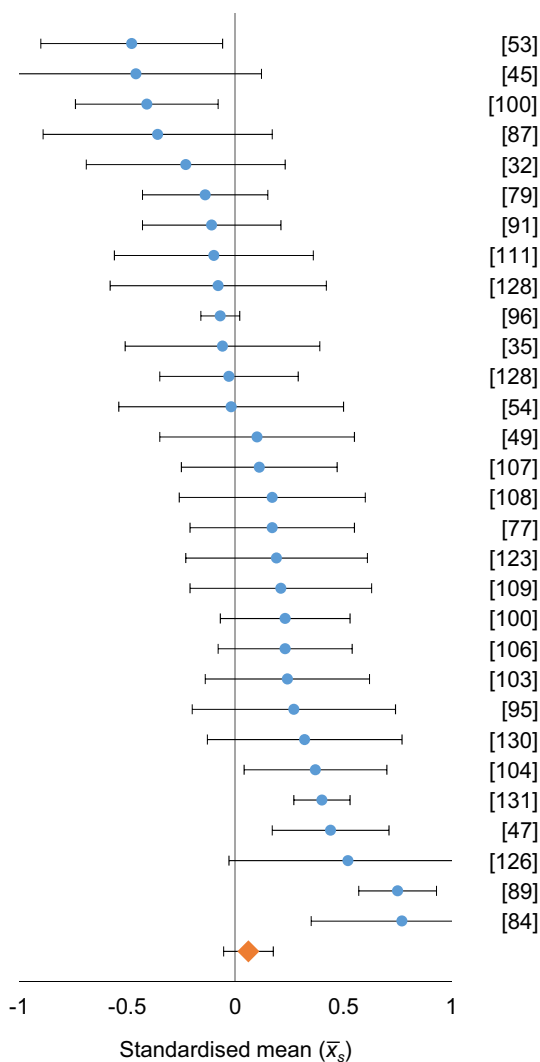
Fig. 5 Plot of pseudo-standardised means ($\bar{x}_s$) for studies measuring acceptance toward social robots. Positive values represent greater acceptance. Error bars of the blue data points represent the standard deviation (s_s) of the mean. The orange data point represents the average weighted mean ($\bar{x}_w$) for acceptance and the error bars represent $95\%CI_{\bar{x}_w}$

We found an average weighted mean of $\bar{x}_w = 0.10$ for anxiety, indicating that, in general, people only feel slightly anxious about social robots. Indeed, the majority of studies ($k = 9$, 45%) found that participants' levels of anxiety were fairly neutral (i.e., $\bar{x}_w < \pm 0.10$, see Fig. 6). The $95\%CI_{\bar{x}_w}$ further support this conclusion with confidence limits that cross 0 but do not exceed $\bar{x}_w = -0.10$ (see Fig. 6).

5.7 Trust

Thirty studies (31%) measured trust in social robots. Unlike the other outcomes, measures of trust were notably more varied and included behavioural [17, 66] as well as self-report measures. However, trust was typically assessed via subscales of adapted questionnaires relating to specific mod-
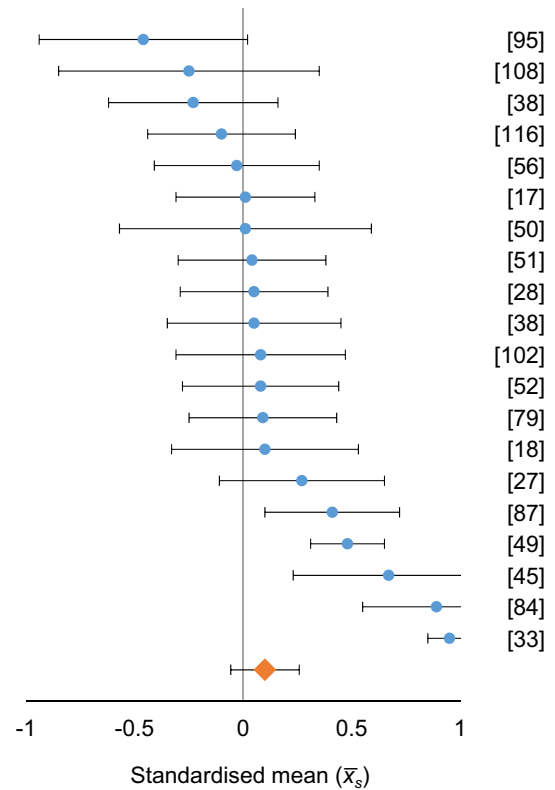
Fig. 6 Plot of pseudo-standardised means ($\bar{x}_s$) for studies measuring anxiety toward social robots. Positive values represent lesser anxiety. Error bars of the blue data points represent the standard deviation (s_s) of the mean. The orange data point represents the average weighted mean ($\bar{x}_w$) for anxiety and the error bars represent $95\%CI_{\bar{x}_w}$

