International Journal of Social Robotics (2023) 15:37–57
https://doi.org/10.1007/s12369-022-00944-4

Robots in Games

Diogo Rato[1] · Filipa Correia[3] · André Pereira[2] · Rui Prada[1]

Accepted: 1 November 2022 / Published online: 13 December 2022

Abstract

During the past two decades, robots have been increasingly deployed in games. Researchers use games to better understand human-robot interaction and, in turn, the inclusion of social robots during gameplay creates new opportunities for novel game experiences. The contributions from social robotics and games communities cover a large spectrum of research questions using a wide variety of scenarios. In this article, we present the first comprehensive survey of the deployment of robots in games. We organise our findings according to four dimensions: (1) the societal impact of robots in games, (2) games as a research platform, (3) social interactions in games, and (4) game scenarios and materials. We discuss some significant research achievements and potential research avenues for the gaming and social robotics communities. This article describes the state of the art of the research on robots in games in the hope that it will assist researchers to contextualise their work in the field, to adhere to best practices and to identify future areas of research and multidisciplinary collaboration.

Keywords Human–robot interaction · Social robotics · Games · Review

1 Introduction

A game is a setting for playful interactions around a predetermined goal, where the players' actions must be permitted by a specific set of rules and the main reason for accepting such constraints is to enjoy the accomplishment of an activity [129]. The applied rules restrict the possible actions inside the game, clearly defining the players' interactive space. Accordingly, actions taken by participants in the real world are not always possible within the game. However, the actions that are possible carry an enhanced meaning in the fictional environment since the game's progression is affected by the actions executed. Furthermore, even though the players' reality is bounded by a magic circle that separates both worlds [52,148], the surroundings directly affect the players' performance and overall experience. This impact is even more prominent in multiplayer games in which players need to engage with each other through in-game actions. Additionally, players may socially interact during the game with other players, whether human or artificial.

Artificial game players have been long used to explore and advance the state-of-the-art of Artificial Intelligence (AI) [113]. Recently, AlphaGo [145] defeated Lee Sedol, the best Go player in the world [122]. However, advanced tactical play is of secondary importance in games that deal with imperfect or social information and where the strategic intuition of players and their social skills is harder to simulate. Indeed, games are often social in nature and therefore provide the perfect opportunity to explore complex social interactions. Several authors, including authors from Google's DeepMind and Google Brain, have recently proposed the Hanabi challenge as a new frontier for AI research as this game deals with imperfect information [10]. However, this proposed challenge for artificial game players does not consider aspects of social interaction which can be even more complex [98]; namely, situations requiring socially adaptability and where embodied social exchanges are key to successfully playing a game [25]. A possible solution to bridge this gap is to employ robots as artificial game players, considering the social embeddedness of its embodiment [35].

Over the past two decades, researchers have already deployed robots in games to explore a wide variety of research questions. However, there is no comprehensive analysis of the resulting literature. This paper is the first attempt

✉ Diogo Rato
diogo.rato@tecnico.ulisboa.pt

1 INESC-ID and Instituto Superior Técnico, Universidade de Lisboa, Lisbon, Portugal

2 KTH Royal Institute of Technology, Stockholm, Sweden

3 INESC-ID & ITI-LARSYS, Universidade de Lisboa, Lisbon, Portugal

to review the most relevant instances of using robots in game settings by analysing the following: (1) the game structure and social dynamics between humans and robots; (2) the potential of games as a research platform; and (3) the societal impact of deploying robots in games.

Considering the first goal of this survey, we identify games which deploy robotic players and the social structure of the parties playing those games. To compare the game space used with the game space of other games (e.g. tabletop or video games), we identify several characteristics of the reviewed games, such as the core mechanics, types of manipulation and their competitive or collaborative nature. With regard to the players involved and their configuration, we propose several categories that illuminate how robots and humans interact in a game environment. These categories include the number of human and robotic players involved, the social roles they assume in the context of the game, and the duration and frequency of the game sessions. By describing the games that have been used and the parties involved, we present an analysis that promotes a better understanding of the interactions and the scenarios that support them. Our findings suggest that there is a wide interactive space for games that has not yet been explored, and the inclusion of robots in games, happening only recently, can provide gameplay features not commonly found in games or other mediums.

Researchers have relied on games to study a broad range of research topics related to both human-robot interaction (HRI) and game experience. Accordingly, we identify and group the different research topics present in the reviewed literature by analysing both how games are used to advance the research in HRI and how robots support the creation of novel game design, supporting the second goal of this survey. Additionally, we collect and report the evaluation metrics, such as questionnaires or annotation schemes, used by researchers to support their findings. Since the body of literature considered in this survey derives from multiple research fields (e.g. HRI, games, AI), in this report we also highlight which communities and venues have published research works on robots in games. Indeed, our results indicate that robots in games have been widely used in research. Topics range from the impact of the players' embodiment on the game experience to the long-term relationship between humans and robots, and the number of topics almost equals the number of research papers. We believe that games have the potential to become the perfect playground to advance the state-of-the-art in HRI.

Finally, the deployment of robots in games with human players also raises questions of societal impact. Thus, to better articulate the contribution of this research to end users, namely humans, we identify the target audience of each article and the game's goals besides providing entertainment. Indeed, there is a considerable number of articles that discuss games designed for children (e.g. for teaching social skills and health related topics) and elderly people (e.g. for physical rehabilitation and cognitive stimulation).

With regard to the structure of this document, we detail in Sect. 2 our methodology and the selection criteria used as well as a brief descriptive analysis that helps to characterise the reviewed literature. We then group our results under four main categories: societal impact of robots in games (Sect. 3), games as a research platform (Sect. 4), social interactions in games (Section 5) and game scenarios and materials (Sect. 6). Finally, in Sect. 7 we discuss the findings reported within the four categories and identify research opportunities for the different research communities, with special emphasis on how researchers can benefit by collaborating with researchers from other fields to jointly create better interactions, robots and games.

2 Methodology

We selected published studies from Google Scholar, Semantic Scholar, Crossref and Scopus by searching for the following terms: "robots games", "social robots", and "robots play". Also, the proceedings of Human–Robot Interaction and Games journals and conferences were manually explored for suitable material. In the field of HRI, we considered the following conferences and journals: *International Conference on Human–Robot Interaction (HRI)*, *International Conference on Social Robotics (ICSR)*, *International Conference on Robot & Human Interactive Communication (RO-MAN)*, *Transactions on Robotics (T-RO)*, *International Journal of Social Robotics* (IJSR), and *Transactions on Human–Robot Interaction (THRI)*. With regard to the games literature, we reviewed the following conferences and journals were reviewed: *International Conference on the Foundations of Digital Games (FDG)*, *Conference on Games (CoG)*, *Conference on Computational Intelligence and Games (CIG)*, *Games and Learning Alliance Conference (GaLA)*, *Transactions on Games (T-G)*, and *International Journal of Serious Games (IJSG)*.

The selected articles were then filtered based on the following criteria:

1. The document must contain both the word "game" and "robot".
2. The robot must have a physical embodiment.
3. The robot must be used and deployed in a game-based interaction with at least one human player.
4. The reported work should include an experimental evaluation.
5. Journal and full conference papers are preferred.

When the scenario involved robots and games but formed part of a vignette study (e.g. [18]), we excluded that article. Additionally, some research works, mostly extended abstracts, included partial results or reported an ongoing study. Typically, these cases would be subsequently reported within a full paper, and we therefore included the version that fully describes the results. Furthermore, we extended our search to include the other contributions of authors of the previously selected literature to further expand our collection of articles. All papers were subject to the selection criteria.

The total number of papers initially identified were 180. Of those, 85 (47.2%) articles were accepted based on the above criteria. The earliest article considered in this review was published in 2003 [11], and the latest was published in 2021 [126].

Of the considered literature the majority of the papers - 49 (57.6%) - were published in journals and conference proceedings on robots. For instance, 14 (16.5%) papers were presented at HRI, 13 (15.3%) papers were presented at RO-MAN and eight (9.4%) papers were presented at ICSR. A total of 12 (14.1%) papers were presented at human-computer interaction related conferences. such as the International Journal of Human Computer Studies (IJHCS)—2 (2.4%)—and Computer Human-Interaction (CHI)—2 (2.4%). There were 5 (5.9%) papers published in venues related with artificial intelligence (e.g. 1 (1.8%) paper on Association for the Advancement of Artificial Intelligence (AAAI) conference and 1 (1.8%) paper on the Autonomous Agents and Multiagent Systems (AAMAS) conference) only one (1.8%) paper [70] was published on a games conference, namely the Game Media Entertainment conference. The remaining 18 (21.2%) papers were published in venues related to interaction studies (e.g. INTERSPEECH and Multimodal Technologies and Interaction (MTI)) and specific areas of application (Interaction Design and Children (IDC) and Cognitive Science Society (CSS)).

3 Societal Impact of Robots in Games

Robots have seen increased usage in industries that feature strenuous or repetitive tasks such as manufacturing, food service and mining. However, using robots for tasks where the robot has to directly collaborate with humans has produced limited results. Making robots collaborate with humans in social and uncertain environments is incredibly complex, which is why the use of robots in industries such as healthcare and education remains an open research problem. Human-robot collaboration implies that humans and robots must work together to optimally achieve a common desired goal. Within these scenarios, robots require decision-making models that consider the collaborator's intentions, actions and preferences. These models require a deep multimodal perception of physical environments and an allocation of robot roles to support collaboration with humans. Using games as a benchmark expands the understanding of the complex dynamics of multimodal interaction in collaborative teams composed of humans and robots. Robots in games allow the study of a rich set of research problems such as increasing the level of robot autonomy in complex social dynamic environments. The outcomes of such research can be applied to real-world, human-robot collaborative tasks that are not focused solely on entertainment.

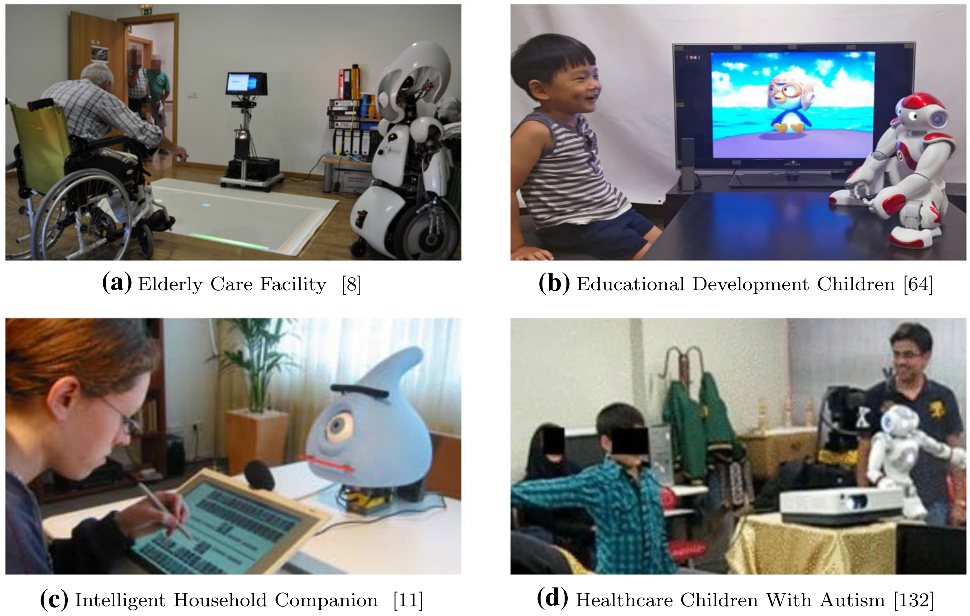
Games are already acknowledged as advantageous tools for other purposes (see Fig. 1). The societal impact of games is also noticeable across the several age groups that the games might engage, from children to the elderly. Among the reviewed papers, we identified which address a specific user-centred goal and which target a particular population. We found 17 papers addressing *learning and education* and nine with *healthcare* goals. A further nine papers focus on *companionship*; one of these specifically addresses an *intelligent home companion* [11]. Finally, two papers report on a user-centred goal of *collaboration* [22,136], whereas the remaining 56% of papers do not report a specific user-centred goal.

