



Human–dog relationships as a working framework for exploring human–robot attachment: a multidisciplinary review

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Abstract

Robotic agents will be life-long companions of humans in the foreseeable future. To achieve such successful relationships, people will likely attribute emotions and personality, assign social competencies, and develop a long-lasting attachment to robots. However, without a clear theoretical framework—building on biological, psychological, and technological knowledge—current societal demands for establishing successful human–robot attachment (HRA) as a new form of inter-species interactions might fail. The study of evolutionarily adaptive animal behavior (i.e., ethology) suggests that human–animal behaviors can be considered as a plausible solution in designing and building models of ethorobots—including modeling the inter-species bond between domesticated animals and humans. Evidence shows that people assign emotional feelings and personality characteristics to animal species leading to cooperation and communication—crucial for designing social robots such as companion robots. Because dogs have excellent social skills with humans, current research applies human–dog relationships as a template to understand HRA. Our goal of this article is twofold. First, we overview the research on how human–dog interactions are implemented as prototypes of non-human social companions in HRA. Second, we review research about attitudes that humans have for interacting with robotic dogs based on their appearance and behavior, the implications for forming attachments, and human–animal interactions in the rising sphere of robot-assisted therapy. The rationale for this review is to provide a new perspective to facilitate future research among biologists, psychologists, and engineers—contributing to the creation of innovative research practices for studying social behaviors and its implications for society addressing HRA.

Keywords Attachment · AIBO · Dog · Social robotics · Ethorobotics · Uncanny valley

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Ethorobotics: a promising path to model human–robot attachment

Social robotics and the “uncanny valley” hypothesis

The latest advances in parallel and distributed computing have led to significant efforts in investigating human robot interaction (HRI). These advances have created a burgeoning and more sophisticated focus on human–robot attachment (HRA). Specifically, researchers and engineers design and build mobile, autonomous robots as social actors who are capable of a wide array of social behaviors in therapeutic, educational, and entertainment environments (Dautenhahn 2007; Fong et al. 2003). Social robots include the following three key dimensions as vital factors for HRIs: *anthropomorphism*, *emotion*, and *personality* (Fong et al. 2003). The employment of *anthropomorphic elements* utilized in the form of face-shaped objects or human-like speech (Baron-Cohen et al. 1995; Cooper and Aslin 1990; Duffy 2003; Fernald 1992), the recognition and manifestation of *internal emotional states* based on verbal and non-verbal indicators (Brooks 2002), and the expression of a *captivating personality* materialized as physical attributes, motion patterns, and communication styles (Breazeal and Aryananda 2002; Kiesler and Goetz 2002) trigger a natural evolutionarily human response (Bloom and Veres 1999; Dautenhahn and Werry 2004; Heider and Simmel 1944). *Human-likeness* mimics the embodiment, and social interaction can be implemented in various types of “human-like” robots (Kanda et al. 2009; MacDorman and Ishiguro 2006): *humanoids* aim to resemble the human’s posture and fundamental anatomy (although still representing a machine-like appearance); *androids* aim to represent a detailed copy of a human’s body (e.g., application of human-like skin); and *geminoids* aim to display duplicates of real people (Becker-Asano et al. 2010). However, there is more than one approach to robotic design. In this review, we provide a new perspective to facilitate future research among biologists, psychologists, and engineers—contributing to the creation of innovative research practices for studying social behaviors and its implications for society addressing HRA. In doing so, we begin with discussing the exciting new discipline of ethorobotics. Next, we tie in how companion dogs can serve as the guiding relationship for future research. We then review research on the ethorobotic dog AIBO and how AIBO has been used in animal-assisted therapy. We conclude with the current outlook and future directions for HRA with social robots.

Ethology—the scientific study of animal behavior seen as evolutionarily adaptive traits—focuses on the purpose of behavior linked to the precise natural settings

throughout the evolution of a species (Miklósi et al. 2017; Tinbergen 1963). Ethorobotics is a relatively new concept originated by Miklosi and colleagues based on recent progress in HRI that integrates ethological, ecological, and evolutionary principles toward the development of social robots (Miklósi et al. 2017). In essence, ethorobotics facilitates the application of the biological rules of animal behavior to build new interactive robotic systems. Ethorobotics was inspired by the “uncanny valley” (Miklósi et al. 2017; Mori 1970). When social robots are created to fully act as “human-like” actors—but are still not quite perfect—their subtle imperfections can cause dismay and evoke revolt from users—a phenomenon recognized as “*uncanny valley*” (Mori 1970) or the “*zombie effect*” (Dautenhahn et al. 2002; Fong et al. 2003). Describing the relationship between human affinity toward the (biological or artificial) agent and an agent’s human similarity, social robotics develops in time—i.e., from left to right having two local maximum values—to design human-like robots (i.e., human likeness) (Fig. 1) (Miklósi et al. 2017). The medium peak occurs when robotic agents have a sufficient but not entire similarity (60–75%) to humans, while the maximum peak arises when robotic agents reach nearly perfect similarity to humans (Mori 1970). The “uncanny valley” hypothesis proposes that social robots may never reach the “maximum peak” (i.e., ideal humanness) because robots getting very similar to humans are being more rejected by users than less similar ones (Mori, 1970).