els such as the Almere Model of robot acceptance [15] and the Unified Theory of Acceptance and Use of Technology [33].

The average weighted mean for trust was close to zero, $\bar{x}_w = 0.06$, suggesting that, in general, people did not particularly trust or distrust social robots. However, the plot of all included studies (see Fig. 7) indicated variation within and between studies with 43% of studies presenting evidence that people did not trust social robots (i.e., $\bar{x}_w < 0$).

5.8 Factors that Influence the Main Outcomes

Table 1 shows the weighted means ($\bar{x}_m$) and confidence intervals ($95\%CI_{\bar{x}_m}$) for each outcome as a function of factors that might influence that outcome (e.g., the nature of the social robot). In addition, the findings have been illustrated graphically in Supplementary Materials 1.

5.8.1 Type of Exposure to Robots

We compared attitudes in studies that included three different types of human–robot interaction: no HRI, an indirect

Fig. 7 Plot of pseudo-standardised means ($\bar{x}_s$) for studies measuring trust toward social robots. Positive values represent greater trust. Error bars of the blue data points represent the standard deviation (s_s) of the mean. The orange data point represents the average weighted mean ($\bar{x}_w$) for trust and the error bars represent $95\% CI_{\bar{x}_w}$

form of HRI, and direct HRI. For studies measuring affective attitudes, the average weighted mean for studies that did not include any type of HRI was larger ($\bar{x}_m = 0.40$) than for studies where indirect contact ($\bar{x}_m = 0.09$) with social robots was included. We also found more positive affective attitudes toward social robots for studies that included direct HRI ($\bar{x}_m = 0.34$) as compared to indirect HRI ($\bar{x}_m = 0.09$). There was no evidence that affective attitudes differed between no HRI and direct HRI ($\bar{x}_m = 0.34$). This suggests that, in general, when people are asked about their feelings toward social robots, they report more positive affective attitudes when they either do not interact with a social robot at all or directly interact with it, rather than when they experience some type of indirect contact.

For cognitive attitudes, there was no overlap between the $95\% CI_{\bar{x}_m}$ for no HRI and direct HRI, indicating that participants thoughts about social robots were more positive in studies where there was no interaction between participants and robots ($\bar{x}_m = 0.35$) than when there was direct interaction ($\bar{x}_m = -0.13$). There was no evidence that cognitive attitudes differed between studies that involved indirect HRI ($\bar{x}_m = 0.37$) and no HRI.

With respect to general attitudes, participants appeared to report more positive attitudes toward social robots in studies with indirect forms of HRI ($\bar{x}_m = 0.22$) than in studies with direct ($\bar{x}_m = -0.14$) or no HRI ($\bar{x}_m = -0.10$). This lack of overlap between the $95\% CI_{\bar{x}_m}$ suggests that participants attitudes toward social robots tend to be more positive when they interact with the robots indirectly (e.g., by watching a video; [67]) rather than when they interact directly or do not interact with a social robot at all.

There was no overlap between confidence intervals for acceptance of social robots between studies where there was no HRI ($\bar{x}_m = 0.42$) and for studies with indirect HRI ($\bar{x}_m = -0.14$), suggesting that, in general, people are more accepting of social robots with which they have had no contact as compared to robots they have interacted with indirectly.

For anxiety, there was no overlap between confidence intervals for studies that included direct and indirect HRI. This indicates that, in general, participants reported considerably less anxiety when directly interacting with social robots ($\bar{x}_m = 0.65$) than when taking part in indirect HRI ($\bar{x}_m = 0.03$) or no HRI ($\bar{x}_m = 0.10$).