Regarding the target populations, 26 papers that focus on *children* as users; of these papers, one specifically supports *children with special needs* [28], and three papers target *children with autism* [32,131,139]. Moreover, we found 11 papers that focus on games for the *elderly*; of these papers, two specifically target *elderly with dementia* [43,134]. We also found one paper discussing a game introduced into a *household* [11]; people that live together were considered users. We could not report any specific target population for the remaining 55% of the reviewed papers. We would like to emphasise that the lack of explicit identification of user-centred goals or target populations might be caused by unrelated research topics or divergent research scopes; for example, the Sueca card-game scenario by Correia et al. was initially designed for the elderly [20] and later tested with young adults without referring to this target population [19,23,93].

While reviewing the societal impact of robots in games, we noticed that some games may be considered as serious games due to their application domain, despite the lack of explicit acknowledgement by the authors. For instance, the work by Johnson et al. uses the game of mastermind in the context of cognitive training for the elderly [59].

4 Games as a Research Platform

To review the scientific contributions of the selected papers we considered their research topics (Sect.4.1), as well as their evaluation methods (Sect. 4.2).



(a) Elderly Care Facility [8]
(b) Educational Development Children [64]
(c) Intelligent Household Companion [11]
(d) Healthcare Children With Autism [132]

Fig. 1 Examples of user-centred goals and target populations among the reviewed papers

4.1 Research Topics

The following overview of the research topics considers only the 83 papers that include a comparative evaluation or an analysis of independent variables, most of them through experimental studies. From the initial selection of 85 papers, we excluded two for lacking a specific analysis of a game deployment [39,86]. To categorise the research topics of each paper, we used the seven categories presented in Table 1. As most papers are focused on HRI, we took inspiration from the framework for characterising social robots proposed by Baraka et al. [9], and we used some of their suggested dimensions. Additionally, we added two new categories: one to cover game experience aspects and another which comprises research topics that compare humans and robots. Where a research paper addresses more than one research topic, we have classified that paper according to the main topic which relates to the evaluation or the comparative analysis. For papers containing experimental user studies, our classification was based on the nature of each independent variable.

Table 1 Distribution of the selected 83 papers according to research topic, noting that 12 papers have more than one research topic

Category	Papers	Percentage
Game experience	13	15.66
Comparing humans and robot	11	13.25
Physical proximity	3	3.61
Relational role	5	6.02
Robot's appearance	14	16.87
Robot's autonomy and performance	5	6.02
Robot's social capabilities	44	53.01

The papers were categorised based on the nature of the independent variables (for experimental study papers) or the target of their analysis

4.1.1 Game Experience

Within this category, we included papers that explore aspects related to the playability of a game or that have manipulated variables with a direct impact on the game experience. The first example is the work by de Haas et al. that considers the interaction flow for each game level and how the game design can support different communication skills of children with autism spectrum disorders [28]. Short et al. compare human interaction with a robot in different tablet-based games [119]. Another example is the work by Hansen et al. exploring the effectiveness of robots in administering fitness exercises, also known as exergames [43].

We found five papers addressing the subject of controllers or input devices to play games and manipulate game objects. Jost et al. use two of their experimental conditions to compare the game experience when a game is played over a tablet versus using only physical objects [62]. Similarly, both Lopez-Samaniego and Garcia-Zapirain and Lupetti et al. compare the experience of controlling actions through body movement detection versus using input control through finger touches on a screen [82,83]. Papadopoulos et al. examine using a traditional keyboard and mouse input to guide a virtual character versus using an autonomous robotic helper [96]. Finally, Avelino et al. analyse how robots can be used in exergames (see Fig. 1a) and explore two controlling modalities according to the fitness level of older adults: walking left and right (high mobility) or waving their hands while sitting on a chair (low mobility) [8].

We also found papers discussing new game experiences such as mixed-reality games with robots, in which the game environment is projected on the floor [8,37,69,105]. Lamberti et al. suggest guidelines and principles to follow in creating these type of games [69]. Additionally, Garcia-Salguero et al. analyse user acceptance of playing games projected by a mobile robot on a tablet surface [37]. Research by Pratticò et al. explores the nuances of embedding a robot in a mixed-reality game by testing how different sets of gestures affect the perception of the robot [105] (see Fig. 3d) or by providing the human player with different degrees of control over the robot [106]. Finally, Özgür et al. evaluate the combination of robots, paper and tablets in physical activity games for children [94].

4.1.2 Comparing Humans and Robots

This category comprises research works that study contrasts between human-human interactions and HRIs to understand the process of human identification with robots. We found five papers that compare a robotic partner to a human partner [13,20,53,58,118] and two that compare a robotic opponent to a human opponent [56,65]. With regard to human-robot group interactions, Thompson et al. compare a robotic partner in a dyadic interaction to a robot partnered with more people [134]. Similarly, Wainer et al. analyse sessions of two children playing a game alone versus sessions with a robotic partner in a triadic setting [139]. In terms of priming effects that might have an impact on categorisation, we found two examples. Häring et al. introduced a robot to participants either by presenting it with an ingroup or with an outgroup bias [44], while Westlund et al. compares the effect of presenting a robot as more humanlike or more machinelike [141].

4.1.3 Physical Proximity

This category contains contributions that explore spatial features of HRI, such as comparing a co-located robot with a remote version in a real-time video stream [68,78,140]. Notably, three papers also fell within the category of *robot's appearance* as they all hold a third condition comparing with a virtual embodiment.

4.1.4 Relational Role

This category includes five papers, and it considers research topics on the roles a robot might have with humans. For instance, Oliveira et al. used a game with two human-robot teams to explore behaviours towards a robotic partner and a robotic opponent [93]. Both Short et al. and Zaga et al. manipulated the role of a robot to engage with children either as a tutor or expert or as a collaborator or peer [121,147]. Fan et al. also compare a peer-like role versus a facilitator-like role for robots in a motion-based collaborative game for older adults [33]. Lastly, Piumatti et al. explore in an observational study whether a robot could be controlled by a person to act as their (physically present) avatar in the game world, or if the robot could act as an opponent of the human player in the game [102].

Beyond explicit manipulations of a robot's role with a human, we cover a wide panoply of roles that a robot may have in a game interaction in Sect. 5.2.

4.1.5 Robot's Appearance

This category considers research topics related to the embodiment of the robot. Researcher experimental manipulations either affect the actual shape of the embodiment or affect other features of the robot's embodiment which is presented to the user. Most research topics within this category include comparisons of a physical robot with a virtual robot [3,11,63,77,80,109,133,140] or a robot in a disembodied condition [13,62,78,143]. Additionally, Sajó et al. compare the impact of adding a virtual face to a robotic arm [112], while Paetzel and Castellano varied the morphology of a robot's face to be either more machinelike and more humanlike [95].

4.1.6 Robot's Autonomy and Performance

This category relates not only to the amount of control a robot has over the execution of a task without external intervention, but also the efficiency shown by the robot in executing that task. We considered the following comparisons: high versus low competence of a robot in playing a game [100] and autonomous versus remotely-controlled robots [27,70]. Additionally, we included the impact of different algorithms for robust and accurate tracking of a robot's location [101], as well as an autonomous representation of gestural patterns and their corresponding gesture in the robot's embodiment [32] (see Fig. 3c).

Despite the aforementioned papers that explored explicit manipulations of the robot's autonomy, we would like to emphasise that the literature that included autonomous robots in their empirical evaluations is larger. The robots operated in a fully autonomous way in 67.0% of the reviewed papers, semi-autonomously in 16.5% of the papers, and 16.5% relied on a fully tele-operated robot.

4.1.7 Robot's Social Capabilities

This category refers to robots' capabilities that facilitate their coexistence with humans in a social environment, and it includes the highest portion of the reviewed papers: 53%. As a result, we decided to extensively use the sub-categories

Table 2 Distribution of the subcategories of the 44 papers with research topics on *robot's social capabilities*

Category	Sub-category	# Papers
Robot's social capabilities	Communication modalities	4
	Expressing and perceiving emotions	9
	Exhibiting character traits	12
	Modelling humans	10
	Learning new competencies	2
	Maintaining relationships	7

suggested by Baraka et al. [9] to further specify the research topic of each paper (see Table 2).

The sub-category of *communication modalities* contains experimental manipulations on the robot's expressiveness through different channels such as speech or gestures. We found two papers exploring the impact of the acoustic features of speech [67,111]. Regarding non-verbal modalities, we included in this category one manipulation of motion and speed [56] and another of head gestures [68].

For the sub-category of *expressing and perceiving emotions*, we identified nine papers in which the focus of the research is the robot's affective capabilities. Four of the papers explicitly manipulated the presence versus absence of emotional behaviours [11,70,77,100]. With regard to emotional expression, one paper analyses how different multimodal behavioural patterns can imitate basic emotions [59], and another compares the expression of two types of emotions, individual- and group-based emotions [23] (see Fig. 2d). Lastly, we include research topics that examine emotional perception, such as the expression of empathy by social robots [74,75,132].

The sub-category of *exhibiting character traits* considers research topics on the robot's expression of human behavioural traits. Among the 11 papers that explore personality or character traits of social robots, one includes a comparison between an agreeable and a disagreeable robot [85], and two others concern learning-oriented and goal-oriented traits displayed by the verbal comments of a robot [19,93]. Several works by Sebo et al. also fit within this category, such as research on robots reinforcing either task cohesion or relational cohesion [128], the uttering of vulnerable comments by robots [127] (see Fig. 2b) and the perception of robot integrity and the impact of a robot apologising after a trust violation situation [115]. We also found a paper exploring the impact of blame attribution by a robot [136] and another on spoken mitigation strategies to repair technical failures [22].

While the previous papers explore personality or character traits through the expression of verbal utterances, we also found four papers manipulating similar traits for the robot's actions in a game. In one paper, the robot either tries to equalise the performance of all teammates or tries to reach the goal as fast as possible [120]. Vázquez et al. explore deceptive behaviours to convey winning or losing [137]. Xin and Sharlin compare obedient and defiant behaviours, through which a robot followed (or did not follow) suggestions given by human players [144]. Lastly, Pereira et al. manipulated the social presence of a robot through several social behaviours, such as gaze, believable verbal utterances, emotional expression, memory and social roles [99].

Within the sub-category of *modelling humans*, we considered robots' perceptive capabilities of human behavioural traits, such as recognising and interpreting social aspects of humans. The first two example papers are a multimodal representation of positive and negative rewards [7] and a model of the player's motion style based on accelerometer data [92]. The work by Lopez et al. also fits within this sub-category, as the researchers explore a robot's mental model of a user that maps previous states and projects expected success in a negotiation task [81]. Skantze et al. evaluate a data-driven model capable of perceiving and generating turn-taking cues through several modalities (e.g. head pose, words, prosody, card movement) [123]. Similarly, de Oliveira et al. compare different strategies for robots to produce deceptive trajectories by modelling humans [29], and Chaspari and Lehman created a model of engagement to explore the relationship between engagement and acoustic patterns of children during a speech-based computer game [17]. Within the sub-category of modelling humans, we found papers considering the autonomous real-time detection by robots of the players' intentions [2,97], as well as an adaptive gaze behaviour displayed by robots that tracks players' contributions with the objective of increasing the participation of the least active person [38]. In the final paper, a robotic player learns a personalised model of students' knowledge from gameplay and applies transfer learning methods to achieve multi-task personalised learning [126].

Within the *learning new competencies* sub-category, we found two papers focused on adaptation techniques to refine previously learnt skills or acquire new ones. One paper includes the generation of visual-linguistic concepts enabling a robot to play a question and answering game [64] (see Fig. 1b), while the other explores techniques to learn game interaction behaviours by observing human demonstrators [73].