Instead of climbing the “maximum peak” for building more human-like robots, researchers can circumvent the “maximum peak”—preventing the “uncanny valley”—by creating social robots that are capable of maximizing their

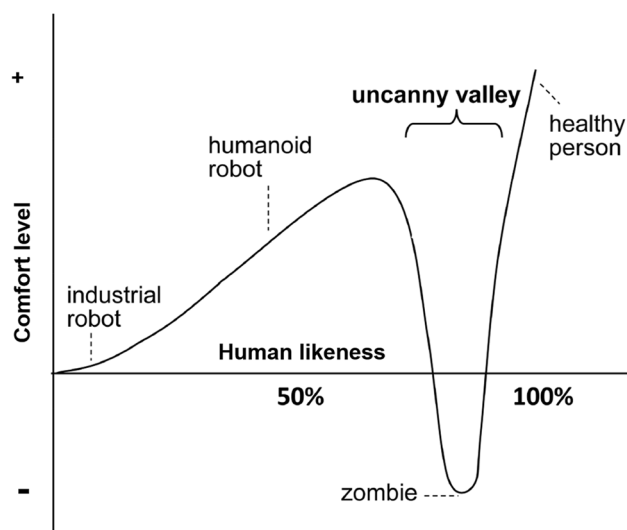


Fig. 1 ‘Uncanny valley’ hypothesis [adjusted from (Miklósi et al. 2017)]

performance for specific functions in its specific environments (Konok et al. 2018). When such *ethorobots* are equipped with specific functions concerning socio-cognitive and behavioral characteristics—e.g., functioning as an attached companion for individuals with limited caretaking capabilities and social interaction—then humans will approach them separately from its human resemblance (Pineau et al. 2003). Those *ethological robots* would occupy a different *social niche*, specific to its function, and evolve without competing with humans (Miklósi et al. 2017). Consequently, robotic engineering could advance by changing between different types of robotic agents without being restricted by the evolutionary continuity of human agents (Miklósi and Gácsi 2012).

Based on an ethological approach, shared interactions with other species during human history can provide behavioral prototypes for social robotic agents (Miklósi and Gácsi 2012). Hence, *human–animal interactions* can serve as plausible alternatives for human-like robots as models of social robotic agents (Korondi et al. 2015). HRIs based on *inter-* rather than *intra-species relationships* are less complex, and simpler to employ in social robots (Konok et al. 2018). An inter-species focus on a functional approach emphasizes the goal that robotic agents are not built for a social state per se but rather for a social process, such as attachment (Miklósi et al. 2017), where the relationship type is not a given feature of a robot but more a consequence of meaningful social interaction between agents (Fujita 2007; Miklósi and Gácsi 2012). This review will examine the foundation of using dog–human relationships as the inspiration for social robotic design and HRA.

Dogs as prototypes for human–robot attachment

Social behaviors in both non-humans and humans have evolved to contribute to the survival of the species (Székely et al. 2010). At the practical stage, social behaviors fulfill unique behavioral purposes and share some commonalities among distinct organisms because of changes in evolution (Fitch et al. 2010). Hence, social interactions can be characterized not only within but also between species (Colgan 1983; Miklósi and Gácsi 2012; Podberscek and Gosling 2000; Serpell et al. 1996). These interactions for humans may have arisen in communities of hunter-gatherers who came in contact with the infant offspring of the chased animals (Clutton-Block 1995).

While there has been multiple genetic studies regarding dog domestication, there is not yet a widely accepted time or location of domestication (Ostrander et al. 2019; von Holdt et al. 2010). The emergence of domesticated animals such as dogs and cats has led to companion animal-keeping habits in humans, which has grown immensely and shifted in purpose—likely resultant of the intensely social character of

human beings (Irvine and Cilia 2017). For example, domesticated animals might have been one of the first opportunities for children to develop their nursing and caring abilities outside of the role of sibling caretakers (Hrdy 2000). Companion animals tend to be the best aspirant for modeling HRIs and HRA since they can establish positive human social experiences (Miklósi and Gácsi 2012).

Owners typically have long-lasting and personalized partnerships toward their animals, which is a goal of designing social robots. Companion animals contribute to socializing people who may have witnessed a decline in social interactions (e.g., sick people), been excluded from society (e.g., homeless people), or become lonely throughout their life (e.g., widowers) (Albert and Bulcroft 1988). Consequently, human–animal relationships could provide a useful non-human model for a wide variety of robots as companions (Bensky et al. 2013; Dautenhahn and Werry 2004; Korondi et al. 2015; Miklósi and Gácsi 2012; Morell 2009).

Dogs are the most popular companion animal among household animals; they encompass excellent social competence with humans because of a successful adaption to the human landscape (Kubinyi et al. 2007; Miklósi and Topál, 2013; Topál et al. 2009). Dog domestication induced some major anatomical, morphological, and behavioral changes, which improved social relationships with humans (Hare and Tomasello 2005; Miklósi 2014). Dogs' specific environments for contact with humans emerged during domestication, while both species retained their autonomous ability to adapt with minimal competition between them (Gácsi et al. 2013). Having specific preferences for recognizing human-based signals (Hare and Tomasello 2005; Reid 2009), dog breeds were chosen for specific reasons, including assisting in human activities and helping disabled individuals (Gácsi et al. 2016; Miklósi 2014).

The evolved behavioral traits and behaviors have tightened *social relationships*, improved *social communication*, and enhanced *cooperative interactions* for human–dog relationships (Csányi 2000; Topál et al. 2009). Dogs can respond to gestural and auditory signals given by humans (Kaminski et al. 2009; Soproni et al. 2002), form human-like personalities (Gosling et al. 2003; Turcsán et al. 2012), and establish bonding partnerships (Gácsi et al. 2001; Valsecchi et al. 2010). Human beings can effectively identify emotional gestures (Bloom and Friedman 2013; Pongrácz et al. 2006; Walker et al. 2010), assign complex emotions (Hecht et al. 2012), and describe personalities to their canine companions (Gosling et al. 2003; Turcsán et al. 2012). Significantly, humans can form deep, long-term bonds with their dogs (Archer and Ireland 2011)—often considering them as members of their family (Berryman et al. 1985; Kubinyi et al. 2009).