Results from the studies measuring trust were consistent with the findings for anxiety. In general, for studies where there was direct HRI, participants exhibited or reported more trust in social robots ($\bar{x}_m = 0.18$) than participants in studies where the contact with the social robots was indirect ($\bar{x}_m = -0.06$). Unfortunately, too few studies measured trust in the absence of HRI so we were unable to compare this group to indirect and direct HRI.

In addition to considering whether the type of exposure to robots provided in experimental studies influences people's beliefs about robots, we also sought to examine the effects of long-term exposure to robots by comparing attitudes and beliefs in studies where the majority (i.e., over half) of the participants indicated that they had seen or interacted with robots with studies where more than half of the participants had not previously seen or interacted with robots. Although fourteen studies reported the number of participants that had seen or interacted with social robots previously, in all but one of those studies the majority of participants had no previous experience with robots. Therefore, it was not possible to examine the effect of long-term interactions on beliefs about social robots in this review.

a weighted least squares regression with the average age of participants in each study as the independent variable, the sample mean ($\overline{x}_s$) as the dependant variable, and the size of the sample in each study as the weight. A Bonferroni correction was applied to account for the multiple comparisons and an adjusted critical p value of .008 was used. These analyses indicated that the age of the participants was not significantly associated with their affective attitudes toward social robots, $F(1, 43) = 1.90$, $p = .176$, cognitive attitudes toward social robots, $F(1, 22) = 1.90$, $p = .182$, general attitudes, $F(1, 22) = 0.00$, $p = .948$, acceptance, $F(1, 21) = 3.80$, $p = .065$, anxiety, $F(1, 16) = 0.00$, $p = .981$, or trust, $F(1, 20) = 1.35$, $p = .259$.

5.8.6 Gender of Participants

In order to investigate whether gender was associated with participants' beliefs about social robots, we conducted a weighted least squares regression with the percentage of female participants in each study as the independent variable, the sample mean ($\overline{x}_s$) as the dependant variable, and the size of the sample in each study as the weights. A Bonferroni correction was applied to account for the multiple comparisons and an adjusted critical p value of .008 was used. The percentage of female participants accounted for 40.9% of the variation in self-reported trust in social robots, $R^2 = .64$, $F(1, 19) = 13.16$, $p = .002$, such that there was a strong positive linear relationship between the two. However, the gender of the participants was not associated with their affective attitudes toward social robots, $F(1, 45) = 1.98$, $p = .166$, cognitive attitudes, $F(1, 24) = 0.04$, $p = .853$, general attitudes, $F(1, 20) = 4.28$, $p = .052$, acceptance, $F(1, 20) = 5.70$, $p = .658$, or anxiety, $F(1, 13) = 5.89$, $p = .031$.

5.8.7 Year of Publication

In order to investigate whether beliefs about social robots have changed over time, we conducted a weighted least squares regression for each of the six outcomes with the year in which the study was published as the independent variable, the sample mean ($\overline{x}_s$) as the dependant variable, and the sample size of each study as the weight. The average number of studies published each year prior to 2014 was quite small ($M = 3.44$) and therefore the findings of the linear regressions should be interpreted with caution. The year of publication was not associated with affective attitudes, $F(1, 55) = 0.17$, $p = .684$; cognitive attitudes, $F(1, 31) = 0.49$, $p = .489$; general attitudes, $F(1, 23) = 3.00$, $p = .096$; acceptance, $F(1, 23) = 0.32$, $p = .575$; anxiety, $F(1, 18) = 0.03$, $p = .856$; or trust, $F(1, 28) = 0.001$, $p = .986$.

5.8.8 Methodological Quality

The average overall methodological quality of the included studies was 2.20 ($SD = 0.50$, range $= 1.30$–3.30) on a scale from 1 (poor quality) to 4 (excellent quality) (see Supplementary Materials 3). It should be noted that most studies received a quality score close to the average, indicating little variation in the overall methodological quality as measured via our Quality Assessment Tool. However, a number of individual criterion may have contributed to this homogeneity. Most notably, the Objectivity criterion ($M = 2.00$, $SD = 0.20$) as the majority of studies (94%) measured our main outcomes using some form of questionnaire or scale which we rated as lower than behavioural and physiological measures. Similarly, the Reliability (a) criterion ($M = 1.30$, $SD = 0.60$) indicated that the majority of studies did not measure test–retest reliability, thus resulting in a score of 1 for the majority of studies (70%). Scores for the External Validity (b) criterion were similarly homogeneous ($M = 1.40$, $SD = 0.60$) as most studies did not employ a randomised sampling technique. By far the most common type of sample used by 30% of the studies consisted of University students recruited on a volunteer basis.