Finally, the last sub-category of *maintaining relationships* contains papers that focus the research on establishing social relationships with robots over a timespan. This includes, for instance, exploring different conversational strategies [1,76] or even the creation of appropriate tools to assess and compare expectations of and satisfaction with robots [5]. Two works by Serholt et al. also fit within this sub-category; one explores how a robot may elicit and maintain students' social engagement and how this engagement is expressed over time [117] and another analyses breakdowns in children's interactions with a robotic tutor [116] (see Fig. 3b). Over the course of 12 sessions, Taheri et al. looked at the impact of robot-assisted therapeutic games for paired individuals with autism in group sessions [131] (see Fig. 1d). Finally, Paetzel and Castellano investigate humans' first impressions of robots, and in particular, whether applying a morphed facial texture to a physical robot still elicits uncanny feelings [95].

4.2 Evaluation Methods

Natural patterns of social responses from human players emerge when playing games with robots. Humans express themselves in a multimodal fashion by displaying both verbal and non-verbal behaviours when playing with robots. The analysis of the presence and prevalence of such behaviours often forms part of the research metrics used to assess the performance of robots in games or to explore the specific research topics identified above. With regard to using non-verbal behaviours as an evaluation metric, players' eye gazes and head pose patterns [1,53,58,65,80,93,96,100,141,143,147] are the most prominently used modalities for estimating engagement and attention. Only a small subset of authors considers other non-verbal modalities by assessing the prevalence of facial expressions [117] such as smiles [65,96,141] and blinks [65] or analysing players' body postures [23,93] and hand gestures [65].

Regarding verbal communication, difficulties in natural language processing still prevent most authors from using free-form bidirectional speech communication in interactions, despite dramatic breakthroughs in speech recognition technology [49]. Limited verbal communication abilities of the AI for current robotic games often results in unnatural interactions when compared to human-human exchanges. This limitation invalidates the use of evaluation methodologies that expect natural communication cues. However, many authors still analyse verbal communication in simple exchanges such as classifying the target or intention of participants' verbal comments or by using Wizard of Oz (WoZ) approaches to simulate more complex, natural verbal interactions that can be unobtrusively recorded and analysed offline [1,7,62,96,100,109,117,139].

The game context and the choice of robot and player actions in games were also commonly used [38,67,68,82,86,94,96,131,136,139,147] as a valuable source of research metrics. The specific moves made by each player in a game, the presence of cooperative behaviours and the duration of each interaction are examples of contextual features authors use as evaluation metrics. To cite an instance, McColl et al. [86] uses a player's level of activity in a game combined with gaze estimation to predict subjective metrics such as user engagement. Given the importance of context in games, it is relevant to develop evaluation methods that combine contextual game information with verbal or non-verbal features.

Notwithstanding, the majority of the reviewed work uses subjective questionnaire data as a source for their research metrics and evaluation methods. The remainder of this section is dedicated to identifying the subjective metrics that are most typically used when researching robots in games. We have identified four main types of assessments in the articles reviewed.

4.2.1 Robot Assessments

The first group of questionnaires we identified focuses on evaluating the properties or attributes of robots in games. The Godspeed questionnaires designed by Bartneck et al. [12] were used in five of the reviewed papers. Godspeed measures the anthropomorphism, animacy, likeability, perceived intelligence and perceived safety of robots. Often, all these attributes were measured for in a paper; sometimes they were evaluated separately depending on the research topic. Another questionnaire drawing inspiration from Godspeed and other sources of social perception psychological literature is the robotic social attribute scale (RoSAS). RoSAS [16] was used three times in our survey, and RoSAS measures the three main dimensions of warmth, competence and discomfort. The Almere model [46] was used five times, and it evaluates attitudes towards and acceptance of robots. Almere measures several factors for robots that include perceived ease of use, perceived sociability, perceived usefulness and trust attributed to a robot. Some authors [63,99] also focus on measuring the amount of presence [45,79] one attributes to a robot, while others focus on more specific metrics such as the levels of uncanniness [50] attributed to a robot player.

4.2.2 Relationship Assessments

The second identified type of subjective assessments focuses on evaluating the perception of human-robot relationships. When addressing dyadic interactions, authors used validated metrics for assessing relationship satisfaction [47], friendship [15,41,89], interpersonal closeness [6,103], interpersonal attraction [87] and positive and negative affect [31]. The relationship between a human and a robot does not necessarily have to mimic or match human-robot relationships. As a case in point, [121] considered a companion animal bonding scale [104] to evaluate the relationship of humans with their robotic player. Some attributes such as empathy [26] and trust can be considered both a robot attribute (e.g. how trustworthy [88] is a robot) or more as a relationship attribute relevant to the overall perception and measurement of human-robot trust [57,71,84,114]. Games are usually multiplayer experiences featuring groups and teams. As such, this review includes several instances that have included robots in teams and groups. In these contexts, authors use measures that evaluate relationship assessments geared towards groups such as group identification [72], group cohesiveness [142], group trust [4] and psychological safety within a group or team [30].

4.2.3 Game Assessments

General interaction or game assessments were often used as a secondary measure to complement HRI research. When evaluating interactions with children, the fun toolkit [108] was utilised as an instrument to gather the opinions of children in playful interactions with robots [118]. General usability scales [14,90,135] were also employed in some of the identified work [82,101,105]. Some authors opted to use metrics created to assess players' experiences in games. The game experience questionnaire (GEQ) [54] appeared twice in our review and considers immersion, flow, competence, positive and negative affect, tension and challenge as relevant factors for assessing game experiences. A metric for measuring game immersion [55], a model for evaluating player enjoyment in games [130] and a scale to determine the enjoyability of user interactions with consumer devices [51] are other examples of relevant questionnaires identified in our analysis. The final assessment type we identified in this category related to metrics that are appropriate for a specific game type. As an example, a negotiation game played with robots [128] employed a questionnaire that measures what people value when negotiating [24].

4.2.4 Player Assessments

Player differences can also play a part in how a robot, a relationship or a game are perceived. Individual differences are often assessed via questionnaires and frequently used as additional factors in analysis or correlation variables. The most common metrics used in this regard are personality questionnaires [34,36,40,60,107] that measure individual differences. These metrics can also be more specific and aim, for instance, to establish intrinsic factors for motivation [48], target specific user groups and demographics such as assessing children's temperament [110] and assess cognitive impairment in the elderly [138]. Specialised questionnaires that measure player personality differences in games are also commonplace within game research literature [42]. However, we did not find their usage in any article in our analysis. One exception was the work of Correia et al. [19] that uses a validated measure designed for games that assesses the competitiveness level of each participant [125]. Specifically related to robots, we found two research papers [95,120] that use a metric measuring players' negative attitude towards robots [91]. An opposite metric employed in [38] measures the willingness to collaborate with a robot [146]. Player assessment metrics are often individual traits that are long-lasting and independent of interactions. However, some authors still choose to repeat these assessments to determine whether, for example, a player's negative attitude towards robots has changed.

5 Social Interactions in Games

In the reviewed literature, games are used to support interaction between humans and robots. In most scenarios, the competitive and collaborative nature of the gameplay prompts social exchanges between players. Often, these exchanges are not prompted by the game itself. Rather, the exchanges occur on an interpersonal level where players directly engage others. Nonetheless, there are some scenarios where human and robot players interact socially with each other within the boundaries of the gameplay, for instance, when both players role-play characters from a television show [3]. Additionally, the authors mainly report the interaction at an interpersonal level with very few exceptions detailing the social actions that occur in the gameplay space. Accordingly, we focus our analysis in this section on the social interactions that happen in the interpersonal space when supported by the gameplay. Details about the game characteristics of the scenarios that support such exchanges are reported in Sect. 6.

5.1 Social Structure

In the reviewed literature, there is a wide variety of combinations of humans and robots playing games, as shown in Fig. 2. To analyse the social structure of interaction, we grouped interactions based on the number of humans and robots participating in the game. As shown in Table 3, there is an extensive body of literature that reports user studies with only one robot in the interaction (92.94% of the articles reviewed), while only 7.06% created scenarios with multiple robots. The number of studies with only one human participant in the interaction is 58, representing 68.24% of the total analysed literature, while only 27 articles included more than one human in the interaction, comprising 31.76%. Additionally, it is significant that 65.88% of the studies designed

Table 3 The social structure of the 85 papers that include experimental user studies reported by the number of robots and human players involved in the interaction

Structure	Number
1 Human–1 robot	56
1 Human–multiple robots	2
Multiple humans–1 robot	23
Multiple humans–multiple robots	4

interactions for one human and one robot. Finally, only two studies included one human with multiple robots [44,144].

The low number of interactions that involve more than one robot player suggests that deploying multiple robotic systems to interact with human players might be technically challenging or an uncommon research focus. Moreover, deploying multiple robots with multiple players not only requires a scenario that supports such a social structure but also creates some challenges related to turn taking. When interacting with a single human, robots do not need to distinguish between multiple interlocutors. However, in [44] the authors report the use of a script to guide both robot game actions and verbal communication. While interacting with multiple human players, robots might need to identify the actor behind the action (both in the gameplay and interaction space). However, in the four scenarios with multiple humans and robots, the autonomous robots did not react to the human players' verbal or non-verbal behaviour [19,23,93,94]. Instead, all robot interaction was solely driven by the players' actions in the game and the current game state.

5.2 Social Roles

In the reviewed literature, robots are often placed in the interaction as an additional player rather than as an element of the game environment. Accordingly, most of the analysed games can be considered multiplayer games. Typically, players assume social roles throughout gameplay in relation to other players and within the game itself.

To assume a social role, a player must socially engage with others around their gameplay goals. For instance, players collaborate to win or they compete with others to reach their target more efficiently (e.g. players coordinate the use of keywords to collect coins [111], or they compete with each other to shoot asteroids [115]). Players can also assume asymmetrical roles (e.g. robots can play the role of a tutor introducing the gameplay rules to a human player [86]).

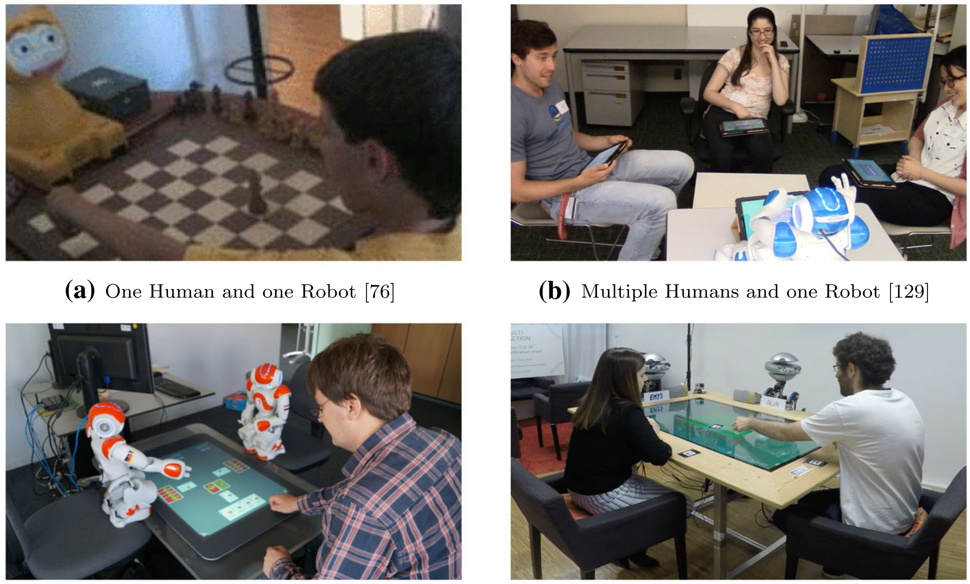
We observed in the reviewed literature that when a robot only participates in the game as a gameplay element, it does not socially interact with others and thus does not assume a social role. For instance, when a robotic train travels on railways [69], when robots are the physical representation of hot air balloons [94] or when they serve as mere transporters carrying physical tokens [109], these robots are not considered as social actors since they do not assume a social role within the game.

Of the 85 papers in this literature review, 82 introduced robots that took one or two social roles during the course of their experiments. In Table 4 we report the number of robots that assumed each social role and when a robot took two roles, the number of pairs of social roles assumed by the robots.