The bond between a human infant and the child's caregiver is typically described as *attachment*—fulfilling an

evolutionary function (e.g., parental care) (Bowlby 1972; Fraley and Roberts 2005; Immerman and Mackey 2003). These attachment relationships from childhood continuously enrich human life through adulthood and are characterized by specific behaviors, including protest and avoidance of feelings of social isolation in challenging situations. Dogs may also form a bond with their owners, behaviorally similar to that between the child and the caregiver, including seeking protection in case of danger, increased demand for communication, and protest when being separated from the owner (Gácsi et al. 2001; Prato-Previde et al. 2003; Topál et al. 1998).

In recent times, the attachment concept has likewise been applied to HRI. In the near future, people will also live with social robots as long-term companions; therefore, they have to accept and see them as social partners capable of emotionally bonding. In the setting of HRI, bonding can be regarded as the amount of a user's emotional interactions with a robot within three dimensions: *visceral level* (e.g., first-time impression through appearance), *behavioral level* (e.g., satisfaction of the robot's features for the user), and *reflective level* (e.g., recall past experiences and utilize them for future actions) (Birnbaum et al. 2016; Herath et al. 2013). Using a dog model can generate emotional expressions without adding unique, otherwise non-functional features to social robots (Gácsi et al. 2016). These ethorobots should effectively carry out behaviors appropriate for their particular purpose (e.g., helping elderly people and people with disabilities) and show credible communicative skills when cooperating with humans—a skill set found in dogs (Miklósi et al. 2017). These similarities between humans and robots regarding social skills—*openness to learn* (Topál et al. 2009), *interactive communication* (Gaunet and Masioui 2014; Miklósi and Gácsi 2012), and *social attachment* (Topál et al. 2005)—should be adequate to form a foundation for social interaction and future attachment.

The dog has been effectively incorporated in HRI studies as a model for *non-human companions* (Ichikawa et al. 2012; Koay et al. 2013; Kovács et al. 2009; Lakatos et al. 2014; Syrdal et al. 2010). For example, a robot was built using a Roomba vacuum cleaner system that represented a crudely canine entity (e.g., fitted with a tail and capable of making barking sounds) and exhibited certain dog-like behavioral traits while interacting with people (Jones et al. 2008). Other research has been published on a blind-guide-dog-inspired robot (Tachi et al. 1985) or a robot designed to help disabled individuals (Nguyen et al. 2008). In the former investigation, the embodiment of the robot did not mimic a dog but used an arm for actions (that could be controlled verbally) that the dog typically does by mouth.

In summary, robotics strives to produce social robots that fulfill users' needs, but modern society does not embrace today's robots due to their restricted skills that undermine

their human-like nature (Mori 1970). The emerging field of ethorobotics provides a different approach, proposing that social robots should be treated as distinct organisms highly suited to their environment, in which their human similarity is insignificant (Miklósi et al. 2017). Ethorobots provide several advantages for human society. No reasons exist to compete with ethorobots as human agents can retain power by manipulating the essence of the relationship. People have the required abilities to adapt their social interactions to robots if those exhibit simple social skills and form attachments as they do with companion animals due to their similar social skill levels.

As one of these ethorobots, this review will highlight Sony's AIBO as a prototype for HRA. While AIBO is physically inspired by dogs, its embodiment is of secondary importance in terms of ethorobotics. AIBO's ability to fulfill the purpose of social companionship via both non-verbal dog-like communication and non-dog-like behaviors is key to its definition as an ethorobot (Abdai et al. 2018).

AIBO

Sony's AIBO—a prototype for human–robot attachment

The next type of autonomous entertainment robot is primarily built to interact with humans that have the propensity to provoke attachment (Donath 2004; Kaplan 2001). Other types of autonomous robots act as educators for children (Billard 2003), museum-guides for visitors (Nourbakhsh et al. 1999; Burgard et al. 1999), and co-therapists for patients (Dautenhahn et al. 2002). The release of these commercial robots supports the assumption that they soon could become common in our everyday environments. This forecast has prompted some studies into the acceptability and perspectives these types of robots produce among human beings (Fong et al. 2003). A new technological category is on the horizon—embodied, autonomous, and personified robots—that will contradict conventional ontological distinctions between animate and inanimate.

Robots are classified as '*zoomorphs*' if they mimic live, current, or imaginary animals. For instance, one of the earliest 'electric dogs'—i.e., radio-controlled robot representing a box rolling on three wheels—was built in 1912. Since then, several high-profile social robotics companies aim at designing and selling social robots specifically intended to serve as long-term companions. These robots—including Paro, Kaspar, the 'Joy for all' robotic pet line, Pepper, and Jibo—are designed with either therapeutic or companionship benefits in mind. Most of them do not fulfill the description of an ethorobot by either physical manifestation or sophistication of communication (Émond et al. 2020; Schrum et al. 2019;

Thunberg et al. 2020; Wada et al. 2010; Wood et al. 2019). One of the most advanced robots of this type entails Sony's dog-like robot AIBO—an acronym for Artificial Intelligence roBOt—meaning in Japanese language “friend,” “pal,” or “companion” (www.sony.com). Introduced in 1999 for the commercial market, until 2006, more than 150,000 robots were sold worldwide over 3 successive AIBO generations (consisting of 8 versions with 23 subtypes). However, Sony discontinued AIBO's production in 2006 and stopped software updates and maintenance in 2014. After years of re-designing, Sony commercially released the fourth generation of the AIBO Entertainment Robot in 2018—designed to be the most advanced “autonomous robot” dog available and commercialized as a “perfect partner with true emotion and intuition” (Fig. 2).

AIBO's behavior is specifically modeled after dog behavior (Arkin 2001)—based on an ethologist-promoted behavioral method approach (Tinbergen 1951; Timberlake 1994). AIBO mimics a small dog's body—including a dog-like metallic architecture with flexible body parts as well as a set of sensors (i.e., microphone, camera, touch sensors)—that allows users to interact by discriminating punitive strokes from affectionate pats. Besides having a movable tail, head, and ears to express dog-like behaviors, AIBO's two expressive OLED eyes display inner mental states to its face, and varying sounds express tiredness, frustration, or enthusiasm. The user can interact with AIBO in two ways: through voice commands and pressure sensors. AIBO has speech recognition, executes about 30 commands given per voice (e.g., sit, lie down, and turn), and takes digital pictures with a camera located in the nose. AIBO recognizes its name after being recorded and responds with computerized sounds when named.