In order to investigate whether the methodological quality of studies was associated with participants' beliefs about social robots, we conducted a Linear Regression with the methodological quality scores of each study as the independent variable, and the sample mean ($\overline{x}_s$) as the dependant variable. A Bonferroni correction was applied to account for the multiple comparisons and an adjusted critical p value of .008 was used. The methodological score given to the included studies was not associated with participants' affective attitudes toward robots, $F(1, 54) = 1.25$, $p = .269$; cognitive attitudes, $F(1, 30) = 0.02$, $p = .878$; general attitudes, $F(1, 23) = 2.39$, $p = .136$; acceptance of robots, $F(1, 24) = 1.33$, $p = .260$; anxiety toward robots, $F(1, 18) = 1.19$, $p = .056$; and trust in robots, $F(1, 31) = 0.37$, $p = .549$.

6 Discussion

The present review quantified and synthesised evidence on people's beliefs about social robots. Although reviews have been conducted in this area [31, 34, 41, 55], none have combined the various measures employed in primary studies in a way that informs the overall valence (i.e., positive, neutral, or negative) and magnitude of the outcomes. The approach described in this paper is, to our knowledge, the first of its kind to provide standardised estimates of the overall valence of people's attitudes toward robots and related beliefs based on evidence from multiple studies and measures.

6.1 What are People's Attitudes Toward Social Robots?

The majority of studies that measured people's affective attitudes suggested that people have slightly positive (bordering on moderate) feelings about social robots. We consider this finding to be fairly robust as only nine studies provided evidence that people have negative feelings toward social robots. Upon further examination of these nine studies, two had somewhat atypical methodologies—one study employed imagined contact with robots [64] and the other tested whether involving users in the development of robots affected their attitudes [68].

Studies measuring cognitive attitudes provided further support for overall positive attitudes toward robots with a sample-weighted mean similar in magnitude to that found for affective attitudes. This similarity between affective and cognitive attitudes is consistent with models in psychology that propose a moderate correlation between the three components of attitude [22, 69]. However, it is possible for there to be differences between what people feel and think about specific robots, as is the case for some of the studies included in the present review [10, 70, 71]. The impact of dissonance between affective and cognitive attitudes in relation to human–robot interaction has not yet been investigated and warrants consideration.

Where studies used measures of attitude that did not reflect purely affective or cognitive attitudes, or it was not possible to obtain data for subscales measuring different outcomes (e.g., the NARS), we coded said measures under the blanket term of general attitudes. Findings for this outcome were not entirely consistent with the results for affective and cognitive attitudes, as the sample-weighted mean was almost zero and thus indicated a relatively neutral rather than slightly positive attitude. Indeed, compared to the other outcomes, the number of studies providing evidence for negative attitudes was much greater (i.e., approximately half of the studies). It is possible that this finding was a product of some difference in the methodology or measures that necessitated the studies' inclusion in the general category. For example, NARS subscales may have been combined if the reliability of the subscales was poor.

Although we coded the outcomes in the primary studies based on definitions rooted in social psychological research on attitudes (see Sect. 1.1), it should be noted that studies generally did not differentiate between the various types of attitudes and often did not provide a definition of attitudes at all. This may be of some concern especially if it indicates a poor understanding of the relationship between attitudes and behaviour. Given the number of studies that measured attitudes in the context of human–robot interaction [27, 39, 72] and sometimes with the purpose of predicting behaviour [24, 27, 39, 72–74], attitude–behaviour models from social

psychology should be used more consistently to inform HRI research [75–77].

6.2 To What Extent do People Accept, Trust, and Feel Anxious Toward Robots?

We found that, in general, people are either willing to use social robots or have the intention to do so given the chance. Given the conceptual overlap between acceptance of social robots and behavioural attitudes, it is not surprising that our findings with respect to acceptance are similar to our findings for affective and cognitive attitudes. This is once again consistent with research supporting a moderate correlation between the three components of attitude [22, 69].