We identified two types of social roles: *symmetrical*, where both players assume the same attitude towards each other and *asymmetrical*, where players have distinct stances towards each other.

Regarding the first social role, we identified some games in which the robotic player, conferred with the same gameplay actions as the human player, actively helped their counterpart to reach their goal. In cases where a robot helps a player, such as sorting physical tokens in a game [141] or memorising braille symbols [132], the robot can be considered a *teammate* of the player. In the analysed games, 27 robots assume a teammate role during the gameplay; of those 27, nine were capable of assuming an additional role. Conversely, we identified scenarios in which the robots assumed a competitive stance towards human players, where the robot directly competed with them, in 33 research works. For instance, we considered players to be the *opponent* of other players during poker games [65] and chess games [112]. When assuming this role, the robot competes with the human player while trying to achieve a better performance or outcome. Of the robotic opponents included in the literature, seven assumed an additional role.

When the role is asymmetrical, players have different duties when assuming their part in the interaction. We identified 11 game scenarios where the robot played the role of a *teacher* trying to help the human player regarding gameplay aspects. For instance, a teacher role was assumed by a robot when providing feedback to a player solving the Tower of Hanoi puzzle [140] or when giving problem-solving strategy lessons [78]. Of the robots that assumed the teacher role, four of them took additional roles. One research work reversed this relationship and positioned a robotic pet as the *student* with the human portraying the role of a teacher [7]. Furthermore, we identified 20 game scenarios where the robot played the role of the *host*: a member of the game party responsible for facilitating and mediating the gameplay. In some scenarios, the robot guarantees that the players adhere to the game rules [86], manages the turn taking during a quiz [134], moderates the intervention of all players [120] or comments on the game itself [74]. Of the robots that assumed the role of host, four also assumed other roles during the gameplay. Moreover, the reviewed literature contains two uses of *subordinate* robots that act when requested rather than proactively. In [85] the



(a) One Human and one Robot [76]

(b) Multiple Humans and one Robot [129]

(c) One Human and Multiple Robots [43]

(d) Multiple Humans and Multiple Robots [22]

Fig. 2 Games with distinct social structures

Table 4 Distribution of the social roles across the 82 papers considered

	Host	Opponent	Student	Subordinate	Teacher	Teammate
Host	16	1	–	–	2	1
Opponent	1	26	–	–	–	6
Student	–	–	1	–	–	–
Subordinate	–	–	–	2	–	–
Teacher	2	–	–	–	7	2
Teammate	1	6	–	–	2	18
Total	20	33	1	2	11	27

The diagonal represents the number of robots that assume just a single social role while the remaining cells indicate the number of robots that assumed two roles

robot follows the player's orders while moving in a maze, and in [101] the robot, after recharging, autonomously moves to a location indicated by the human player.

Furthermore, there is an implicit role that robots widely adopt during a game: the role of an *observer*. While actively contributing to the game itself, they perceive the game state and others' performances to autonomously react to the surroundings. However, when robots solely assume a passive stance, they can be considered as the *audience* of the game. But this role can also be inverted. If no human players take part in the gameplay but are spectators to the performances of robots, in addition to any other role the robot might assume in relation to other players, these robots can be considered *performers*, as in the RoboCup competition [66].

Robots can also take multiple social roles within a single gameplay experience. Twelve robots in this survey assumed multiple roles, either because of the game phase or because the multiparty social structure of the game forced them to adopt distinct roles towards different parties. Regarding the latter, we identified six articles in which the robot played either as a *teammate* or as an *opponent*. Of these, two authors reported on a study with a single robot [20,126], whereas in the remaining four cases more than one robot was involved in the interaction [19,23,44,93]. Regarding games in which the robots changed social roles throughout the game, there are two scenarios in which robots changed between the role of *host* and *teacher* [33,86], one scenario in which the robot took the role of *host* and *opponent* [119] and one scenario in which the robot changed between *host* and *teammate* [116]. In two further scenarios the robot played both the role of *teacher* and *teammate* [121,147].

Notably, robots assumed symmetrical roles 60 times, whereas they only adopted asymmetrical roles on 34 occasions. Robotic players adopted multiple symmetrical roles in six games (six as *opponent* and six as *teammate*) [19,20,23,44,93,126] and multiple asymmetrical roles in two research works (two as *teacher* and two as *host* [33,86]). Only in four occasions did robots assume both symmetrical and asymmetrical roles (one as *host* and *opponent* [119], one as *host* and *teammate* [116] and two as *teacher* and *teammate* [121,147]).

5.3 Duration and Frequency

In addition to the number of participants and their relationship during the interaction, authors also report on the duration of sessions, frequency of sessions and time between sessions. However, it was possible within the reviewed literature to observe a lack of consistency among authors regarding the description of the interaction's duration. Some authors only reported on the duration of the gameplay (e.g. [64,109]), whereas others reported on the entire interaction, including the gameplay, questionnaires and other exchanges outside of the actual game (e.g. [1,100]). Furthermore, researchers reported on duration in two formats, either as an interval of times or an average time (with few authors reporting the standard deviation [38,97,139]). Due to the lack of clarity and absence of a widely adopted structure to report the duration of each experiment, we reviewed them in accordance with the following three reference frames:

– *Gameplay duration*—the duration of a single gameplay interaction. For instance, the duration of a single game of chess was, on average, 15 minutes in [75], and the duration of a round of the Desert Survival Task took a maximum of 15 minutes in [81].
– *Session duration*—the duration of the set of games that comprise an interaction. For instance, in [120], participants played a puzzle game five times, adding up to a session of approximately 30 minutes.
– *Experiment duration*—the duration of all the sessions associated with the experiment (which might include multiple conditions) as well as the time to introduce the participant to the robot or game and other tasks performed in the presence of the participant, such as filling questionnaires.

Most research works do not report on the duration in terms described above. Only 10 (11.8%) articles clearly describe the gameplay, session and experiment duration. However, in some situations it was possible to infer the duration based on the information provided. For instance, in [68] the authors report that each gameplay lasted two minutes but also state that each session is composed of three games. Accordingly, we can conclude that each session lasted six minutes, but we do not have enough information to determine the whole experiment duration. However, the structure of the interaction in most cases is not clearly described thus precluding any inferences from being made.

As shown in Table 5, the duration of the gameplay never exceeded 60 minutes, and the majority of the games lasted between one and 15 minutes. Indeed, the reported gameplay durations are not aligned with the typical length of tabletop or video games. This might suggest that the interactions with the robots are distinct and to some extent not representative of common gameplay duration. In laboratory settings, researchers rely on the games' repeatability and ask participants to play several rounds of the same game. For instance, when the gameplay duration was less than one minute, players were always asked to play the game multiple times.

It is noteworthy that the vast majority of the reviewed literature did not detail the duration of the interaction. Accordingly, the findings presented should be treated with caution since they do not describe all the included games. Reporting such details is of the utmost importance since it allows an understanding and framing of the robots' capabilities based on the interactions in which they participate. For instance, the capacity to recall past experiences might not affect the relationship between players in a single session of five minutes as much as it does in multiple weekly sessions that last half an hour.

Indeed, we also determined the number of game sessions and time between them, in addition to analysing the duration of the three reference frames. In 69 (81.18%) reviewed articles, the interaction with each player was restricted to a single session. Of the remaining articles, one reports two sessions [80], four report three sessions [1,19,93,117], one reports four sessions [126], one reports six sessions [121], and one reports 12 sessions [131]. Two articles report a variable number of sessions throughout the experiment: in [116] the experiment had four to eight sessions, and in [86] 10% of the participants played more than once. For six (7.06%) papers it was not possible to identify the number of sessions.

When the experiments had multiple sessions, the authors report on the time between sessions as follows. Two experiments report a negligible time between sessions, that is to say, the sessions were consecutive [19,93]. One reports that sessions occurred twice a week [121], and in another study the sessions were five days apart [1].

In two articles the sessions were seven days apart [80, 131]. In [117] the sessions occurred every month, and in [82], although not specifying the frequency of sessions, the author reports that the sessions occurred every three months. Additionally, in [116] the authors report a variable interval between sessions ranging from two days to two weeks.

Similar to the duration of the sessions, reporting the number of and time between sessions provides a stronger understanding of the robots' capabilities based on the temporal span between encounters. Although the vast majority of the experiments occurred in a single session, interactions that endure for several sessions with a significant interval of time between them might create additional challenges for the design of the robot, in particular, regarding the interpersonal relationship between players. Robots must be conferred with mechanisms that not only allow them to operate at the gameplay level but also the interpersonal level. For instance, researchers have studied how a robot's capability to recall and

Table 5 The distribution of papers based on the gameplay, session, and experiment duration using time intervals

Duration interval	Gameplay		Session		Experiment	
	Number	Percentage	Number	Percentage	Number	Percentage
[0, 1 min]	5	5.88	–	–	–	–
[1, 15 min]	28	32.94	6	7.06	1	1.18
[15, 60 min]	8	9.41	22	25.88	12	14.12
[60, 1 day]	–	–	2	2.35	2	2.35
[1 day, inf]	–	–	–	–	8	9.41
Not defined	44	51.76	55	64.71	62	72.94

share past events helped to sustain long-term social engagement in [1,121].

6 Game Scenarios and Materials

In the reviewed papers, we identified several scenarios that encompass a broad number of games and interaction modalities. In fact, very rarely was the same scenario used for multiple research items. Nevertheless, we observe that some researchers tend to rely on the same game scenario and even framework in multiple research works. For instance, in [19–21,23] the authors reused the same trick-taking card game while studying different research questions and introducing different social structures for the players. Additionally, the authors of [70,83,101,102] adjusted and enhanced a game's mixed reality framework to use across multiple studies. The partial or full reusability of games is a common practice for researchers and might suggest that the effort to design and implement new scenarios surpasses the benefits. Conversely, the use of games as a platform to study multiple research questions emphasises that this medium offers a flexible framework to explore several phenomena.

Notwithstanding the above, we classified the surveyed games to better understand the design and permissions of each scenario according to five main factors: the *turn-taking* approach of the game, the *collaborative or competitive nature* of the game, the *core mechanic* of the game, the *game representation and manipulation* used to change the game state and the *modality* used to interact during gameplay with the player, robot and game world. Additionally, it is notable that most of the reviewed literature was found in HRI communities, and the focus of these reports were on the interaction and robot rather than on the game and its characteristics; therefore, the aforementioned factors are not thoroughly detailed in all analysed articles.

6.1 Turn Taking

With regard to the turn-taking mechanism, we could not identify the game's turn approach for six of the 85 articles. Of the remaining 79 games, here were 56 (70.89%) games progression, whereas 23 (29.11%) were real-time games. The existence of a large number of games that rely on turn-based mechanisms, more than double the real-time games, might indicate that the development of robots for real-time games creates challenges not yet tackled by researchers. It is possible that the cognitive capabilities necessary to engage in an unstructured interaction are more demanding when compared to turn-taking ones.

6.2 Collaborative or Competitive Nature

In most games, the player is presented with a challenge that must be addressed alone or alongside other players. Additionally, the challenge might be initiated by other players, such as in chess games, or implicitly embedded in the game environment, such as in a puzzle. In 30 (35.29%) articles, the game had a collaborative nature, and in another 30 articles the player was introduced to competitive scenarios. A further nine (10.59%) games were both competitive and collaborative; the players were organised in teams in which they had to work together with their teammates while playing against opponents. In 16 (18.81%) games, the player did not have to work alongside or against others.

