Tail Wagging the Dog: Perceptions of Canine vs Non-Canine Behavior in a Quadruped Robot

Ruchi Bhalani[1], Alekhya Kuchimanchi[1], Hanaa Siddiqui[1], and Justin Hart[1]

***Abstract*— A variety of quadruped robots have recently become more broadly available. The Boston Dynamics Spot in particular has become a highly-visible robot in the public eye through robot demonstrations, videos, and news coverage. Commonly, these robots are referred to not only as quadrupeds, but more specifically as robot dogs; a metaphor which is extended to the name of the Spot (a stereotypical name for a dog in North America). Despite this metaphor, the programming of the Spot lends itself to very robotic — and not very canine — looking behavior. This paper presents a development process to improve upon the basic building-blocks of Spot navigation behaviors to produce behaviors that are more dog-like in appearance. The process begins with the distribution of an open-ended survey which asks study participants what behaviors the robot could perform to look more dog-like. From these survey responses, a set of behaviors are chosen for development on the Spot. These behaviors are then developed (including some small enhancements to basic Spot SDK functionality), and compiled into "canine" and "non-canine" montages, which are then performed by the robot in a busy public space. Nearby pedestrians are able to log into an online survey using a QR code to provide their impressions of the robot, rating its behavior on a modified version of the Godspeed Questionnaire. The results of the study show that participants find the robot to be more dog-like, and that they rated it more positively on several other measures, when the robot is running the "canine" montage. These results can be used to develop more socially-engaging software architectures for the Spot and other quadruped robots.**

I. Introduction

Quadruped robots — often already called robot dogs — provide an exciting opportunity to extend the study of human-robot interaction in a new direction; leveraging interactions with a dog-like robot rather than a human-like robot. Dogs have a special position in human society, as the first species to be domesticated [1] and one that has a remarkably robust set of social skills for interacting with people [2]. As of 2018, 38.4% of American households have a dog [3]. As a starting point and a building block for human-robot interaction in the canine form-factor, this work builds a set of behaviors chosen to encourage people to perceive quadruped robots as though they are dog-like.

The Boston Dynamics Spot is a quadruped mobile robot. This research seeks to enhance study participants' perceptions of the robot as being "dog-like" by developing a set of robot behaviors reminiscent of canine behavior. The work proceeds in three phases. In the first phase, a brief survey is developed and distributed to study participants. The survey first presents a variety of canine emotions, and asks respondents for free-form text responses about what behaviors they associate with those feelings in dogs. It ends with a short video of a Spot robot, asking what behavior that robot could perform that would make it seem more canine. These free-form responses are condensed into short forms such as "wag tail" or "run in circles," and the number of respondents choosing specific behaviors is counted. From the survey data, a set of five basic behaviors is chosen for implementation; along with a general note to make the robot move more smoothly. Implementations of these behaviors are written and compiled into a brief continuous vignette, the "canine" vignette; alongside another vignette composed exclusively of the robot walking in circular patterns, the "non-canine" vignette. In a second study, on two separate days the robot performs these motions in a busy pedestrian area on the University of Texas at Austin campus. Posted nearby is a QR code leading study participants to a brief survey based on the Godspeed Questionnaire [4], inquiring about their perceptions of the robot, including how dog-like it is. Results of this study indicate that the added behaviors increased peoples' perception of the robot as being dog-like, and improved their perceptions across several other metrics.

II. Related Work

Recently, a variety of quadruped robots have entered into the market, including the Boston Dynamics Spot[1], the Ghost Robotics Q-UGV[2], the Unitree A1[3], and others. Often, these devices are referred to as robot dogs (as in this news article [5]). The Spot itself is sold as a mobile robot base upon which systems and tasking can be built. The quadruped form factor offers advantages over wheeled platforms such as the ability to climb stairs or walk on gravel and other terrain inaccessible to wheeled robots. Boston Dynamics provides both C++ and Python-based SDKs[4] enabling usages such as graph-based navigation.