Findings from the studies measuring trust indicated that, in general, people neither explicitly trusted or mistrusted robots; rather they typically were neutral with respect to trust. However, given the variability in estimates of trust across studies (i.e., some studies reported high trust and others low trust) it is likely that the extent to which people trust social robots is moderated by other factors, some of which we discuss below in Sect. 6.3.

Finally, we found evidence suggesting that people are fairly neutral in terms of the anxiety that they report with respect to social robots. This finding may, to a certain extent, be a product of the general tendency for social robots to be designed in such a way as to appear less threatening. For example, NAO, a generally well-liked robot [42, 78, 79], was used in 45% of the studies measuring anxiety and may have contributed to the overall neutral to positive valence for anxiety and trust.

6.3 What Factors Affect the Main Outcomes?

We found mixed evidence that exposure to robots, domain of application and design of the robots, and the age and gender of participants was associated with people's beliefs about robots. This was predominantly due to a limited number of studies which meant that it was not possible to reliably estimate beliefs for the different categories of many of the factors of interest. Indeed, affective attitudes was the only outcome for which it was possible to compare all categories across all the factors. Additionally, whether participants were exposed to robots (directly or indirectly) before their beliefs were measured was the only factor for which comparison across the outcome measures was possible. As such we will focus on these findings first.

We found mixed evidence on whether and how exposure to robots affects people's attitudes and beliefs. Participants typically reported positive affective attitudes regardless of whether they interacted with a robot or not. However, people's affective attitudes toward social robots in studies with indirect HRI were typically less positive than participants'

affective attitudes in studies with no HRI or direct HRI. This suggests that interacting with a robot face-to-face elicits more positive feelings toward said robot (or robots in general) than does some form of indirect contact such as watching a video of the robot. These findings may be an important consideration when measuring attitudes in HRI contexts where the affective evaluation of a robotic platform during indirect contact may not accurately represent people's feelings toward that robot, or social robots in general [72, 80].

Notably, interaction did not seem to have the same effect on cognitive or general attitudes. For example, studies involving direct contact typically found that people held negative cognitive and general attitudes toward social robots. This finding is somewhat contrary to assertions that directly interacting with robots is a potential strategy for improving attitudes toward them [51, 72, 81]. It could be that while the novelty of directly interacting with a social robot results in positive affect it also allows participants to identify potential issues with robotic platforms or make general observations about their usefulness that result in negative thoughts. Supporting this idea is our finding that, unlike affective attitudes, participants typically reported more positive cognitive and general attitudes in studies utilising indirect contact (where it could be more difficult to identify issues with robotic platforms) than in studies with direct HRI. Due to a lack of studies utilising contact other than direct HRI, it was not possible to draw definitive conclusions regarding the impact of exposure to robots on people's acceptance of, anxiety toward, and trust in social robots.

Although we found some differences in participants' affective, cognitive, and general attitudes between geographical locations, these findings were limited by the number of studies available for comparison for nearly all outcomes. This was partly due to the fact that the majority of studies were either conducted in the USA, in Germany, or in Japan. As a consequence, the present review cannot draw conclusions about the influence of people's culture on their beliefs about social robots. Additionally, we would note that the geographical location in which the studies were conducted is only an approximation of participants' cultural background as most studies did not report this information. Even where the nationality and/or ethnicity of participants was reported, it may not necessarily reflect the participants' cultural background. The present review identified only six studies labelled as cross-cultural which may indicate a lack of cross-cultural research on people's attitudes toward social robots.

Similarly, our data and findings do not provide a strong enough base for conclusions regarding the extent to which the design (i.e., level of human-likeness) and application area of the robot moderated people's attitudes and anxiety toward, trust in, and acceptance of robots. We also found no evidence that the age of participants was associated with any of the outcomes despite existing empirical evidence to the contrary. Previous studies comparing young and elderly adults have demonstrated that, in general, older adults have more negative attitudes toward robots and are less willing to use robotic technology [65]. We did find evidence that the gender of participants was associated with the extent to which they trusted robots (in general, samples with a larger percentage of female participants reported more trust in robots). However, for most outcomes, the number of studies was quite small and it was difficult to draw clear conclusions regarding the effect of gender.