6.3 Core Mechanic

Tipically, game mechanics are one of the game aspects that best describes the gameplay experience. It is a core element of the interaction between players and the game. A large portion of the scenarios reported within the reviewed literature are inspired by game mechanics and genres that already exist, in particular from board games, card games, trivia contests and videogames. However, there is a subset of the reviewed literature that is altering the established mechanics by introducing robots in games. Additionally, while some games can be characterised as a combination of multiple mechanics (e.g. setting up a railway while managing resources, constructing objects and solving puzzles [127]), others explore very well-defined mechanics that are not yet widely adopted (e.g. shooting a drone with projectiles [70]). To analyse the selected papers'

Table 6 Descriptive analysis of game's representation and manipulation and modality

(a) Representation and Manipulation		
Manipulation	Number	Percentage
Digital	37	43.53
Physical	24	28.24
Hybrid	17	20.00
None	7	8.24

(b) Modality		
Interfaces	Frequency	Percentage
Display	59	69.41
Touch	30	35.29
Mixed reality	11	12.94
Gesture	9	10.59
Speech	31	36.47
Physical token	36	42.35
Physical cards	12	14.12

games, we only consider the core mechanic of the game and use a classification based on typology commonly used by researchers and game developers.[1]

In the reviewed literature, we identified 17 different core mechanics. *Strategy* was the most widely used mechanic as it was present in 23 (27.06%) games. The next most used was the *puzzle* mechanic which appeared in 12 (14.12%) of the games followed by *guessing* and *resource management* games, both appearing in eight (9.41%) games. Additionally, we identified seven (8.24%) *trivia* games, seven *rhythm* games, five (5.88%) *platform* games and four (4.71%) *memory* games. We also found three (3.53%) *shooting* games, three *construction* games, three *sorting* games and only one (1.18%) game of each of the following core mechanics: *role play* [3], *party* [44], *matching symbols* [109], *fighting* [13], *counting* [136] and *chance* [1]. Notably, in four games we identified two core mechanics since they both played an important role in the game design.

6.4 Game Representation and Manipulation

The interactive space of robotic players has the potential to often enlarge the interactive space of the game overall and therefore, also increases the number of types of manipulation available. One of the criteria used to distinguish the nature of the task was the medium used to manipulate the game world and its entities. In some cases, these manipulations could happen entirely in the physical or digital world. However, we identified some games that mix both the digital and virtual world as well as others where there was no direct manipulation of the game entities, as shown in Table 6. Accordingly, we identified from the literature review the following four types of manipulation:

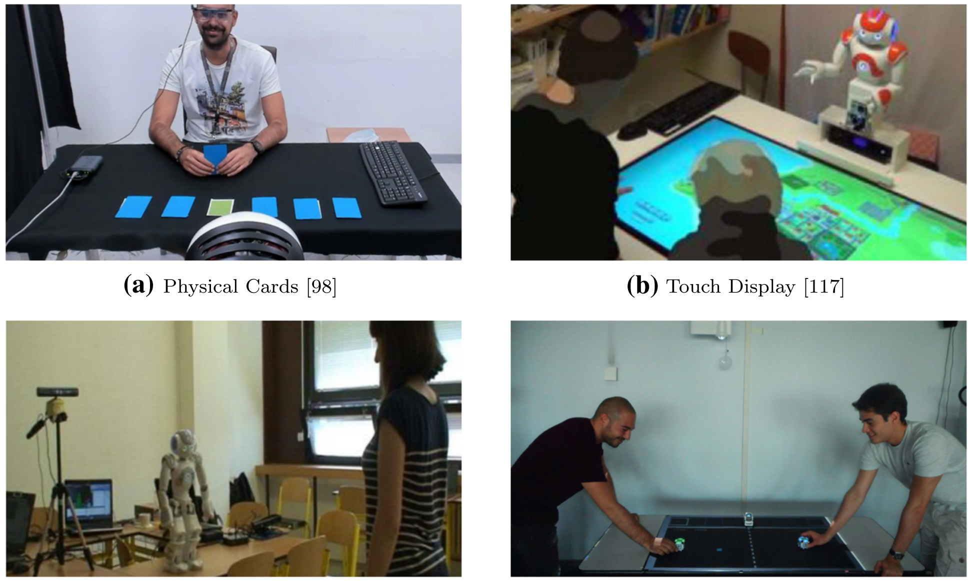
- *Physical*—when game participants may only change the state of physical objects that are game entities. Examples include moving a piece on a chess board [112] or tokens in a puzzle game [59].
- *Digital*—when game participants modify the state of the game only in the digital world. Examples include using speech to modify the position of a virtual character [17] or collecting coins on a virtual board [100].
- *Hybrid*—when any actor in an interaction may manipulate both the physical and digital entities. Usually, such manipulations are made in both worlds. Examples include playing a physical card over a fiducially enabled digital table to modify a digital game world [20] or changing the position of a token that moves a pad in a virtual environment [105].
- *None*—when there are no manipulations of physical or digital game entities. Examples include when a player needs to copy a robot's gestures [131] or play a rock paper scissors game [2].

It is noteworthy that 16 (18.82%) articles heavily relied on games that required participants to physically manipulate the game entities. In this games the human and robotic player had to constantly perform movements with their bodies to succeed in the game, also known as *exergames*. However, the effort necessary to complete the task is not equal across all such scenarios and is often tailored to a target audience (e.g. children, the elderly). On the one hand, there are research works that require players to perform simple hand coordination tasks involving touching a robot while sitting down [43] or playing a pattern on a drum kit [68]. On the other hand, some scenarios require the player to run between towers [29] or to dodge laser attacks made by a drone [70].

In all of the exergames identified, the scenario and the robotic systems were purposely designed for a very specific target. Notwithstanding, the gameplay might need to be adjusted based on the players' capacities. For instance, researchers designed a slow-paced version of pong for a care facility where the lateral movement of elderly players would control their game character [8]. However, the researchers also allowed for another type of manipulation when a human player could not freely move, specifically, by allowing the waving of hands. This adaptation not only increases the game's accessibility but also its re-playability since the interactive space of the game is now larger and presents another mechanical challenge for players that want to explore it.

[1] https://boardgamegeek.com/browse/boardgamemechanic.

Fig. 3 Some different types of modalities found in the reviewed literature



(a) Physical Cards [98] **(b)** Touch Display [117] **(c)** Gesture [29] **(d)** Mixed Reality [106]

6.5 Modality

Another aspect that helps to categorise multiple game scenarios with robots is the modality of the interaction (see Fig. 3). Although dependent on the game scenario, interaction goals and the robot's capabilities, there was nonetheless a wide variety of means in the literature used to support interactions in games. In the literature reviewed, it is possible to observe a group of seven different modalities used to perceive and act in the game, but also to interact with other players (Table 6).

One of the most widely used modalities to perceive the state of the game was *displays*. In the reviewed literature, we identified 59 (69.41%) scenarios that rely on a type of monitor, projector or screen. In some scenarios the display was integrated as part of the robot embodiment [82], in others a device projected the relevant information about the game [7] and in yet further scenarios, the display completely defined the interaction space [101]. However, physical monitors were adopted in the vast majority of the research works. With regard to displays in general, there were two sub-modalities used among the selected articles worth highlighting: *touch*, where the gameplay involves touching a display to manipulate the game world, and projector-based *mixed reality*, where interactions in the virtual world are projected into the physical surroundings of the player. The latter modality requires humans and robots to play the game over its projection using a device capable of recognising player movement. We found eleven games that used this modality and most were reported after 2017. In contrast, a touch interface requires that players directly interact with a display that recognises their touches. This modality was used in 30 (35.29%) articles and the first occurrence of its use with robots in games was in 2003; since 2014, it has become more widely adopted.

Thirty six (42.35%) of the games presented the players with *physical tokens* that could be manipulated. Depending on the scenario, different tokens were used: rings for the Tower of Hanoi [56], a coloured cube [105] and chess pieces [77] (see Fig. 2a), among others. It was notable that of the 36 games that used physical tokens, 12 relied on physical *cards*, specifically, cards from a standard 52-card deck [23] (see Fig. 2d), picture cards [86] and text captions [53].

In 31 (36.47%) articles, the gameplay was supported by *speech* exchanges. Examples include when a player orders their avatar to execute a certain action by voice command [85] or when a player's choice is confirmed by voice in a trivia game [80]. Of the scenarios that involved speech-based interaction, only in [63] did the game not involve any other interface between the player and the game world. In the remaining scenarios the voice commands were always used alongside an additional modality. As such, the number of scenarios that only rely on voice commands as the core channel through which the humans and robots manipulated and evolved the game state is very low.

In 9 (10.59%) scenarios, the players were requested to execute *gestures* to succeed in a game. In the reviewed literature, authors reported interactions that required synchronised or pattern-based physical motions during gameplay. In two of these games, the gestures of the players were the sole actions afforded by the game: in [2] the players play a rock paper scissors game and in [131] the players need to copy each other's movements.

The usage of the abovementioned modalities tends to follow technological advancements and the commercial availability of devices that support them. As early as 2003, Christoph Bartneck used a touch screen to support gameplay with a robot [11] (see Fig. 1c); however, researchers only started to widely adopt touch screens in 2014 when tablets and their development kits became more accessible. Similarly, the adoption of mixed-reality for robots in games might also be driven by a future availability of more capable hardware. However, some researchers evolved these state-of-the-art modalities to enable new types of gameplay rather than allowing the interaction to be constrained by pre-existing interfaces. For instance, Piumatti et al. researched new methods of tracking off-the-shelf robots to support a mixed-reality game with a human and a robot [101].

Additionally, designing games that fully rely on digital interfaces removes the burden of conferring the robotic player with capabilities to physically manipulate the game world. Notably, almost half of the selected articles still involved physical tokens despite the need for added capabilities, although, sometimes, human players were asked to manipulate tokens on behalf of a robot [20,75]. This might indicate a bias to use game scenarios inspired by tabletop games since they tend to promote more social interactions between the parties involved, perhaps due to the face-to-face nature of the game. However, it also highlights the absence of the necessary physical manipulation capabilities in favour of direct manipulation of computational representation of the game world.

7 Discussion

Our review analysed the most recent research papers exploring robots in game settings. The first aim of our analysis was focused on the user-centred goals and the target audience of the reviewed papers. The wide panoply of populations, including several generations, and explicit applications, such as health or education, revealed that *robotic game players can be a positive and impactful tool in our society for several purposes*. Additionally, as we have considered entertainment as a primary goal that is inherently present in all of the reviewed papers, it is worth mentioning some of the possible implicit benefits of games as entertainment activities, such as mental health [61] and mindfulness [124].

While analysing how games can be used as a research platform, we highlight two additional observations. The first is that *games can support advances in the field of HRI*. This is particularly evident considering that we categorised the main research topic of 85% of the selected papers as either robot-related (e.g. appearance or autonomy) or interaction-related (e.g. proximity or role). Interestingly, fairly half of the selected papers explored research topics specifically on the robot's social capabilities, which additionally suggests that the social context of games can well support the development of social behaviours in robots. We observed such advances at three different levels of development: design [69,98], technical implementation [101,123] and evaluation [109,131]. Overall, this observation is aligned with the idea that the next significant challenge for artificial agents is the development of advanced social capabilities [10].

The second observation is that *robots can provide new gaming opportunities*. We initially noticed this aspect from the analysis on the research topics, in which we identified only a small portion of papers covering aspects of the gameplay or game experience. The current lack of research on this category presents many possibilities for future research. Other than the analysis of games as a research platform, the remaining analysed aspects of the reviewed papers (e.g. the game mechanics or the social structure) in fact also shed some light on possible avenues to include robots in new game experiences. For instance, a large number of mechanics were identified in the reviewed games; however, there is still a large portion of the core mechanical space to explore. The use of social robots as players creates a game design challenge as well: *game designers need to consider robots' characteristics while conceiving the game mechanics* to ensure that their autonomy does not collide with the game design goals and, potentially, strengthens them. Furthermore, rather than being included as players, *robots placed as game elements can open up an interactive space where autonomous physical entities extend the virtual gameplay*. For example, Lamberti et al. deployed a small robot in a game where it played the role of a train in a digital projection of railways [69]. Even when not exhibiting social capabilities, robots with agency can promote the emergence of new mechanics and roles not yet explored. However, there are other social roles more centred on the gameplay that have not yet been explored by researchers. Although a wide range of social roles are present in video games, these social roles have not yet been fully explored in scenarios with robots. Game designers should consider *deploying robotic players that cover a wide range of social roles since they enable richer social interaction within the game itself*. For instance, robots might assume the role of a *provider* to grant other players with information or resources that can be directly used in the gameplay. Moreover, robots can also be used as *background agents* inside a game world: without directly affecting the gameplay or engaging the human player, these robots can still help to set up the context for the game and establish a dynamic world. Although we identified two robotic players that were used as *subordinates*, there are many opportunities to further explore such a role. In addition to ordering a single robot, human players might strategically guide swarms of minions, to extend the human players' range of action. Additionally, the human players can be introduced into a chain of command in which they receive requests from robots while delegating actions to other robotic, and perhaps human, players.