AIBO can sit or lie down, get up, or walk similarly to a real dog. It can further be taught to perform basic behaviors (Kaplan et al. 2002) and is able to learn after experiencing unfamiliar situations (Oudeyer et al. 2005). AIBO is a lifetime companion—through its technological infrastructure—it evolves slowly from a puppy, adolescent, to a fully

grown adult dog. Although it is autonomous, the combination of AIBO's behavior and interaction with his owner produces its personality and facilitates attachment—no two AIBOs are ever alike. Via repeated touch, AIBO learns to avoid (repeat) actions that have been punished with a brief and robust strokes. AIBO cannot only initiate dog-like interactions with humans (e.g., offering its paw) but can also change its future actions based on human feedback. Finally, the new AIBO generation can store and expands its ‘mind’ into the cloud, and hence, can also be operated and played with remotely (Knox and Watanabe 2018).

Because of these capacities, AIBO has been utilized in many research projects with two general research agendas: (1) questionnaires exploring if people consider AIBO as a “real” companion animal and the feelings allocated to this robotic dog and (2) observation of HRI based on behavior analyses (Bartneck et al. 2007; Friedman et al. 2003; Kahn Jr et al. 2002; Kertész and Turunen 2019; Melson et al. 2005). The design of AIBO incorporates key components of dog–human interaction and dog-like communication as a framework for human–robot attachment. By imitating a dog–human relationship, which is behaviorally similar to that of a human–child relationship, AIBO is able to access built-in biological and emotional responses to its behavior. Indeed, the schemata by which this ethorobot makes choices is dependent on sensor activation, previously activated schemata, and emotion, instincts, and user expectation (Kaplan et al. 2002). These schemata are organized into hierarchical trees and are activated in terms of general goals (Kaplan et al. 2002). This aligns at the very least with human expectation of dog decision-making (Kaminski et al. 2009; Kosfeld et al. 2005; Marshall-Pescini et al. 2012; Sanders 1993; Turcsán et al. 2015).

Studies investigating attitudes and behavioral interactions with AIBO

Assuming that autonomous social robots will inhabit human beings' daily living space as attached heterospecifics in the

Fig. 2 Sony AIBO. Fourth (current) generation (a) and first to third generations (b) (adjusted from Kertész and Turunen 2019)



foreseeable future, it is crucial to investigate the human attitude toward interacting with a diverse range of robots founded on how they are received and communicate. Contrasting people's beliefs regarding robotic dogs and live dogs, most customers will not buy a companion animal robot because they believe that robots cannot be enjoyed as dogs are—being able to express emotions, personality, and attachment (Konok et al. 2018). Numerous research investigations concentrate on surveys from children or adults engaging with AIBO (as opposed to actual or stuffed dogs) and how both groups perceive and attribute social and ethical stances as well as ascribe emotions and attachment to the robotic dog. Besides investigating attitudes about AIBO, behavioral analysis of HRIs can help in inventing interactive robots because the chronological sequence of interaction is a reliable predictor of the ascribed attitudes and the potential for attachment (Table 1).

An online analysis of discussion-forum posts showed that AIBO psychologically engages its adults' owners as seen by ascribing 49% life-like essences, 59% social rapport, 60% mental states, and 75% technological essences (Friedman et al. 2003). Users neither think that AIBO is alive nor ascribe moralistic aspects to it, even if they assign social, psychological, and biological characteristics to the robotic dog. In contrast, interviews about AIBO revealed that although children distinguish the live from the robotic dog, they still ascribe mental, emotional, and moral characteristics to the robotic companion animal (Melson et al. 2005). Other research reveals that although children agree that anthropomorphic toys with different levels of interactivity are not realistic, they regard more interactive toys (including AIBO) as having actual and deliberate qualities (Francis and Mishra 2009). Moreover, independent of both the look and the behavior of the robots, younger children

Table 1 Studies investigating human attitudes and/ or behavioral interactions with the robotic dog AIBO

Study	Participants	Exposure	AIBO Model	Control	Measure
Bartlett et al. (2004)	Children: $n = 242$, 3–10 years	1 (30–60 min)	ERS-210 + ball	No control	Video/audio, observation
Francis & Mishra (2009)	Children: $n = 25$ (9 F), 3–8 years	12 (10–31 min)	N/A	Stuffed dog, Mechanical cat	Video
Friedman et al. (2003)	Adults: $n = 6438$	N/A	ERS-110/111, ERS-210	N/A	Online discussion-forum postings
Fujita (2004)	Adults: $n \sim 4000$, > 20–60 years	N/A	ERS-110/111, ERS-210, ERS-311/312	N/A	Online discussion-forum posting
Kahn et al. (2006)	Children: $n = 80$ (40 F), 3–6 years	1 (~15 min)	ERS-210	No, stuffed dog used	Video/audio, questions
Kerepesi et al. (2006)	Children: $n = 28$ (14 F), 6–8 years Adults: $n = 28$ (14 F), 18–22 years	1 (5 min)	ERS-210 + ball	Dog puppy	Video (Themecoder)
Kertész and Turunen (2019)	Adults: $n = 78$ (19 F)	N/A	N/A	N/A	Online questionnaire
Lee et al. (2005)	Adults: $n = 40$ (20 F), 19–24 years	4 (30 min)	N/A	N/A	Questionnaire
Melson et al. (2009)	Children: $n = 72$, 7–15 years	1 (5 min)	ERS-210	Large-sized dog	Video/audio, Interview
Okita & Schwartz (2006)	Children: $n = 32$, 3.5–5.5 years	1 (10–15 min)	ERS-210, ERS-220A, ERS-311	No control	Video/audio, questions
Pepe et al. (2008)	Adults: $n = 29$ (20 F), 18–45 years	1	ERS-7	Small-sized dog	Audio
Ribi et al. (2008)	Children: $n = 14$ (6 F), 3–6 years	11 (5 min)	ERS-210 + ball	Small-sized dog	Observation
Schellin et al. (2020)	Adults: $n = 33$ (12 F), 18–26 years	1 (10 min)	ERS-1000	AIBO in fur suit	Video/audio, questionnaire
Sinatra et al. (2012)	Adults: $n = 111$ (75 F), 18–26 years	1 (5 min)	ERS-7	Dog, Cat, Legobot	Video, audio
Weiss et al. (2009)	Children: $n = 129$ (70 F), 3–15 years Adults: $n = 18$ (6 F), 21–68 years	1 (1–20 min)	ERS-7 + ball & bone	No control	Video, observation, questionnaire