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[1]Department of Computer Science, The University of Texas at Austin, Austin, Texas 78712 ruchi.bhalani@utexas.edu akuchima@utexas.edu hanaasiddiqui@utexas.edu hart@cs.utexas.edu

[1]https://www.bostondynamics.com/products/spot
[2]https://www.ghostrobotics.io/
[3]https://shop.unitree.com/products/unitree-a1
[4]https://dev.bostondynamics.com/

The Spot is certainly not the first quadruped robot used in research. Spot is one of a series of quadruped robots, among others, developed at Boston Dynamics[5]. The Mini Cheetah (and its various iterations) [6] is also another quadruped robot, designed to study control systems and perhaps most well-known for performing backflips [7]. The ANYmal [8] was developed to navigate on challenging terrain, and is now commercially available[6]. The StarlETH [9] is a quadruped designed entirely around series elastic actuators.

A somewhat different quadruped robot that has seen extensive use in research is the Sony Aibo[7]. A significant contributor to the success of the Aibo as a research platform is its use in the RoboCup Standard Platform League [10] from 1999-2008. This lead to extensive research contributions in the area of robot learning [11].

The Aibo has also been used in the study of human-robot interaction. Kerepesi et al. [12] directly compared people interacting with real live puppies versus people interacting with the Aibo running their software, attributing differences in the interaction to the limited ability of their software to model temporal structure in the interaction. Ribi et al [13] performed a study comparing children's play with an Aibo versus a dog of similar size, finding that children played more with the Aibo than with the real dog. Weiss et al. [14] performed a study in a shopping mall observing peoples's (predominantly children) interactions with an Aibo, measuring expressions of emotion during engagement with the robot. They found that children were very enthusiastic to interact with the robot, but also that 99.3% ascribed emotions to it. Friedman et al. [15] analyzed postings in online Aibo discussion forums, similarly finding that users attribute mental states and social rapport to the robot. The Aibo's built-in software emulates the developmental process from a "puppy" to a "dog". Lee et al. [16] present a study demonstrating that this increases perceptions of life-likeness and social presence, and improves social responses towards the robot.

Going in the opposite direction — dogs interacting with robots — Qin et al. [17] present a study in which dogs gaze at a robot and obey its command to "sit" more often than a loudspeaker.

Canine social behavior has been studied extensively by psychologists. Dogs interact with each other and people through body postures, facial expressions, tail and ear positions, raising of hair or "hackles," vocalizations, and scents [18]. Tami and Gallagher [19] present a study in which they survey observers with various levels of experience with dogs (owners, veterinarians, trainers, non-owners) and ask them to classify the behavior of dogs. The study shows that experience level with dogs does not determine the ability to interpret canine behavior, and that tail movement is the most frequently cited cue to interpreting canine behavior. Kilely-Worthington [20] presents an extensive comparative study discussing only the movement of animal tails, contrasting dogs to other vertebrates. The canine social behavior of wagging a tail is an effective way to communicate between dogs and humans as humans perceive a dog that wags its tail as "happy" [21].

The goal of the present work is to develop a high-level understanding of what behaviors people perceive as canine and to implement these behaviors on a Boston Dynamics Spot in order to make the robot seem more dog-like.

III. Identification of Canine Social Behaviors

The first step in this work is to determine what people think of as canine behaviors to, then to implement the most popular behaviors from this list.

A. Methodology

We developed an online survey asking what respondents believe constitutes canine behavior. The survey begins with a series of questions of the form, "What behaviors do you think make dogs seem <blank>?" For each question, the <blank> is an emotion that a dog might feel. The emotions are: a) friendly, b) happy, c) aggressive, d) anxious, e) sad, and f) relaxed. Each of these questions takes a short-form free text response. After these questions, participants are instructed to watch this brief video featuring a Boston Dynamics Spot [8], then to respond to the question "Based on the video clip, what social behaviors should be added to the Spot robot in order to appear more dog-like?" with another free-text response.

The studies appearing in this paper were submitted to the University of Texas at Austin Institutional Review Board, who determined that this study is allowed to proceed because it is not a type of research that is regulated under DHHS or FDA regulations under STUDY00002579.

The survey was distributed through social media. A total of 57 people participated. No demographic or identifying information was collected.