We observed that in more than two thirds of the scenarios, robots manipulate the game in a digital or hybrid fashion. As such, there is a direct manipulation of the computational representation of the game instead of a verbal or non-verbal action reassembling the possible actions of a human counterpart. Although the level of autonomy regarding decision making by robots has evolved, there is still an absence of fully autonomous robots playing games with interactive capabilities that are natural to humans. To an extent, *the autonomy of a robotic player has some strings attached*. One could say that the reviewed games afford a different set of manipulations when comparing a human player with a robotic player. Being so noticeable during gameplay, this disparity might raise concerns regarding a player's perceived fairness of the game. These concerns may arise not only because players have different capabilities but also due to the possibility of a robot's actions being attributed to the actual game system, rather than to an individual with a perceived agency. Additionally, the social exchanges of the robots with humans are often prompted by gameplay actions but are shared on the interpersonal level, in particular in scenarios with multiple robots or multiple players. Our survey suggests that there is a lack of robotic systems that can understand, and in some cases even acknowledge, the human players' actions that are not directly mapped in the game world. The identified body of research did not focus on robotic players that can interpret and act based on others' social interaction features (e.g. speech, emotions, gaze). Nevertheless, most robots were still able to produce their own social reactions, solely based on the gameplay actions. More research to *confer robotic players with capabilities that allow them to autonomously understand the game and surrounding reality* is still needed.

Some of the selected articles conducted experimental studies on the impact of a robot embodiment on the interaction, comparing digital to physical versions of the robot player (see Sect. 4.1.5). Among these articles, the type of manipulation performed by the human player was either the same across different conditions (e.g. always using physical chess pieces [77] or digital stamps [11]), or the manipulation was aligned with the robot embodiment (e.g. the game tokens were digital when the robot was digital and physical when the robot was physical [3]). However, no literature was found on the impact of the type of game manipulation (the game world) in scenarios with robots. Since a robot's appearance seems to give rise to significant differences in a robot's interaction with humans in game environments, such findings might also apply to the types of manipulation and their modalities. Furthermore, *HRIs in games can support other types of interactions not feasible only with human players*. An example would be interactions which exploit robots' distinct characteristics (e.g. embodiment or cognitive capabilities). Identifying the aspects that affect the game experience when both robots and human players are involved can help design better games and, to an extent, yield contributions for better HRIs in other domains.

When multiple players are involved, the game's social space affords a larger set of social roles. The increased complexity and richer environments demand a stronger understanding of the relationships between players (both human and robotic) to confer social robots with better mechanisms to appropriately behave alongside other social actors. Whether competitive or collaborative, the nature of such roles in games can be used as the basis to study more complex social phenomena that exist in HRI. On the one hand, the social dynamics that emerge during gameplay can be studied and, to an extent, applied to other real-life scenarios such as other collaborative settings that require teamwork between humans and robots. In teams with robots and humans, for example, the latter's perception of their mechanical teammates might produce ingroup and outgroup bias that can be shaped by the context of the interactions, an aspect easily manipulated in games. On the other hand, *games can empower researchers with a reliable framework to study and measure social interactions* that are harder to analyse in other contexts due to their unpredictability by introducing a controlled environment with well-defined rules and metrics.

8 Conclusion

In this survey, we have presented a comprehensive overview of the state-of-the-art research on robots in games. The deployment of robotic players in games alongside human players provides researchers with scenarios to explore a broad range of research questions, from social interactions with robots to distinct interaction modalities and the players' experience itself. Furthermore, the set of rules and well-defined environments offer an interesting framework to study HRI without the noise and unpredictability of open-ended real-world encounters. Often researchers try to simulate these real-world exchanges in laboratory settings that fall short of an interesting experience for participants. Therefore, robots in games have been applied in many works of research to take advantage of the interactive and playful nature of games.

The social robotics and HRI communities have welcomed the opportunities that game activities offer to strengthen the understanding of robotic systems. By focusing on the game and interaction between players, researchers have been able to use scenarios not considered in the traditional robotics research that is mostly dominated by dialogue, manipulation and perception. However, most of the employed game designs are heavily inspired by, and sometimes fully replicate, multiplayer games, usually tabletop and video games. Although the majority of the robotics researchers focus on the interaction rather than on the game design, it is worth acknowledging these recent pursuits to explore new game opportunities uniquely afforded by games with robots. This is an attempt not matched by game communities.

Game research communities have not shown a strong indication of being willing to explore the potential that robots as players or game elements have in game research. The void of research in game-related venues and journals highlights that there is a weak or non-existent intersection of the efforts from academics in the two research fields. Researchers have already shown promising results from the deployment of robots in games and raise challenging research questions that demand a stronger collaboration between the two communities. Not only is it possible to better understand robots by placing them in games with humans, but it is also possible to expand the design space of games to support a deeper comprehension of players and their experience.

The first research works on robots in games we identified were published in the early 2000s, but this research field has seen an increasingly higher number of contributions throughout recent years. Nevertheless, the potential of deploying robotic players in games has not yet been fully explored. In fact, it is possible to acknowledge in the literature a research field still establishing its reporting methods and standard research metrics. Many research opportunities are still open, some of them identified in this article. The academic and commercial interest in robots and games reveals a promising future for both robotics and game research communities.

Funding This work was supported by national funds from Fundação para a Ciência e a Tecnologia (FCT) with reference (SFRH/BD/131024/2017, SFRH/BD/118031/2016 and UIDB/50021/2020) and the Swedish Research Council (2021-05803).

Declarations

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

References

1. Ahmad MI, Mubin O, Orlando J (2017) Adaptive social robot for sustaining social engagement during long-term children-robot interaction. Int J Hum-Comput Interaction 33(12):943–962
2. Ahmadi E, Pour AG, Siamy A, Taheri A, Meghdari A (2019) Playing rock-paper-scissors with rasa: a case study on intention prediction in human–robot interactive games. In: International conference on social robotics. Springer, pp 347–357
3. Ali H, Bhansali S, Köksal I, Möller M, Pekarek-Rosin T, Sharma S, Thebille AK, Tobergte J, Hübner S, Logacjov A, et al. (2019) Virtual or physical? Social robots teaching a fictional language through a role-playing game inspired by game of thrones. In: International conference on social robotics. Springer, pp 358–367
4. Allen K, Bergin R, Pickar K (2004) Exploring trust, group satisfaction, and performance in geographically dispersed and co-located university technology commercialization teams. In: VentureWell. Proceedings of open, the annual conference. National Collegiate Inventors and Innovators Alliance, p 201
5. Alves-Oliveira P, Ribeiro T, Petisca S, Di Tullio E, Melo FS, Paiva A (2015) An empathic robotic tutor for school classrooms: considering expectation and satisfaction of children as end-users. In: International conference on social robotics. Springer, pp 21–30
6. Aron A, Aron EN, Smollan D (1992) Inclusion of other in the self scale and the structure of interpersonal closeness. J Pers Soc Psychol 63(4):596
7. Austermann A, Yamada S (2008) "good robot","bad robot"-analyzing users' feedback in a human-robot teaching task. In: RO-MAN 2008—The 17th IEEE international symposium on robot and human interactive communication. IEEE, pp 41–46
8. Avelino J, Simão H, Ribeiro R, Moreno P, Figueiredo R, Duarte N, Nunes R, Bernardino A, Čaić M, Mahr D, et al. (2018) Experiments with vizzy as a coach for elderly exercise. In: Proc. workshop pers. robots exercising coaching-HRI conf. (PREC), pp 1–6
9. Baraka K, Alves-Oliveira P, Ribeiro T (2020) An extended framework for characterizing social robots. In: Human–robot interaction. Springer, pp 21–64
10. Bard N, Foerster JN, Chandar S, Burch N, Lanctot M, Song HF, Parisotto E, Dumoulin V, Moitra S, Hughes E et al (2020) The Hanabi challenge: a new frontier for AI research. Artif Intell 280:103216
11. Bartneck C (2003) Interacting with an embodied emotional character. In: Proceedings of the 2003 international conference on designing pleasurable products and interfaces, pp 55–60
12. Bartneck C, Kulić D, Croft E, Zoghbi S (2009) Measurement instruments for the anthropomorphism, animacy, likeability, perceived intelligence, and perceived safety of robots. Int J Soc Robot 1(1):71–81
13. Bowman ND, Banks J (2019) Social and entertainment gratifications of videogame play comparing robot, ai, and human partners. In: 2019 28th IEEE international conference on robot and human interactive communication (RO-MAN). IEEE, pp 1–6
14. Brooke J (1996) A quick and dirty usability scale. Usability evaluation in industry. Int J Hum-Comput Interact 189:4–10
15. Bukowski WM, Hoza B, Boivin M (1994) Measuring friendship quality during pre-and early adolescence: the development and psychometric properties of the friendship qualities scale. J Soc Pers Relat 11(3):471–484
16. Carpinella CM, Wyman AB, Perez MA, Stroessner SJ (2017) The robotic social attributes scale (ROSAS) development and validation. In: Proceedings of the 2017 ACM/IEEE international conference on human–robot interaction, pp 254–262
17. Chaspari T, Lehman JF (2016) An acoustic analysis of child-child and child-robot interactions for understanding engagement dur-