n number of participants, f female, min minutes, N/A not applicable

over-simplify their animistic preconceptions about living animals in comparison to older children—indicating that children progressively recategorize the robot as they discover distinct details about how technology varies from living objects (Okita and Schwartz 2006). Furthermore, when comparing attitudes toward AIBO and other robots, children perceive AIBO as a “robotic companion animal” (whereas adults interpret it to be less similar to dogs but more to machines) and use pronouns such as “s/he” instead of “it” when communicating with AIBO—indicating that children see aspects of the animal and the machine in this novel technical artifact based on their concepts and language formations (Bartlett et al. 2004).

Another study showed parallel patterns in preschool-age children thinking about AIBO and a stuffed dog: biological properties (46%), moral standings (63%), mental states (66%), and social rapports (76%) (Kahn et al. 2006). Compared to the “stuffed dog,” however, children differ in their interpersonal encounters with AIBO by engaging in more exploration and hesitant behavioral habits, attempts at reciprocity, and less mistreatment of AIBO after an initial play session. Moreover, user experience was examined in an online questionnaire-based study through the lens of several key criteria: gender, age, culture, and length of ownership (Kertész and Turunen 2019). Women are more likely to ascribe emotional value to AIBO, while men are more attentive to the technological aspects of ownership. Although age plays no major part in the perception of the robotic dog, older age groups use more “negative” descriptors when describing AIBO. Within the scope of this study, Westerners have an overall more positive view of robots, whereas the Japanese have more concerns about the robots’ role in society. AIBO owners did not experience a decrease in utility value over time—indicating that emotional attachment could play a role in their perception of AIBO.

One investigation revealed that when children were visited for 11 weeks (once in a week) first with a live dog and then with AIBO, no differences in contact initiation were observed between the two entities (Ribi et al. 2008). Over the observation period, the children more often initiated approaches to AIBO, whereas the live dog approached the children more often than AIBO. Overall, most children preferred the dog to AIBO and stroked it more frequently than AIBO, but the dog was less often touched than AIBO. In another study, comparing the natural, free form of communication while interacting with robotic artifacts such as Legobot and AIBO in comparison to live animals, such as a cat and dog, adults did not prefer live entities as a default because AIBO was often rated and communicated with similarly to the cat, although overall the dog was considered more competent and directly addressed more compared to the cat and the artifacts (Sinatra et al. 2012). Further, adults were less positive toward AIBO when framed

as a puppy instead of a robot, and it was considered less “scary” after being dressed in a fur suit compared to having no fur (Schellin et al. 2020). Although adult reactions during encounters with a live and robotic dog appear identical, they assign more desirable traits (e.g., affectionate, responsive) and apply a higher voice level for commands when they think that they are leading a live dog instead of AIBO through a labyrinth (Pepe et al. 2008). Finally, both children and adults terminated T-patterns (i.e., a complex repeated temporal pattern for completing a given task for human–dog interactions) more frequently due to AIBO’s slower movement when playing freely compared to a live puppy (Kerepesi et al. 2006).

Evaluating the perceived relationship with AIBO, most consumers (70–80%) have a close bond to their robotic companion animal, and a decent number of owners (33%) continue playing with AIBO in their daily lives (Fujita 2004). Further, about 26% of users consider AIBO as a playmate, and about 42% have feelings toward AIBO—indicating that the attachment between users and their robotic dogs is comparable to the bond owners have with their living dogs (Weiss et al. 2009). In assessing emotional attachment, children have more positive attitudes toward AIBO in comparison to adults: they assign more cognitive abilities (e.g., AIBO can see [76%] and understand [78%] them, has emotional feelings (e.g., AIBO may be happy [99%] or sad [87%]), attachment (e.g., AIBO could be a playfellow [91.6%] and a companion while alone at home [90.2%])). Finally, over a month of research, the impact of AIBO’s long-term artificial development on owners’ sense of social presence and reactions was examined. The capacity of AIBO to evolve from a “puppy” to a “dog” enhanced the understanding of AIBO as a living being and resulted in higher feelings of social engagement and reactions toward AIBO (Lee et al. 2005).

In summary, users characterize their relation to AIBO to some degree in an analogous way as to a living dog, assign animal traits to it, treat it as a social “friend,” and regard it as part of the family, a key assessment for human–animal attachment. However, when examining the behavior of owners, the studies revealed that they respond somewhat differently while interacting with AIBO or a living dog and regard it as a technological artifact that embodies characteristics of living animal species. AIBO’s interactive capacities allow the robotic companion animal to appear to behave intentionally, which leads to mental characteristics and attributions—starting from essence and advancing to an agency, over social to moral standing (Kahn Jr et al. 2002). AIBO fulfills *animistic biological underpinnings* (e.g., referring to its embodiment and behaviors similar to real companion animals), *agency properties* (e.g., attributing intentions, feelings, emotional states, wishes, desires, and goals), *social standings* (e.g., ascribing an emotional connection and

companionship), and *moral standings* (e.g., holding morally accountable for actions). The studies indicate that a new technology category is arising—children are constructing new conceptual categories for personified artifacts—that challenge conventional ontological genres. Based on those research findings, future HRI studies should focus specifically on the feelings of social presence and emotional attachment when building social robots.

