The Evolving Design of a Socially Therapeutic Robotic Dog*

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***Abstract*—This paper presents data from an exploratory user design evaluation of Therabot™, a robotic support companion in the form of a stuffed animal dog and discusses how these findings fit into the larger design process of a therapeutic platform with a focus on implications that may extend to similar platforms. While prior investigations have guided the robot's technical development, in this work participants wore physiological sensors while engaging in an interview similar to cognitive behavioral therapy followed by an interactive design evaluation of the robot. Physiological measures of heart and respiration rate data were collected during the interactions with the robot. Participants holding the robot during their interview experienced a significant reduction in heart rate compared to those not holding the robot. The evaluations from the 32 participants in the study highlighted platform-specific refinements, characterized essential attributes of aliveness in animal-like companion robots, and emphasized the importance of privacy in the design of personal robots, especially for companionship and therapeutic applications.**

***Index Terms*—Human-robot interaction, design, evaluation, socially therapeutic robot, companion robot**

I. Introduction

The therapeutic use of social robots is an area with promising results and tremendous potential to impact society in a positive way. Efforts in the field of human-robot interaction (HRI) have examined specific care domains, developed unique robotic platforms, and explored an array of design and evaluation methods. This paper contributes to the design of social robots in general through an evaluative study of an iteratively-developed robotic support companion called Therabot™, designed as a stuffed-animal dog.

We begin by providing a brief overview of the growing landscape of socially assistive and supportive companion robots and common design approaches used in their development. Next, we detail the hardware, software, and design path involved in the development of the Therabot™ platform. The remainder of the paper focuses on the techniques, results, and implications of an evaluative design study conducted using the robot. Additionally, we provide an analysis of the physiological effects experienced by participants during a brief talk therapy session. We discuss the broader value of these insights to social robots and how they will shape the ongoing development of the Therabot™ platform.

II. Related Work

Social robots have been used in a wide variety of therapeutic contexts, spanning from physical rehabilitation to talk therapy to long-term use in Autism Spectrum Disorder (ASD) therapy [1]–[3]. Some of the more frequently explored domains include longer-term interactions with the elderly [4], short-term use in pediatric hospital settings [5], [6], and use with healthy adults for the reduction of stress or anxiety [7]. In some prior studies, physiological signals like heart rate and heart rate variability have been collected to measure the effectiveness of the robotic system [8], [9]. While a wide variety of robotic platforms have been used to support therapeutic interactions, this section provides a brief snapshot of research and commercial robots designed to provide companion-like support in a form-factor that is intended for touch interactions.

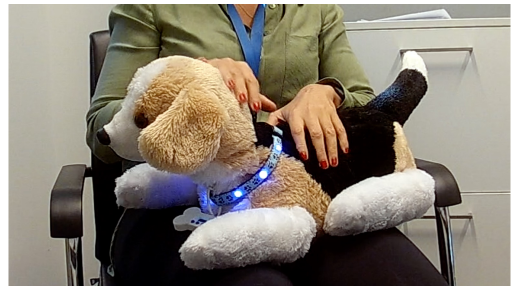

Fig. 1: A participant petting the robot during the study.

Paro, a therapeutic robot in the form of a seal with a soft fur covering over a rigid structure, is perhaps the most well-known and widely deployed robot in this domain [10]. While Paro is used in academic research and is available for purchase, several platforms in this domain have been used only in research. An early example is the Haptic Creature robot, which effectively lowered participant anxiety and, when used with breathing movements activated, led to decreases in participant heart and respiration rates [11]. Its success inspired further developments like CuddleBits [12], Haptic Creature modifications, and Ommie, a robot that guides deep breathing exercises to reduce anxiety [13]. The Huggable is a teddy bear robot that incorporates touch sensing skin and is intended to promote health and well-being [14]. Hasbro has developed a line of cat and dog robotic companions, "Joy for All", available for purchase by the general public. Though limited in functionality, positive user responses have been reported [15], [16]. While similar in purpose, Therabot's unique design incorporates ample soft padding to achieve a feel closer to that of a stuffed animal than a rigid structure covered with soft fur. In addition to understanding the direct interaction needs of users, our design process focuses on privacy, which is an emerging concern related to the use of therapeutic robots [17].