B. Results

The free-text responses to all of the questions on the survey were read by the authors of this study and summarized as short phrases. The number of participants who mentioned each of these phrases at least once was then counted. The count associated with each behavior appears in Figure 1. The most popular responses include: tail wagging, laying down, putting the dog's tail between its legs, and jumping. Many responses are not behavioral in nature, but rather describe physical changes to be made to the robot, such as adding a tail, ears, or a face with eyes. Other responses include behaviors that require body features that the robot does not have, such as baring teeth, raising the dog's hackles (hair standing up on end), or sniffing around. Four responses are audio additions, including growling, whimpering, barking, and panting/sighing. Finally, four are ambiguous in nature and so not precise enough for implementation. These four responses are behaving slowly or lethargically, behaving

[5]https://www.bostondynamics.com/legacy
[6]https://www.anybotics.com/
[7]https://www.sony-aibo.com/
[8]https://www.youtube.com/watch?v=lwaVAkI5-zk

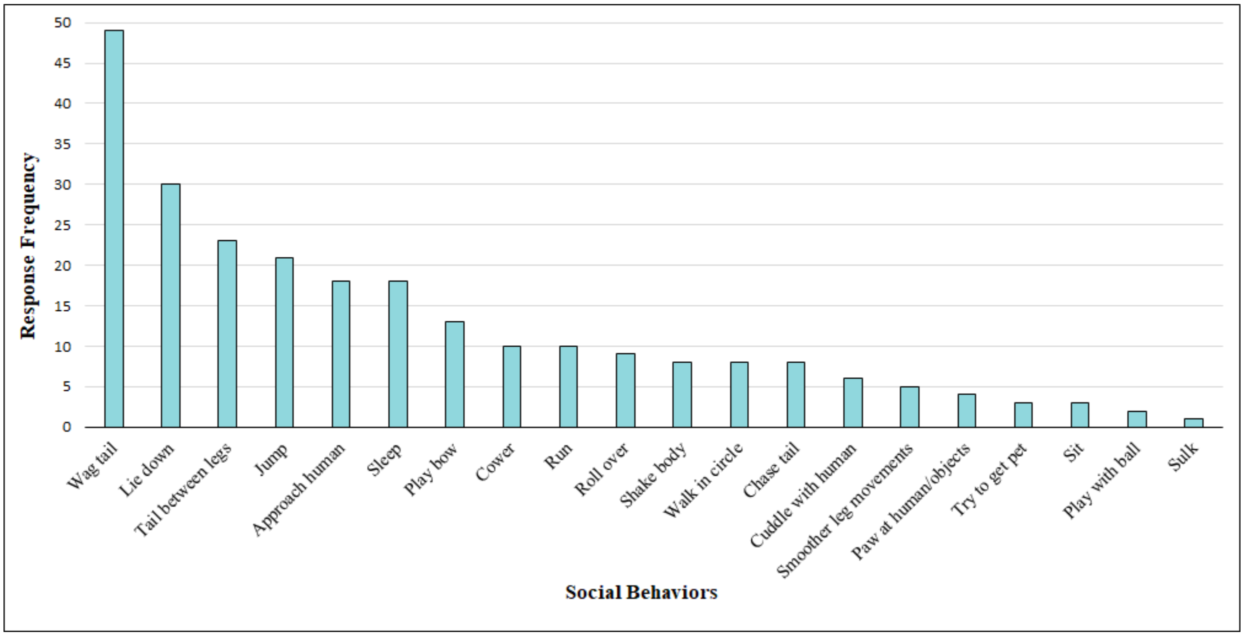


Fig. 1: Responses to the free-text responses to the first survey, asking what behaviors people associate with dogs, were summarized by the authors. This chart presents the number of respondents indicating each of these behaviors.

restlessly, making excited movements, or behaving in a calm or relaxed fashion.

IV. Development of Social Canine Behaviors

The behaviors implemented on the robot are chosen from the responses to the first survey, listed in Figure 1. To narrow down which behaviors to implement, the audio features are removed, as are those requiring physical changes and those which are unclear. Some, though they pass these criteria, are not possible to implement. The robot is unable to jump, move quickly enough to be perceived as running, or place its non-existent tail between its legs. The robot cannot roll over due to the hardware mounted to its back. Similarly, it would be very difficult to develop an animation that looks as though it is shaking its body in the way that a dog does, sulking, or sleeping rather than simply being turned off or laying down. Some of the remaining behaviors are interactive in ways that do not lend themselves to crowds passively observing the robot, as is required by the setup of the study in Section V. Other behaviors are impractical. For instance, the robot is not at all cuddly. Finally, the behavior of cowering is simply not in-line with the lighthearted and fun nature of this study, and so is omitted.

The final list of implemented behaviors comprises: tail wagging, play bow, sitting, walking in circles, and chasing its tail. The matters of smoother movement and varying walking speed are also addressed in the implementation. The robot also lies down at the end of its performance, but this functionality is already implemented in the robot's stock software.