The reported studies had limitations in terms of design and methodology. Most investigations were underpowered and unbalanced for gender (Ioannidis 2005; Kerepesi et al. 2006; Ribí et al. 2008; Sinatra et al. 2012). Further, various findings were restricted to single exposure observations, while the true value of those investigations would be increased if multiple exposures were included over a longer time frame. Moreover, little care has been made to track differences in the type of actions recorded for AIBO compared to a live dog, and in most cases, the activities for both agents were not recorded. Also, little effort was made to manage differences in familiarity and experience that might trigger differences in approach or resistance behavior for either the robotic agent or animal agent. Last but not least, although most experiments contrasted an experimental (AIBO) with a control condition (live dog), the observed disparities between the two agents relied on different dependent variable measures used to capture the agents' behavior.

These experiments and surveys offer a foundation for future investigations comparing a social human–robot with human–dog interactions and evaluating attitudes toward robotic agents as an antecedent to forming attachments by self-reported measures, behavioral analysis, and hormonal measures. For example, a more effective approach would be to compare differently behaving AIBOs (Okita and Schwartz 2006) rather than contrasting AIBO with a real dog as owners can differentiate between AIBOs that either behave “introvertly” or “extrovertly” after play (Lee et al. 2006). Moreover, more long-term experiments are needed to expose social robots' daily functionality and limitations (Kidd and Breazeal 2006). Finally, teaching techniques for autonomous robots could be applied. A promising technique for teaching behavioral sequences and uncommon behaviors for robotic companion animals include robotic clicker training—a technique used by animal trainers to direct animals toward specific activities (e.g., Kaplan et al. 2002). This type of training provides a clear demonstration of how robotics may benefit from ethology.

Studies investigating animal-assisted therapy with AIBO

In the United States, approximately 75 percent of households with children under the age of 18 have domestic companion animals—making dogs and/or cats a significant contributor

to these children's ecological growth (Melson et al. 2009). A plethora of medical and psychological literature exists that demonstrates the benefits of having a companion animal, such as enhancement of social-emotional skills and empathy toward others (Ribí et al. 2008). Further, the formation of a bond with a companion animal is favorably linked with increased self-esteem in kindergarten children (Bergesen 1989). Children who own a companion animal have a more favorable view of companion animals in general (Beck et al. 1989). Animal lovers, for instance, are less likely to feel isolated and distressed and more likely to have satisfying relationships with others (Sparrow 2002). Interacting with companion animals leads to an acute, physiologically calming state of relaxation that makes owners happier, and improves their psychological and physiological well-being (Sparrow 2002). Owners need to take their companion animals to regular checkups, walks, and grooming—those chores provide ways to socialize with other people and help to reduce the feelings of loneliness and social isolation. However, it should be noted that there are many studies with opposite outcomes than the ones highlighted above, including increased BMI in pet owners, lowered survival rates after a cardiovascular event, and higher reported incidence of depression, anxiety, and other disorders (Koivusilta and Ojanlatva 2006; Müllersdorf et al. 2010; Parslow et al. 2005). Despite these findings, the majority of owners report they benefit from ownership and the relationship forged with their companion animal (Herzog 2011). The inconclusive results of many of these studies could be explained by poor methodological rigor, small and homogenous sample sizes, and small effect sizes (Ioannidis 2005).

Owing to the fact that companion animal owners believe that the mutual attachment improves health and psyche, *animal-assisted therapy* (AAT) has become a popular form of therapy (Tamura et al. 2004), in which children, elderly, and patients engage with companion animals in the form of recreation or therapeutic care. The effectiveness of AAT in healing includes physiological (e.g., improved blood pressure), psychological (e.g., reduced depression symptoms), cognitive (e.g., improved memory), and socio-emotional (e.g., improved communication with others) effects (Fujita 2004). A meta-analysis of AAT finding found moderate effects for improving autistic, medical, and psychological symptoms (Nimer and Lundahl 2007). In contrast, animal health concerns, varying cultural beliefs about animals, uncertainties, and liability problems are drawbacks to AAT (Melson et al. 2009). Further, AAT requires trained animals and a licensed caregiver, which most hospitals, nursing homes, or residential care centers providing physical, occupational, rehabilitation, or recreational therapy often cannot afford (Tamura et al. 2004). Instead of real animals, entertainment robots can be used to treat patients by implementing *robot-assisted therapy* (RAT) (Fujita 2004). In contrast

to AAT, RAT has several advantages for robotic dogs such as AIBO: cleanliness, safety, low noise level, more robust workload, low costs, and no companion animal-loss (Fujita 2004; Miklósi and Gácsi 2012).

Indeed, robot-assisted activities have already been applied in several cases, including reducing loneliness in elderly care, mitigating stress and fatigue in workplaces, and promoting therapies for vulnerable social groups (Schellin et al. 2020). Especially, AIBO-assisted therapy has been implemented as a catalyst for stimulating socio-emotional functioning, attachment, and psychological well-being among *elderly feeling lonely* (Banks et al. 2008) and *patients with schizophrenia* (Narita et al. 2016), *dementia*; (Kimura et al. 2010; Tamura et al. 2004), and *autism spectrum disorder (ASD)* (François et al. 2009; Stanton et al. 2008) (Table 2).