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III. THERABOT

Therabot™ is a robotic support companion designed to look and behave like a dog in a stuffed animal form factor. The robot's initial form factor and features were informed by an online survey of 1,045 participants and in-depth surveys of 36 past trauma survivors and 13 clinicians experienced in treating post traumatic stress [18]. Therabot's external appearance remained constant, but its internal design has undergone many revisions; this section describes the latest version.

A. Hardware

The robot's primary mechanical structure is comprised of two 3D-printed ABS plastic base sections linked by a pivoting joint. Each base section has two rubber legs attached, which are actuated using Dynamixel AX-12A smart servos. The neck and head assembly, composed of three AX-12A actuators (tilt, pan, roll) and two SG90 ear servos, is attached to the front section. An inertial measurement unit, audio surface transducer, and capacitive touch sensing board are also mounted to the front section. On the rear section, a single AX-12A actuator is directly attached to a flexible wire tail structure. All actuators have been modified for ventilation and have controllable fans attached for heat dispersion.

A single board computer (Raspberry Pi 3A+) and USB Dynamixel motor interface (U2D2) are located on the underside of the rear section of the body frame. The underside of the front section contains a 10.8V lithium-ion battery (56Wh), a micro-controller (Teensy 3.2), power regulation components, and an audio amplifier.

This base structure is covered with a thick layer of padding that incorporates capacitive fabric in 12 distinct touch areas and includes a small speaker embedded in the robot's muzzle. Externally, a costume layer covers the padding. Around the robot's neck is a collar with equidistant RGB-LEDs; from the collar, a hang-tag interface shaped like a dog bone (with a 0.96" OLED screen and three tactile buttons) provides an interface for easily activating the robot's features. The fully assembled robot weighs approximately two kilograms.

B. Software

Therabot's software framework manages low-level tasks (e.g., thermal management) and provides high-level abstractions for the robot's functionality, allowing custom behavior development. With the exception of micro-controller code, all software is written in JavaScript and executed in the Node.js run-time environment.

The robot's default operation mode provides "aliveness" and "awareness" behaviors. Aliveness behaviors include animations such as looking around, wagging its tail, and raising up on its front paws. The system plays a heartbeat (60 bpm) through its surface transducer and uses its muzzle speaker to communicate using barks, whimpers, and pants. Awareness behaviors enable the robot to respond based on sensor values. Awareness behaviors are given priority over conflicting aliveness behaviors to increase interactivity. A web-based configuration interface allows sensor sensitivity tuning, choreographing new poses, and linking actions, sounds, and sensors to create responsive behaviors. For example, when being pet under its muzzle, the robot turns its head to the side and makes a panting sound. The robot's hang-tag allows quick toggling of awareness, aliveness, and audio features.

IV. USER DESIGN STUDY

As part of an interactive design study, 32 healthy adult participants were asked to first engage in a 20-minute structured interview derived from the American Psychiatric Association's Structured Clinical Interview (SCID-5-CV) related to anxiety disorders. Participants were randomly assigned to one of three conditions during the interview session: holding the therapeutic robot Therabot™, holding a non-robotic stuffed animal version of Therabot, or not holding anything. Throughout the study, participants wore a QardioCore Monitor, measuring heart and respiration rates, to identify changes related to stress and anxiety. Sessions were audio and video recorded using a small action camera. Three participants elected to have video recording disabled, but session audio was captured.

Each study session lasted approximately one hour and was divided into five segments (see Table I); during the study, video and audio of the session, responses to survey questions, and physiological measures were collected. For the purposes of this analysis, we will primarily focus on the physiological signals captured during the interview portion of the study. Data from the surrounding portions of the study will be used to help contextualize findings from within the interview.

Prior to the interview, participants completed a basic health survey used by psychophysiologists, the stress indicators questionnaire [19], the trait portion of the State-Trait Anxiety Inventory [20], and a modified Positive and Negative Affect Schedule (PANAS) survey [21]. Following the interview portion of the study a modified PANAS survey was administered. At this point participants in conditions without a robotic Therabot™ were provided one for the design evaluation.