ing speech-controlled computer games. In: INTERSPEECH, San Francisco, CA, pp 595–599
18. Chita-Tegmark M, Law T, Rabb N, Scheutz M (2021) Can you trust your trust measure? In: Proceedings of the 2021 ACM/IEEE international conference on human–robot interaction, pp 92–100
19. Correia F, Petisca S, Alves-Oliveira P, Ribeiro T, Melo FS, Paiva A (2019) "i choose... you!" membership preferences in human–robot teams. Auton Robot 43(2):359–373
20. Correia F, Alves-Oliveira P, Maia N, Ribeiro T, Petisca S, Melo FS, Paiva A (2016) Just follow the suit! trust in human-robot interactions during card game playing. In: 2016 25th IEEE international symposium on robot and human interactive communication (RO-MAN). IEEE, pp 507–512
21. Correia F, Alves-Oliveira P, Ribeiro T, Melo F, Paiva A (2007) A social robot as a card game player. In: Proceedings of the AAAI conference on artificial intelligence and interactive digital entertainment, vol 13
22. Correia F, Guerra C, Mascarenhas S, Melo FS, Paiva A (2018) Exploring the impact of fault justification in human–robot trust. In: Proceedings of the 17th international conference on autonomous agents and multiagent systems, pp 507–513
23. Correia F, Mascarenhas S, Prada R, Melo FS, Paiva A (2018) Group-based emotions in teams of humans and robots. In: Proceedings of the 2018 ACM/IEEE international conference on human–robot interaction, pp 261–269
24. Curhan JR, Elfenbein HA, Xu H (2006) What do people value when they negotiate? Mapping the domain of subjective value in negotiation. J Pers Soc Psychol 91(3):493
25. Daniel E, Johan P, Staffan B (2005) Socially adaptable games. In: DiGRA & # 3905—Proceedings of the 2005 DiGRA international conference: changing views: worlds in play
26. Davis MH (1980) A multidimensional approach to individual differences in empathy. In: JSAS Cat Sel Doc Psychol 10(85)
27. de Haas M, Aroyo AM, Barakova E, Haselager W, Smeekens I (2016) The effect of a semi-autonomous robot on children. In: 2016 IEEE 8th international conference on intelligent systems (IS). IEEE, pp 376–381
28. de Haas M, Smeekens I, Njeri E, Haselager P, Buitelaar J, Lourens T, Staal W, Glennon J, Barakova E (2017) Personalizing educational game play with a robot partner. In: Robotics in education. Springer, pp 259–270
29. de Oliveira E, Donadoni L, Boriero S, Bonarini A (2020) Deceptive actions to improve the attribution of rationality to playing robotic agents. Int J Soc Robot 1–15
30. Edmondson A (1999) Psychological safety and learning behavior in work teams. Adm Sci Q 44(2):350–383
31. Egloff B (1998) The independence of positive and negative affect depends on the affect measure. Pers Ind Differ 25(6):1101–1109
32. Ertuğrul BS, Gurpinar C, Kivrak H, Kose H (2013) Gesture recognition for humanoid assisted interactive sign language tutoring. In: 2013 21st signal processing and communications applications conference (SIU). IEEE, pp 1–4
33. Fan J, Beuscher L, Newhouse P, Mion LC, Sarkar N (2018) A collaborative virtual game to support activity and social engagement for older adults. In: International conference on universal access in human-computer interaction. Springer, pp 192–204
34. Ferguson CJ, Negy C (2014) Development of a brief screening questionnaire for histrionic personality symptoms. Pers Ind Differ 66:124–127
35. Fong T, Nourbakhsh I, Dautenhahn K (2003) A survey of socially interactive robots. Robot Auton Syst 42(3–4):143–166
36. Francis LJ, Brown LB, Philipchalk R (1992) The development of an abbreviated form of the revised Eysenck personality questionnaire (EPQR-a): its use among students in England, Canada, the USA and Australia. Pers Ind Differ 13(4):443–449
37. Garcia-Salguero M, Monroy J, Galindo C, Gonzalez-Jimenez J (2019) Extending an assistance robot with the ability to play board games. In: Proceedings of the 2nd international conference on applications of intelligent systems, pp 1–6
38. Gillet S, Cumbal R, Pereira A, Lopes J, Engwall O, Leite I (2021) Robot gaze can mediate participation imbalance in groups with different skill levels. In: Proceedings of the 2021 ACM/IEEE international conference on human–robot interaction, pp 303–311
39. Gonzalez-Pacheco V, Ramey A, Alonso-Martín F, Castro-Gonzalez A, Salichs MA (2011) Maggie: a social robot as a gaming platform. Int J Soc Robot 3(4):371–381
40. Gosling SD, Rentfrow PJ, Swann WB Jr (2003) A very brief measure of the big-five personality domains. J Res Pers 37(6):504–528
41. Groom V, Chen J, Johnson T, Kara FA, Nass C (2010) Critic, compatriot, or chump?: Responses to robot blame attribution. In: 5th ACM/IEEE International Conference on Human- Robot Interaction (HRI), 211–217
42. Hamari J, Tuunanen J (2014) Player types: a meta-synthesis
43. Hansen ST, Krogsager A, Fredslund J (2017) A multimodal robot game for seniors. In: CEUR workshop proceedings. CEUR workshop proceedings, vol 2059, pp 9–18
44. Häring M, Kuchenbrandt D, André E (2014) Would you like to play with me? How robots' group membership and task features influence human-robot interaction. In: 2014 9th ACM/IEEE International Conference on Human- Robot Interaction (HRI), pp 9–16
45. Harms C, Biocca F (2004) Internal consistency and reliability of the networked minds measure of social presence
46. Heerink M, Kröse BJ, Evers V, Wielinga BJ (2010) Assessing acceptance of assistive social agent technology by older adults: the Almere model. Int J Soc Robot 2:361–375
47. Hendrick SS (1988) A generic measure of relationship satisfaction. J Marr Fam pp. 93–98
48. Hidi S (2000) An interest researcher's perspective: the effects of extrinsic and intrinsic factors on motivation. In: Intrinsic and extrinsic motivation. Elsevier, pp 309–339
49. Hinton G, Deng L, Yu D, Dahl GE, Mohamed A, Jaitly N, Senior A, Vanhoucke V, Nguyen P, Sainath TN et al (2012) Deep neural networks for acoustic modeling in speech recognition: the shared views of four research groups. IEEE Signal Process Mag 29(6):82–97
50. Ho CC, MacDorman KF (2017) Measuring the uncanny valley effect. Int J Soc Robot 9(1):129–139
51. Hoonhout J (2002) Development of a rating scale to determine the enjoyability of user interactions with consumer devices. Tech. rep., Technical report, Philips Research
52. Huizinga J (1938) Homo ludens. Random House
53. Iacob DO, Tapus A (2019) The impact of a robot game partner when studying deception during a card game. In: International conference on social robotics. Springer, pp 399–409
54. IJsselsteijn WA, de Kort YA, Poels K (2013) The game experience questionnaire. eindhoven: technische universiteit eindhoven
55. Jennett C, Cox AL, Cairns P, Dhoparee S, Epps A, Tijs T, Walton A (2008) Measuring and defining the experience of immersion in games. Int J Hum Comput Stud 66(9):641–661
56. Jerčić P, Hagelbäck J, Lindley C (2019) An affective serious game for collaboration between humans and robots. Entertain Comput 32:100319
57. Jian JY, Bisantz AM, Drury CG (2000) Foundations for an empirically determined scale of trust in automated systems. Int J Cogn Ergon 4(1):53–71
58. Johansson M, Skantze G, Gustafson J (2013) Head pose patterns in multiparty human–robot team-building interactions. In: International conference on social robotics. Springer, pp 351–360
59. Johnson DO, Cuijpers RH, Pollmann K, van de Ven AA (2016) Exploring the entertainment value of playing games with a humanoid robot. Int J Soc Robot 8(2):247–269

60. Jones DN, Paulhus DL (2014) Introducing the short dark triad (sd3) a brief measure of dark personality traits. Assessment 21(1):28–41
61. Jones C, Scholes L, Johnson D, Katsikitis M, Carras MC (2014) Gaming well: links between videogames and flourishing mental health. Front Psychol 5:260
62. Jost C, Grandgeorge M, Le Pévédic B, Duhaut D (2014) Robot or tablet: users' behaviors on a memory game. In: The 23rd IEEE international symposium on robot and human interactive communication. IEEE, pp 1050–1055
63. Kidd CD, Breazeal C (2004) Effect of a robot on user perceptions. In: 2004 IEEE/RSJ international conference on intelligent robots and systems (IROS) (IEEE Cat. No. 04CH37566), vol 4. IEEE, pp 3559–3564
64. Kim KM, Nan CJ, Ha JW, Heo YJ, Zhang BT (2015) Pororobot: a deep learning robot that plays video Q&A games. In: 2015 AAAI fall symposium series
65. Kim MG, Suzuki K (2011) Analysis of bluffing behavior in human-humanoid poker game. In: International conference on social robotics. Springer, pp 183–192
66. Kitano H, Asada M, Kuniyoshi Y, Noda I, Osawa E (1997) Robocup: the robot world cup initiative. In: Proceedings of the 1st international conference on autonomous agents, pp 340–347
67. Komatsu T, Yamada S, Kobayashi K, Funakoshi K, Nakano M (20120) Artificial subtle expressions: intuitive notification methodology of artifacts. In: Proceedings of the SIGCHI conference on human factors in computing systems, pp 1941–1944
68. Kose-Bagci H, Ferrari E, Dautenhahn K, Syrdal DS, Nehaniv CL (2009) Effects of embodiment and gestures on social interaction in drumming games with a humanoid robot. Adv Robot 23(14):1951–1996
69. Lamberti F, Cannavò A, Pirone P (2019) Designing interactive robotic games based on mixed reality technology. In: 2019 IEEE international conference on consumer electronics (ICCE). IEEE, pp 1–4
70. Lamberti F, Pratticò FG, Calandra D, Piumatti G, Bazzano F, Villani TR (2018) Robotic gaming and user interaction: impact of autonomous behaviors and emotional features. In: 2018 IEEE games, entertainment, media conference (GEM). IEEE, pp 1–9
71. Larzelere RE, Huston TL (1980) The dyadic trust scale: toward understanding interpersonal trust in close relationships. J Marr Fam 42:595–604
72. Leach CW, Van Zomeren M, Zebel S, Vliek ML, Pennekamp SF, Doosje B, Ouwerkerk JW, Spears R (2008) Group-level self-definition and self-investment: a hierarchical (multicomponent) model of in-group identification. J Pers Soc Psychol 95(1):144
73. Lee H, Kim H, Park KH, Park JH (2008) Robot learning by observation based on Bayesian networks and game pattern graphs for human–robot game interactions. In: 2008 IEEE/RSJ international conference on intelligent robots and systems. IEEE, pp 319–325
74. Leite I, Pereira A, Mascarenhas S, Martinho C, Prada R, Paiva A (2013) The influence of empathy in human-robot relations. Int J Hum Comput Stud 71(3):250–260
75. Leite I, Castellano G, Pereira A, Martinho C, Paiva A (2012) Modelling empathic behaviour in a robotic game companion for children: an ethnographic study in real-world settings. In: Proceedings of the 7th annual ACM/IEEE international conference on human–robot interaction, pp 367–374
76. Leite I, Pereira A, Lehman JF (2017) Persistent memory in repeated child-robot conversations. In: Proceedings of the 2017 conference on interaction design and children, pp 238–247
77. Leite I, Pereira A, Martinho C, Paiva A (2008) Are emotional robots more fun to play with? In: RO-MAN 2008-the 17th IEEE international symposium on robot and human interactive communication. IEEE, pp 77–82
78. Leyzberg D, Spaulding S, Toneva M, Scassellati B (2012) The physical presence of a robot tutor increases cognitive learning gains. In: Proceedings of the annual meeting of the cognitive science society, vol 34
79. Lombard M, Ditton TB, Crane D, Davis B, Gil-Egui G, Horvath K, Rossman J, Park S (2000) Measuring presence: a literature-based approach to the development of a standardized paper-and-pencil instrument. In: 3rd international workshop on presence, delft, the Netherlands, vol 240, pp 2–4
80. Looije R, van der Zalm A, Neerincx MA, Beun RJ (2012) Help, I need some body the effect of embodiment on playful learning. In: 2012 IEEE RO-MAN: the 21st IEEE international symposium on robot and human interactive communication. IEEE, pp 718–724
81. Lopez MG, Hasegawa K, Imai M (2017) Adaptive behavior generation for conversational robot in human–robot negotiation environment. In: Proceedings of the 5th international conference on human agent interaction, pp 151–159
82. Lopez-Samaniego L, Garcia-Zapirain B (2016) A robot-based tool for physical and cognitive rehabilitation of elderly people using biofeedback. Int J Environ Res Public Health 13(12):1176
83. Lupetti ML, Piumatti G, Germak C, Lamberti F (2018) Design and evaluation of a mixed-reality playground for child-robot games. Multimodal Technol Interact 2(4):69
84. Madsen M, Gregor S (2000) Measuring human-computer trust. In: 11th Australasian conference on information systems, vol 53. Citeseer, pp 6–8
85. Martínez-Miranda J, Pérez-Espinosa H, Espinosa-Curiel I, Avila-George H, Rodríguez-Jacobo J (2018) Age-based differences in preferences and affective reactions towards a robot's personality during interaction. Comput Hum Behav 84:245–257
86. McColl D, Louie WYG, Nejat G (2013) Brian 2.1: a socially assistive robot for the elderly and cognitively impaired. IEEE Robot Autom Mag 20(1):74–83
87. Mccroskey JC, Mccain T (1974) The measurement of interpersonal attraction. Commun Monogr 41:261–266
88. McCroskey JC, Teven JJ (1999) Goodwill: a reexamination of the construct and its measurement. Commun Monogr 66(1):90–103
89. Mendelson MJ, Aboud FE (1999) Measuring friendship quality in late adolescents and young adults: Mcgill friendship questionnaires. Can J Behav Sci 31(2):130
90. Nielsen J, Molich R (1990) Heuristic evaluation of user interfaces. In: Proceedings of the SIGCHI conference on Human factors in computing systems, pp 249–256
91. Nomura T, Kanda T, Suzuki T (2006) Experimental investigation into influence of negative attitudes toward robots on human–robot interaction. Ai & Soc 20(2):138–150
92. Oliveira EL, Orrú D, Morreale LL, Nascimento TP, Bonarini A (2018) Learning and mining player motion profiles in physically interactive robogames. Future Internet 10:22
93. Oliveira R, Arriaga P, Alves-Oliveira P, Correia F, Petisca S, Paiva A (2018) Friends or foes? Socioemotional support and gaze behaviors in mixed groups of humans and robots. In: Proceedings of the 2018 ACM/IEEE international conference on human–robot interaction, pp 279–288
94. Özgür A, Lemaignan S, Johal W, Beltran M, Briod M, Pereyre L, Mondada F, Dillenbourg P (2017) Cellulo: versatile handheld robots for education. In: 2017 12th ACM/IEEE international conference on human–robot interaction (HRI). IEEE, pp 119–127
95. Paetzel M, Castellano G (2019) Let me get to know you better: Can interactions help to overcome uncanny feelings? In: Proceedings of the 7th international conference on human-agent interaction, pp 59–67
96. Papadopoulos F, Dautenhahn K, Ho WC (2012) Exploring the use of robots as social mediators in a remote human–human collaborative communication experiment. Paladyn 3(1):1–10