A. Implementation

These behaviors are implemented using our custom Spot C++ API; developed in conjunction with the Autonomous Mobile Robotics Lab (Joydeep Biswas's group) and provided as free open source software[9] Development began prior to the Boston Dynamics offering a C++ API, though it provides some custom functionality used in this study.

The Boston Dynamics Spot SDK[10] provides a class called `RobotCommand`, which has a `velocity_command` function that allows the programmer to specify a velocity in x and y directions (orthonormal axes parallel to the ground plane, with x parallel to the robot's torso) and a rotation about the z (yaw) axis. `RobotCommand` also has a `stand_command` function that allows the programmer to specify Euler angles (translated to roll, pitch, yaw in the descriptions below) for the robot to pose into, but without any locomotion component.

The Boston Dynamics Spot SDK provides commands designed around moving into a single pose, with the movement to be completed within a specified time-frame. Though not exposed by the SDK, the underlying protocol allows for multiple trajectory points to be specified at a time and also provides the framework to synchronize the client program's internal clock to that of the robot. The custom Spot C++ API provides methods to specify longer trajectories which are interpolated through, synchronized with the robot's internal clock, and communicated over the network with the robot at a rate that prevents overfilling the robot's internal buffer. This allows for long, smooth trajectories to be provided to the robot in a way that prevents jerkily changing motions. Each

[9]Thanks to our development team for the API: Nathaniel-Nemenzo, Mateusz Kozlowski, Swathi Mannem, Daksh Dua, Shikhar Gupta, Geethika Hemkumar, Maxwell Svetlik, Parth Chonkar, Marika Murphy, Joydeep Biswas, and Justin Hart. The API can be found at https://github.com/ut-amrl/spot_cpp.

[10]https://dev.bostondynamics.com/

of the motions developed for this study uses these methods and is hand-tuned for smooth transitions. This addresses the "smoother leg movements" response to the first survey.

B. Library of Social Behavior Movements

Each of the chosen behaviors is hand-coded as a motion defined through a set of trajectory points that the robot follows, approximating the behavior of a real dog. Each of these motions are defined with respect to a neutral body posture, with the robot's torso parallel to the floor and its legs slightly bent. The motions defined are periodic motions, and angles are defined with respect to the center of the torso. Trajectory points are specified using system described above. There are two basic trajectory types. One is based on is roll, pitch, yaw coordinates with respect to the robot's body in a neutral posture; with the robot moving through those coordinates, but not otherwise walking. The other trajectory type is deltas with respect to the robot's current position, specified as a velocity (back-to-front along the x-axis, or left-to-right along the y-axis) and a rotation through the robot's yaw angle.

1) Tail Wagging: In the tail wagging motion, the robot rocks synchronously across its roll and yaw axes, between the extremes of $\frac{-\pi}{16}$ to $\frac{\pi}{16}$, and $\frac{-\pi}{8}$ to $\frac{\pi}{8}$ radians off of the neutral pose. The robot tilts to the right, returns to the center, tilts to the left, returns to the center, and continues in a smoothly-interpolated motion. See Figure 2a.

2) Play Bow: The play bow motion approximates a dog "bowing" during play (a canine invitation to engage in play). The robot tilts its torso entirely forward to edge of its ability, at $\frac{3\pi}{14}$ radians, and then back. See Figure 2b.

3) Sit: The sit motion is the opposite of play bow, at a less severe angle of $\frac{\pi}{7}$ See Figure 2c.

4) Walk in Circle: To walk in a circle, the robot follows uniform linearly-interpolated waypoints placed at 1.5 radians per second of rotation about the yaw axis and 2 meters per second of forward motion. See Figure 2c.

5) Spin: The "spin" motion mimics a dog chasing its tail, which was one of the popular survey responses. Spinning is the motion closest to tail-chasing that the robot can make as it does not possess a spine and cannot twist to mimic actual tail-chasing. To execute this motion, the robot moves through waypoints placed at 1 radian per second, similar to the "Walk in Circle" motion, but with no forward motion component. See Figure 2e.

Descriptions of each behavior in terms of trajectory end-points are listed in Table I.

V. Human Surveying for Social Canine Behaviors

Finally, the developed canine behaviors are tested to see if people perceive them as more dog-like and whether they affect people's impressions of the robot.