The interactive design evaluation phase began by discussing how the robot could be used therapeutically, then focused on the robot's behaviors. Participants were asked open-ended questions about their perceptions of Therabot's purpose, use, movements, sounds, and potential companion app; they also discussed desired touch interaction styles and privacy considerations. Next, participants watched a brief video of a live dog playing and were asked to enumerate benefits and drawbacks between a live dog and the robotic dog. Finally, participants completed the Almere Model Survey [22] for the robot and a demographics survey.

This study was conducted in Australia at the University of Technology, Sydney as part of a Fulbright Senior Scholar research project performed by Dr. Cindy Bethel. The study was approved as a clinical trial by and conducted with guidance from the university's research ethics review board.

V. RESULTS

Each session was conducted by the last author, and video recordings were later analyzed by the first and second authors.

Time (h:mm)	Activity	Measures
0:00 - 0:10	Wearable QardioCore attached to participant. Participant completed questionnaires on tablet.	Health Survey, Stress Indicators, STAI-Y2, PANAS
0:10 - 0:30	Participant engaged in interview about anxiety and stress.	Audio/Video Recording, Physiological Data
0:30 - 0:35	Participant completed questionnaires on tablet.	PANAS
0:35 - 0:55	Participant engaged in interactive design evaluation of the robot.	Audio/Video Recording
0:55 - 1:00	Participant completed questionnaires on tablet. Wearable equipment removed.	Modified Almere, Demographics

TABLE I: Phases of the study, the associated activities, and survey/recording/physiological measures.

Participant responses for each question were segmented and aggregated. The aggregated responses were then grouped by similarity, given a representative label, and counted. We report the counts for each representative label as well as specific responses to help characterize the label.

While the robot executed the same basic behaviors for each participant, some minor variations in functionality occurred between participants as a result of fluctuations in the environment and minor technical issues. For example, the robot's touch sensing may have behaved differently due to changes in humidity or shifts in sensor placement over time. In some cases the robot's neck tilt motor reduced its activity to prevent overheating. Though overall participants were able to experience the same set of features, we also report relevant idiosyncrasies that may have affected participant responses.

A. Participants

A total of 32 participants (16 female) with a median age of 30.5 took part in the study. Participants were recruited through university mailing lists and were mostly members of the community with some association to the university. On average participants had a high level of experience with pets (Average = 3.8 of 5, SD=0.92) and computers (Average = 3.9 of 5, SD=0.6), but a low level of experience with robots (Average = 2.3 of 5, SD=1.1).

B. Physiological Results

While there were no differences in measures of respiration rates and heart rate variability (RMSSD), significant differences were observed for mean heart rate between the conditions of the study. An overview of the results and related statistical comparisons of physiological data between conditions are summarized in Table II.

The change in mean heart rate between the baseline period and the first five minutes of the talk session was significantly different between conditions ($F(2,29) = 3.509, p = 0.0432$). Post-hoc testing revealed a significant difference between the No Support and Robot Support conditions, with those in the robot condition experiencing a decrease in mean heart rate.

No statistically significant differences were found between the study conditions for changes in respiration between baseline and the first ($F(2,29) = 0.519, p = 0.6$) nor between baseline and the last ($F(2,29) = 0.352, p = 0.706$) five minutes of the talk session, or between the beginning and the end of the talk session ($F(2,29) = 0.031, p = 0.969$). Furthermore, measures of heart rate variability did not indicate any significant condition-dependent differences between baseline and the first five minutes of the talk session ($F(2,29) = 1.22, p = 0.31$).

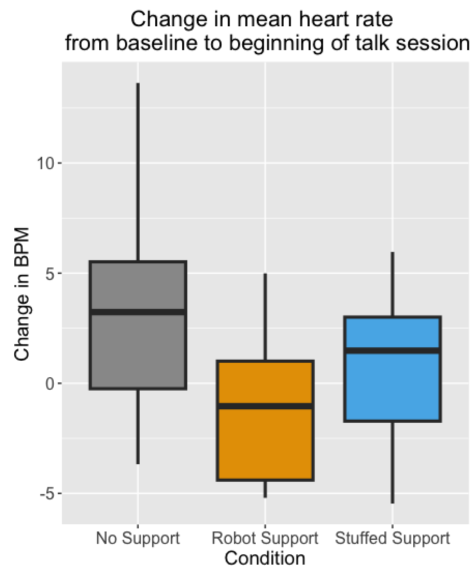

Fig. 2: A comparison of the change in heart rate between baseline and first five minutes of the talk session by condition.