Loneliness is a subjective perception regardless of objective assessments or outside opinions caused by *predisposing factors* (e.g., personality, beliefs, status) and *precipitating events* (e.g., divorce, disease, unemployment) (Banks et al. 2008). Visits with an AAT animal (as infrequent as once per week) can reverse loneliness to some degree. Even though the process by which AAT leads to reduced loneliness remains unknown, human bonding to the AAT animal is one potential explanation. A fascinating trend is the usage of robotic companion animals—particularly for people in Western countries whose lifestyles are not conducive of caring for a biological dog. One study contrasted AIBO and a live dog’s ability to alleviate loneliness in a long-term care center. Elderly residents interacting with both dogs showed a reduction in loneliness in comparison to residents not receiving AAT (Banks et al. 2008). High levels of attachment in both dogs were observed in residents; however, psychological measures of attachment did not predict a reduction in loneliness—highlighting the fact that attachment cannot be the only process by which AAT changed loneliness. Another study suggests that AIBO-assisted therapy, broadly termed robot-assisted therapy (RAT), maybe also effective for schizophrenic patients—enhancing socialization, socio-emotional functioning, and therefore reducing loneliness and overall well-being (Narita et al. 2016).

With people living longer, the number of geriatric patients with severe dementia is increasing. The population of older individuals from the United States is estimated to rise to 80 million by 2050, potentially contributing to an accelerated rate of dementia (Kramer et al. 2009). Dementia patients ultimately lose their short-term memory while maintaining long-term memory—increasing challenges in keeping communication with the outside world. While AAT services were developed as rehabilitation opportunities for long-term care patients, some of these facilities might be hesitant to offer AAT due to concerns regarding disease, cleanliness, or animal safety. Robotic dogs (e.g., AIBO) may encourage social communication among dementia residents without the disadvantages of encounters with a live dog. One investigation examined the impact of visitation by a human, a human escorted by a living dog, and a human escorted by AIBO on outcome measures of social encounters (e.g., touch, visual observation, and communication) for female women with dementia residing in a nursing home (Kramer et al. 2009). Human joined by a live dog and AIBO induced more social encounters than a human visit alone, and AIBO triggered more looks and contact than the dog—suggesting that RAT stimulating social interaction in dementia may be a realistic solution to live animal visits.

Another investigation collected electroencephalogram (EEG) measurements on a group of dementia patients in a nursing facility and a group of normal healthy controls to calculate the positive impact of RAT using a robotic dog (AIBO) (Kimura et al. 2010). Improvement of neuroactivity was detected in the dementia patients compared to healthy controls after 15 min of RAT based on EEG recordings (i.e., alpha bipolarity as an index of a brain function of loss of uniformity of an alpha wave distribution) performed in resting state for five minutes before and after RAT. Finally, another study compared the effectiveness of AIBO with a battery-driven toy dog at a health care facility housing patient with severe dementia (Tamura et al. 2004). Instead of traditional AAT, AIBO was used in occupational therapy to help dementia patients to remember emotions and memories combating short-term memory loss. Increased social contact

Table 2 Studies investigating robot-assisted therapy with the robotic dog AIBO

Study	Participants	Exposure	AIBO model	Control	Measure
Banks et al. (2008)	Adults: $n = 38$, loneliness	8 (30 min)	ERS-210A	Dog	Questionnaire
François et al. (2009)	Children: $n = 6$, 4–11 years, ASD	10 (30 min)	ERS-7	No control	Video
Kimura et al. (2010)	Adults: $n = 15$, 60–97 years, dementia	2 (15 min)	ERS-7	Remote controlled	EEG
Kramer et al. 2009	Adults: $n = 18$ (18 F), dementia	1 (3 min)	ERS-7	Large-sized dog	Video
Narita et al. (2016)	Adults: $n = 3$ (2 F), schizophrenia	8 (20 min)	ERS-210 + ball	No control	Questionnaire
Stanton et al. (2008)	Children: $n = 11$ (1 F), 5–8 years, ASD	1 (30 min)	ERS-210 + ball	Mechanical toy dog	Video
Tamura et al. (2004)	Adults: $n = 13$ (12 F), dementia	2 (5 min)	ERS-312	Stuffed dog	Video

n number of participants, f female, min minutes, *ASD* autism spectrum disorder, *EEG* electroencephalography

was found in both dogs' presence; however, patients had difficulty connecting emotionally with AIBO (i.e., recognizing that AIBO was a robot) without the intervention of a therapist. Overall, those studies demonstrated that implementing AAT strengthened communication between patients with dementia and AIBO.

ASD is a prevalent *developmental disorder* portrayed by the following three manifestations: *inadequate social interaction* (e.g., focus on objects instead of people, poor social skills, social withdrawal), *diminished communication* (e.g., lack of spoken language, atypical mannerisms, and verbal patterns) and *presence of repetitive habits and restrained ambitions* (e.g., repeated motor movements, use of items in an inoperative, repeated fashion) (Stanton et al. 2008). Pioneering HRI studies suggested that robots could help to minimize any of these manifestations. Different types of robotic therapeutic agents might help in different ways in the therapy of children with autism—addressing not only bodily and physical, but also emotional attachment and social interactions (Yun and Yoon 2018). A preliminary long-term study in a school setting investigated the possible application of robotic companion animals to assist children diagnosed with ASD to minimize some of their social deficits (François et al. 2009). An instructor—guided by principles of non-directive play therapy—took part in the social interactions, while the autistic children played with AIBO as the leading participant. Based on case-study evaluations, a progressive improvement was reported for the children for at least one category (i.e., affect, reasoning, play) over the sessions. Children who initiated social play enjoyed higher degrees of play, reasoned more about the robot, and occasionally expressed positive interest toward the robot. The encouraging findings for this innovative method—including planning, performing, and evaluating robot-assisted play—are promising to become part of conventional therapy for ASD. Another investigation examined whether a robotic dog could assist in the improvement of social competences in ASD-diagnosed children (Stanton et al. 2008). Compared to a simple mechanical toy dog, children are engaged in more behaviors (e.g., communication, cooperation) with AIBO. However, no differences were found for animating and showing affection for AIBO.