97. Pasquali D, Gonzalez-Billandon J, Rea F, Sandini G, Sciutti A (2021) Magic icub: a humanoid robot autonomously catching your lies in a card game. In: Proceedings of the 2021 ACM/IEEE international conference on human–robot interaction, pp 293–302
98. Pereira A, Prada R, Paiva A (2012) Socially present board game opponents. In: International conference on advances in computer entertainment technology. Springer, pp 101–116
99. Pereira A, Prada R, Paiva A (2014) Improving social presence in human-agent interaction. In: Proceedings of the SIGCHI conference on human factors in computing systems, pp 1449–1458
100. Petisca S, Dias J, Alves-Oliveira P, Paiva A (2016) Emotional sharing behavior for a social robot in a competitive setting. In: 2016 25th IEEE international symposium on robot and human interactive communication (RO-MAN). IEEE, pp 730–735
101. Piumatti G, Lamberti F, Sanna A, Montuschi PA (2017) Robust robot tracking for next-generation collaborative robotics-based gaming environments. IEEE Trans Emerging Top Comput
102. Piumatti G, Sanna A, Gaspardone M, Lamberti F (2017) Spatial Augmented Reality meets robots: Human-machine interaction in cloudbased projected gaming environments. In: 2017 IEEE International Conference on Consumer Electronics (ICCE), pp 176–179
103. Popovic M, Milne D, Barrett P (2003) The scale of perceived interpersonal closeness (PICs). Clin Psychol Psychother: Int J Theory Pract 10(5):286–301
104. Poresky RH, Hendrix C, Mosier JE, Samuelson ML (1987) The companion animal bonding scale: internal reliability and construct validity. Psychol Rep 60(3):743–746
105. Pratticò FG, Baldo P, Cannavò A, Lamberti F (2019) Investigating tangible user interaction in mixed-reality robotic games. In: 2019 IEEE 9th international conference on consumer electronics (ICCE-Berlin). IEEE, pp 205–210
106. Pratticò FG, Cannavò A, Chen J, Lamberti F (2019) User perception of robot's role in floor projection-based mixed-reality robotic games. In: 2019 IEEE 23rd international symposium on consumer technologies (ISCT). IEEE, pp 76–81
107. Rammstedt B, John OP (2007) Measuring personality in one minute or less: a 10-item short version of the big five inventory in English and German. J Res Pers 41(1):203–212
108. Read JC, MacFarlane S (2006) Using the fun toolkit and other survey methods to gather opinions in child computer interaction. In: Proceedings of the 2006 conference on Interaction design and children, pp 81–88
109. Robert D, Breazeal C (2012) Blended reality characters. In: Proceedings of the 7th annual ACM/IEEE international conference on human–robot interaction, pp 359–366
110. Rothbart MK, Ahadi SA, Hershey KL, Fisher P (2001) Investigations of temperament at three to seven years: the children's behavior questionnaire. Child Dev 72(5):1394–1408
111. Sadouohi N, Pereira A, Jain R, Leite L, Lehman JF (2017) Creating prosodic synchrony for a robot co-player in a speech-controlled game for children. In: 2017 12th ACM/IEEE international conference on human–robot interaction (HRI). IEEE, pp 91–99
112. Sajó L, Ruttkay Z, Fazekas A (2011) Turk-2, a multi-modal chess player. Int J Hum Comput Stud 69(7–8):483–495
113. Samuel AL (1959) Some studies in machine learning using the game of checkers. IBM J Res Dev 3(3):210–229
114. Schaefer K (2013) The perception and measurement of human–robot trust
115. Sebo SS, Krishnamurthi P, Scassellati B (2019) "I don't believe you": investigating the effects of robot trust violation and repair. In: 14th ACM/IEEE International Conference on Human- Robot Interaction (HRI), pp 57–65
116. Serholt S (2018) Breakdowns in children's interactions with a robotic tutor: a longitudinal study. Comput Hum Behav 81:250–264
117. Serholt S, Barendregt W (2016) Robots tutoring children: longitudinal evaluation of social engagement in child-robot interaction. In: Proceedings of the 9th Nordic conference on human-computer interaction, pp 1–10
118. Shahid S, Krahmer E, Swerts M (2014) Child-robot interaction across cultures: How does playing a game with a social robot compare to playing a game alone or with a friend? Comput Hum Behav 40:86–100
119. Short ES, Swift-Spong K, Shim H, Wisniewski KM, Zak DK, Wu S, Zelinski E, Matarić MJ (2017) Understanding social interactions with socially assistive robotics in intergenerational family groups. In: 2017 26th IEEE international symposium on robot and human interactive communication (RO-MAN). IEEE, pp 236–241
120. Short E, Mataric MJ (2017) Robot moderation of a collaborative game: towards socially assistive robotics in group interactions. In: 2017 26th IEEE international symposium on robot and human interactive communication (RO-MAN). IEEE, pp 385–390
121. Short E, Swift-Spong K, Greczek J, Ramachandran A, Litoiu A, Grigore EC, Feil-Seifer D, Shuster S, Lee JJ, Huang S, et al. (2014) How to train your dragonbot: socially assistive robots for teaching children about nutrition through play. In: The 23rd IEEE international symposium on robot and human interactive communication. IEEE, pp 924–929
122. Silver D, Huang A, Maddison CJ, Guez A, Sifre L, Van Den Driessche G, Schrittwieser J, Antonoglou I, Panneershelvam V, Lanctot M et al (2016) Mastering the game of go with deep neural networks and tree search. Nature 529(7587):484–489
123. Skantze G, Johansson M, Beskow J (2015) Exploring turn-taking cues in multi-party human-robot discussions about objects. In: Proceedings of the 2015 ACM on international conference on multimodal interaction, pp 67–74
124. Sliwinski J, Katsikitis M, Jones CM (2015) Mindful gaming: how digital games can improve mindfulness. In: IFIP conference on human-computer interaction. Springer, pp 167–184
125. Smither RD, Houston JM (1992) The nature of competitiveness: The development and validation of the competitiveness index. Educ Psychol Measur 52(2):407–418
126. Spaulding S, Shen J, Park H, Breazeal C (2021) Towards transferrable personalized student models in educational games. In: Proceedings of the 20th international conference on autonomous agents and multiagent systems, pp 1245–1253
127. Strohkorb Sebo S, Traeger M, Jung M, Scassellati B (2018) The ripple effects of vulnerability: the effects of a robot's vulnerable behavior on trust in human–robot teams. In: Proceedings of the 2018 ACM/IEEE international conference on human–robot interaction, pp 178–186
128. Strohkorb S, Fukuto E, Warren N, Taylor C, Berry B, Scassellati B (2016) Improving human–human collaboration between children with a social robot. In: 2016 25th IEEE international symposium on robot and human interactive communication (RO-MAN). IEEE, pp 551–556
129. Suits B (1967) What is a game? Philos Sci 34(2):148–156
130. Sweetser P, Wyeth P (2005) Gameflow: a model for evaluating player enjoyment in games. Comput Entertain (CIE) 3(3):3–3
131. Taheri A, Meghdari A, Alemi M, Pouretemad H (2018) Human–robot interaction in autism treatment: a case study on three pairs of autistic children as twins, siblings, and classmates. Int J Soc Robot 10(1):93–113
132. Tan XZ, Vázquez M, Carter EJ, Morales CG, Steinfeld A (2018) Inducing bystander interventions during robot abuse with social mechanisms. In: Proceedings of the 2018 ACM/IEEE international conference on human–robot interaction, pp 169–177

133. Tapus A, Tapus C, Mataric M (2009) The role of physical embodiment of a therapist robot for individuals with cognitive impairments. In: RO-MAN 2009-The 18th IEEE international symposium on robot and human interactive communication. IEEE, pp 103–107
134. Thompson C, Mohamed S, Louie WYG, He JC, Li J, Nejat G (2017) The robot tangy facilitating trivia games: a team-based user-study with long-term care residents. In: 2017 IEEE international symposium on robotics and intelligent sensors (IRIS). IEEE, pp 173–178
135. Van Schaik P, Ling J (2005) Five psychometric scales for online measurement of the quality of human-computer interaction in web sites. Int J Human-Comput Interaction 18(3):309–322
136. Van der Hoorn DP, Neerincx A, de Graaf MM (2021) " i think you are doing a bad job!" the effect of blame attribution by a robot in human–robot collaboration. In: Proceedings of the 2021 ACM/IEEE international conference on human–robot interaction, pp 140–148
137. Vázquez M, May A, Steinfeld A, Chen WH (2011) A deceptive robot referee in a multiplayer gaming environment. In: 2011 international conference on collaboration technologies and systems (CTS). IEEE, pp 204–211
138. Vertesi A, Lever JA, Molloy DW, Sanderson B, Tuttle I, Pokoradi L, Principi E (2001) Standardized mini-mental state examination. Use and interpretation. Can Fam Phys 47(10):2018–2023
139. Wainer J, Robins B, Amirabdollahian F, Dautenhahn K (2014) Using the humanoid robot kaspar to autonomously play triadic games and facilitate collaborative play among children with autism. IEEE Trans Auton Ment Dev 6(3):183–199
140. Wainer J, Feil-Seifer DJ, Shell DA, Mataric MJ (2007) Embodiment and human–robot interaction: a task-based perspective. In: RO-MAN 2007—the 16th IEEE international symposium on robot and human interactive communication. IEEE, pp 872–877
141. Westlund JMK, Martinez M, Archie M, Das M, Breazeal C (2016) Effects of framing a robot as a social agent or as a machine on children's social behavior. In: 2016 25th IEEE international symposium on robot and human interactive communication (RO-MAN). IEEE, pp 688–693
142. Wongpakaran T, Wongpakaran N, Intachote-Sakamoto R, Boripuntakul T (2013) The group cohesiveness scale (GCS) for psychiatric inpatients. Perspect Psychiatr Care 49(1):58–64
143. Wrobel J, Wu YH, Kerhervé H, Kamali L, Rigau AS, Jost C, Le Pévédic B, Duhaut D (2013) Effect of agent embodiment on the elder user enjoyment of a game. In: ACHI 2013—the 6th international conference on advances in computer-human interactions
144. Xin M, Sharlin E (2006) Exploring human-robot interaction through telepresence board games. In: International conference on artificial reality and telexistence. Springer, pp 249–261
145. Yannakakis GN, Togelius J (2018) Artificial intelligence and games, vol. 2. Springer
146. You S, Robert Jr LP (2018) Human–robot similarity and willingness to work with a robotic co-worker. In: Proceedings of the 2018 ACM/IEEE international conference on human-robot interaction, pp 251–260
147. Zaga C, Lohse M, Truong KP, Evers V (2015) The effect of a robot's social character on children's task engagement: peer versus tutor. In: International conference on social robotics. Springer, pp 704–713
148. Zimmerman E, Salen K (2003) Rules of play. MIT Press