A. Methodology

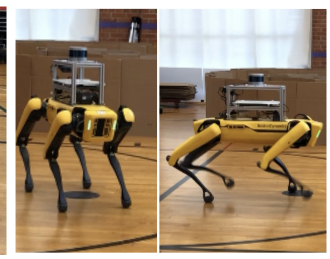
To test people's reactions to the robot's canine behavior over a non-canine baseline, two brief vignettes were developed. The *Canine Behaviors Vignette* performs a sequence of the "canine" behaviors developed in the previous section. A brief video of the canine vignette can be seen here: `https://youtu.be/R9vWQJpmh-0`. In the *Non-Canine Behaviors Vignette* the robot walks in a semi-circle, then continues forward for a few steps before entering into another semi-circular pattern. The non-canine walking behavior loops four times before the robot comes to a stop. A brief video of the non-canine vignette can be seen here: `https://youtu.be/f2sfL1cJ4PE`. The vignettes are designed to take the same amount of time.

(a) Tail wagging

(b) Play bow

(c) Sit

(d) Walk in circle



(e) Spin

Fig. 2: Images of the robot performing the various "canine" behaviors developed for this study.

The robot ran the canine vignette and the non-canine vignette on two separate days, at a busy pedestrian intersection on the University of Texas at Austin campus. On both days, QR codes linking to an online survey were displayed nearby. The survey is an abbreviated version of the Godspeed Questionnaire [4]. The abbreviated version is a subset of a questionnaire developed by Elliot Hauser and Justin Hart for several studies being performed using the Boston Dynamics Spot by collaborating robotics research groups at The University of Texas at Austin. The Godspeed questionnaire measures perceptions of robots on Likert scales

Body Movement	**Roll** (rad)	**Pitch** (rad)	**Yaw** (rad)	$velocity_x$(m/s)	**Rotation Angle** (rad)
Tail Wagging	-π/16 to π/16	0	-π/8 to π/8	0	0
Play Bow	0	0 to 3π/14	0	0	0
Sit	0	-π/7 to 0	0	0	0
Walk in Circle	0	0	0	2	-1.5 to 1.5
Spin	0	0	0	0	-1 to 1

TABLE I: The most prevalent responses from the first survey, asking which behaviors respondents associate with dogs, are implemented on the robot. Each behavior is implemented as a simple motion smoothly interpolating between fixed poses of the robot's torso or walking trajectories.

of Anthropomorphism, Animacy, Likeability, Perceived Intelligence, and Perceived Safety. The scales presented in the questionnaire can be seen in Table II, and are measured as 7-point Likert scales.

Machinelike vs Doglike
Fake vs Natural
Unconscious vs Conscious
Artificial vs Lifelike
Moving Rigidly vs Moving Elegantly
Inert vs Interactive
Apathetic vs Responsive
Incompetent vs Competent
Ignorant vs Knowledgeable
Dislike vs Like
Unfriendly vs Friendly
Unpleasant vs Pleasant
Awful vs Nice
Remote controlled vs Autonomous

TABLE II: A brief version of the Godspeed Questionnaire [4] is used in this study to measure people's perceptions of the robot when performing the "canine" versus "non-canine" vignettes. The survey is briefer than the full questionnaire, to encourage responses from nearby pedestrians (who may skip a lengthier questionnaire when simply walking by on the street). The questionnaire also substitutes "Doglike" for "Humanlike."

A total of 222 people responded to the survey: 112 saw the canine demonstration and 110 saw the non-canine demonstration. The participant pool consisted of 202 UT Austin students, 6 UT Austin faculty members, and 14 individuals with no UT affiliation.

B. Results

Participants found the canine vignette to be more dog-like than the non-canine vignette (Question: Machinelike vs Doglike. canine: mean=4.24, sd=1.54; non-canine: mean=3.77, sd=1.38). This result is statistically significant by a one-way analysis of variances (ANOVA) ($F_{1,220}$=5.628, p=0.019). The intention behind this work is to increase participants' perceptions of the robot as being doglike by changing its behavior, and this result affirms the effectiveness of the implemented behaviors.