In summary, encouraging preliminary evidence exists that AIBO as an autonomous robotic dog may promote attachment helping to relieve loneliness in elderly people (Banks et al. 2008), stimulate social interactivity and socio-emotional functioning in schizophrenic patients (Narita et al. 2016), dementia (Tamura et al. 2004), and ASD (François et al. 2009; Stanton et al. 2008). Nevertheless, social robots still have restricted receptive and engaging capacities, potentially stagnating attachment bonds between humans and robots. Future studies should overcome the methodological and statistical shortcomings of those preliminary studies

(e.g., lack of well-powered gender-balanced target populations, matched control conditions and groups, and absence of inferential statistical testing). As long as people consider robots to be social, RAT is devoted to an alternate approach where cleanliness, safety, and animal welfare could replace AAT with live animals. Importantly, robot–animal activities may become especially relevant given the current mass social distancing procedures practiced due to the global COVID-19 pandemic.

Outlook—what does it mean for HRA?

Despite substantial advances in designing persuasive social robots, caution is required in drawing conclusions based on the reviewed study results of RAT. The emerging category of robotic companion animals is in a position where hypothesis-driven investigations are needed to address obvious shortcomings and potentially facilitating HRA. Previous HRIs' studies with dog-like ethorobots have focused primarily on short- but not long-term social interactions that explore dynamic change in behavior and development of attachment over time. Further, little effort has been shown so far in studying the consequences of a robot's physical or socio-cognitive developmental abilities—being one of the essential features of social living creatures. There is no question that robots with evolving skills will have a greater influence on social interactions and will elicit more human socio-emotional feedback. Moreover, little is known about group-based HRIs since current research examines primarily individual interactions with social robots. Robots are most commonly expected to assist groups of people, such as in public places (e.g., shopping malls, airports) (Burgard et al. 1999; Nourbakhsh et al. 1999). Group-driven HRIs are expected to yield lower degrees of social replies and participation than individual-driven HRIs.

HRIs and HRA may be affected not only by the robot's design but also by demographic elements such as age, gender, and experiences with technology. Social robots have to be designed and built that consider these factors so that the HRIs are beneficial and attachment bonds are possible to a range of targeted individuals. For instance, the development of personas exhibiting human behaviors and traits may be applied in the development of subject-focused HRI and attachment applications (dos Santos et al. 2014). Also, robotic dogs may be used as social partners for other species. Employing animal-like robots may provide new ways of studying animal–robot interactions if the animal recognizes the autonomous robot as a social companion. Preliminary research has shown that while dogs respond much quicker than AIBO, improving appearance and speed may make it more desirable as a social partner (Kubinyi et al. 2004). As the development of robotic companion animals is only at the

beginning, AIBO is the initial significant effort to build a profitable autonomous robot that can communicate socially and bond with humans.

However, no breakthroughs have been seen so far to invent a robotic companion animal that might genuinely function as a “real” animal in daily life. To accomplish this goal, social robots would have to pass the “Turing test” of social attachment (Kaplan 2001). Robots must display artificial attachment for being capable of creating and maintaining a fulfilling companionship with their owners. The “Turing test” requires social robots completing the Ainsworth Strange Situation Test to unveil their attachment style (Ainsworth 1969). While this test can inform whether the social robot is exhibiting attachment-type behavior, it does not determine whether the human owner perceives attachment toward the social robot. This could be achieved by implementing functional magnetic resonance neuroimaging (fMRI) to look at the attachment system in the human brain. Specifically, neural activation signatures of the human–dog attachment system could be characterized by scanning humans and dogs simultaneously in different MRI machines while they interact with each other—utilizing recently demonstrated awake canine imaging procedures (Jia et al. 2014; Ramaihgarai et al. 2018; Robinson et al. 2016; Strassberg et al. 2019; Thompkins et al. 2018). Such findings could then be used as an alternate “Turing test” to prove whether social ethorobots activate this system in the human brain, which is also activated by their canine companion animals.

In the near future, robotic companion animals will become more technologically advanced, eliciting more human psychological reactions. Therefore, the social implication of artificial companion animals has still further to be explored: for instance, are they teaching children to nurture or to waste empathy on robotic animals that should be invested in human beings? It is possible a child may not experience the same benefits associated with companion animal care with the adoption of robotic companion animals without the moral obligations of genuine cooperation and companionship. It is not clear whether children will suffer from “nature-deficit disorder” (Louv 2008), but the social implications revealed by future research will be relevant to society. Furthermore, future research on HRI, especially HRA, will need to account for the moral dimensions of human interactions. Moral psychology, for example, has demonstrated that children develop notions of fairness, reciprocal care, and justice not only via human–human but also via human–animal partnerships (Friedman Jr. et al. 2003).

The evolution of artificial companion animals will occur in an environment of market forces and technological development with a current trend of more complex “intelligent” companion animals that are designed as robotic creatures to develop a long-term attachment with their owners. It will be

interesting to see what qualities of live animals are replicated in these artificial beings, and what unique features are developed for them—a progression that will provide a unique viewpoint on the co-evolution of humans and domesticated animals. The reviewed literature reinforces the significance of a transdisciplinary framework for designing and building social ethorobots. Fascinating and significant findings can be accomplished by bridging the fields of robotics, psychology, and ethology so that social robots can provide not only emotional support but also satisfy therapeutic demands. In the foreseeable future, robotic companion animals will challenge traditional boundaries—expanding our understanding of relationship, friendship, and companionship—and continue to substitute our encounters with real companion animals. Ultimately, studying HRA will encourage us to learn more about ourselves.

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Compliance with ethical standards

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