6.4 Have Attitudes Changed Over Time?

We found no evidence that beliefs about social robots have changed over time. However, the earliest paper in our review was published in 2005 and the majority of studies were published between 2014 and 2018. As such, our analysis was based on a rather constrained data set with the majority of data points falling within a four-year period. While we cannot say for certain whether people's beliefs about social robots have changed over time, we should probably first ask whether social robotics has existed long enough for such changes to have occurred at all.

One approach might be to consider the changes in attitudes, trust, and acceptance that have taken place in relation to robotics in general and past technological developments such as the modern computer and smartphones and then use these trends to predict how peoples' beliefs about social robots might change over time. For example, Gnambs and Appel [82] investigated changes in attitudes towards robotic systems within the European Union between 2012 and 2017. They found that, although attitudes toward various robotic systems were generally positive, there was a significant decrease in favourable opinions over the five-year period. Most notably, attitudes towards autonomous robots in the workplace were overall the most positive but also saw the largest negative shift in attitudes between 2012 and 2017. Gnambs and Appel proposed that the change in people's attitudes may be the result of increasing media coverage of robotic systems and growing fears about automation and its impact on the job market [2, 3]. Therefore, although the present review suggests that people's attitudes toward social robots are typically slightly positive, it may be that we should expect a negative shift in attitudes over the coming years.

6.5 Suggestions for Future Research

The present review identifies a number of methodological issues that should be addressed by future research. Some of these limitations are not specific to the study of social robotics—for instance, the tendency to rely on samples of student volunteers. Although practical and financial limita-

tions are often a barrier to the acquisition of more diverse sample groups, it is important to acknowledge the limitations of sampling procedures and consider potential bias when drawing conclusions. Where broader questions about the way that robots should be designed and integrated into specific domains are asked, it is important to acknowledge that making broader generalisations about the rest of society based on this limited sample of participants may not be appropriate. A further observation was the reliance on self-report measures (typically multi-item Likert scales). While using self-report measures often makes sense and yields useful data, some consideration should be given to applying other types of measures alongside well-known scales such as the NARS, especially given the intention-behaviour gap in technology usage [83]. Indeed, there have been advances in both behavioural and/or physiological measures (e.g., of arousal) that may prove useful in future research.

Finally, we attempted to analyse the effect of previous experience with robots on participants' attitudes, as research has found that this might play a role in shaping people's beliefs about robots [54, 84, 85]. Although fourteen studies reported information about the extent to which participants had interacted with social robots previously, there was only one study in which more than half of the participants had seen or interacted with a robot before. The rest of the studies reported that the majority of participants had little to no experience with social robots. As such, the findings of our review should probably be considered a reflection of people's *initial* attitudes toward social robots; something that—given that most people rarely have any contact with social robots—is likely to currently reflect most people's attitudes toward social robots. Readers interested in the effect of long-term interactions on attitudes might consult a review by Leite, Martinho, and Paiva [54], which suggests that, while people are generally willing to interact with robots repeatedly, their attitudes may change over time.

7 Conclusion

The evidence presented in this review suggests that people—at least people who do not have extensive experience of social robots—generally have a positive view of social robots. More specifically, the evidence suggests that people typically have positive feelings and thoughts toward social robots and are willing to interact with robots should the chance present itself. These findings may help to alleviate some of the concerns regarding the likelihood that people will adopt robotics in socially focused domains such as healthcare and education. However, knowing that people typically have somewhat positive beliefs about social robots does not necessarily help us to predict the economic and social impacts of widely adopting this type of technology. A

positive disposition is only one of a number of factors that may determine the landscape of human–robot relationships in the future and we suggest that applying theories of inter-group relations and attitude–behaviour models [75–77] to the study of social robotics might help to understand what these relationships may look like. Finally, although we may draw parallels between the progression and impact of other technology (such as computers) and social robotics, we should also acknowledge the qualities that mark social robots as not just another technological development but perhaps as an entire new social group with its own complexity [86].

Compliance with Ethical Standards

Conflict of interest Tony Prescott is a director and shareholder of the company Consequential Robotics that develops social robots and chair of the company Cyberselves that develops immersive technologies.

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