Participants' perceptions also statistically significantly improve on several other metrics in the canine condition versus the non-canine condition. Participants perceive the canine robot as more conscious (Question: Unconscious vs Conscious. canine: mean=4.53, sd=1.84; non-canine: mean=4.04, sd=1.77; $F_{1,220} = 4.057$, $p = 0.045$). Despite the robot not actually interacting with them or responding to them, participants perceive the robot as more responsive (Question: Apathetic vs Resonsive. canine: mean=4.76, sd=1.75; non-canine: mean=4.15, sd=1.80; $F_{1,220} = 6.581$, $p = 0.011$) and more friendly (Question: Unfriendly vs Friendly. canine: mean=5.86, sd=1.35; non-canine: mean=5.17, sd=1.61; $F_{1,220} = 11.685$, $p < 0.001$) when performing the canine vignette. Though not statistically significant, the robot is also perceived as more interactive (Question: Inert vs Interactive. canine: mean=4.77, sd=1.64; non-canine: mean=4.35, sd=1.62) and more lifelike (Question: Artificial vs Lifelike. canine: mean=4.21, sd=1.62; non-canine: mean=3.85, sd=1.58) in the canine condition. Perhaps more difficult to interpret is that the robot is perceived as more autonomous in the non-canine condition (Question: Remote-Controlled vs Autonomous. canine: mean=4.24, sd=1.95; non-canine: mean=4.78, sd=1.73). These results indicate that the developed behaviors can be leveraged to create rich, entertaining interactions with the robot that enhance people's perceptions of the robot in positive ways.

VI. Conclusion

In this work, people were surveyed asking what behaviors they associate with dogs. The results of this first survey were distilled into a set of behaviors that were implemented on a Boston Dynamics Spot quadruped robot. Two brief vignettes were developed, showing off the robot performing in a "canine" fashion or a "non-canine" fashion. A second survey, based on the Godspeed Questionnaire [4], was developed and used to determine people's attitudes towards the robot when performing the two vignettes in a public space. Results indicate that people perceive the robot as more doglike when it performs the "canine" behaviors, as well as more positively on several scales. Using these behaviors can help developers to create fun interactions with the emerging category of quadruped robots as and to leverage the positive perceptions associated with them to increase the acceptance of these robots in their deployments.

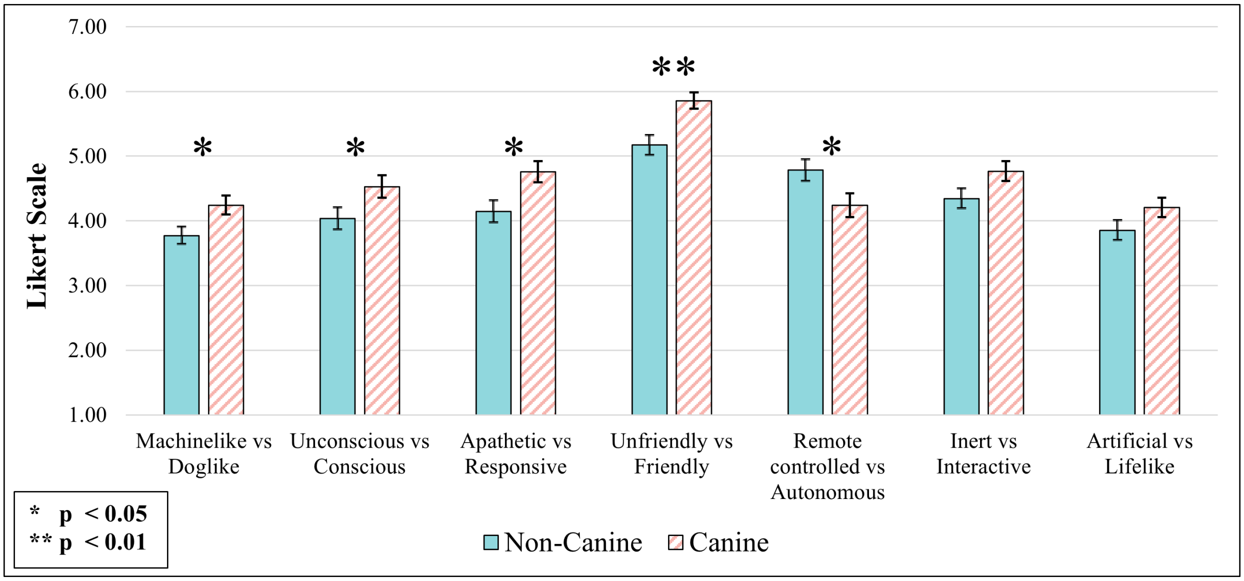


Fig. 3: Means and Standard Error of Statistically Significant Results

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