Notably, participants in all conditions experienced decreases in respiration rate between baseline and the first five minutes of the talk session, and between baseline and the last five minutes of the talk session.

C. Design Study Results

All study conditions included the same design evaluation feedback segment. During the interactive design evaluation phase, which lasted 17 minutes and 41 seconds on average, participants discussed aspects of the robot's behavior, such as movements and sounds, and external factors like privacy implications, a companion app, and comparisons with a video of a living dog. With the exception of four items in the Almere Survey administered at the end of each session, we found no correlations between the feedback provided about the robot and the type of support received in the non-design feedback portion of the study. Though not our primary focus for this work, for completeness we report the differences found in the Almere Survey items in Table III. We discuss and examine other potential effects of the study conditions in the implications section.

1) Purpose and Use: The most frequently reported potential general uses for the robot were: comfort and calming (17), touching and holding (10), a good distraction (9), and companionship (6). Several participants also reported the system would be useful with specific populations (e.g., elderly or children) or in specific domains (e.g., therapy sessions or

Comparison	None	Stuffed	Robot	F(2,29)	p	Effect Sizes
Mean Heart Rate difference between baseline and first five minutes of talk	3.33 (4.84)	0.59 (3.94)	-1.31 (3.48)	3.509	0.0432	d=1.1, large effect
Mean HRV (RMSSD) difference between baseline and first five minutes of talk	-2.19 (21.53)	16.8 (33.54)	44.32 (115.41)	1.218	0.311	-
Mean Respiration difference between baseline and first five minutes of talk	-4.80 (3.71)	-3.74 (3.20)	-5.53 (4.94)	0.519	0.6	-
Mean Respiration difference between first five and last five minutes of talk	0.13 (1.95)	0.10 (2.40)	0.36 (3.49)	0.031	0.969	-
Mean Respiration difference between baseline and last five minutes pf talk	-4.67 (3.69)	-3.64 (2.25)	-5.17 (5.83)	0.352	0.706	-

TABLE II: Means and (Standard Deviations) for physiological measures with significant differences ($p < .05$) between conditions. Shaded cells indicate a significant difference compared to the no-support condition. Post-hoc comparisons are reported for significant differences.

nursing homes). When asked, most participants felt the robot would work best with a therapist by providing comfort to a patient during therapy sessions (21). Participants were less certain about how the robot might work best with family, friends, or caregivers, with some speculating it could be useful when people could not be present (4) or as something for everyone to interact with (2).

The features participants felt were most important for helping someone included: general aliveness behaviors (9), overall physical feel (8), responsiveness (6), heartbeat (5), looking at the user's face (4), and warmth (3). Within the overall physical feel category, participants included attributes like the feel of the fur, weight of the system, and ”cuddly-ness”.

2) Movements and behaviors: Reporting on the robot's overall movements, participants most frequently indicated the current movements were good (9), the tail movement needed improvement (4), and that the robot should move more (4). Some participants addressed specific movement attributes like speed (2) and predictability (2), while others addressed specific movements they liked (5). Two participants included the robot's heartbeat as a movement and reported liking its presence.

When asked specifically about the robot's head, tail, and leg movements, most participants indicated the current movements were sufficient and some suggested minor adjustments in speed or frequency. Although the tail movements were generally appraised as positive, nine participants felt reducing the motor noise would be helpful.

3) Sounds: When asked what type of sounds the robot should make, most participants reported specifically on the areas of barking, whimpering, and panting. Figure 3 shows the percentage of participants that thought each of these sounds should or should not be part of the robot's behaviors. Some participants reported that specific sounds should be included if specific conditions were met. For example, the robot should not bark at night while the user is trying to sleep.

In addition to typical dog sounds, participants were asked if the robot should be used to playback instructions or recordings of therapy sessions. For example, a user could playback a guided meditation exercise from a session at a later time. A majority of participants (62%) felt that the robot should not be used for this type of playback, while some (26%) thought this feature should be provided depending on the preferences of the user.

Most participants (70%) also felt the robot should not use a human voice to communicate with users, though some thought it would (17%) or could (13%) be useful to some users. Of the participants feeling a human voice could be incorporated,

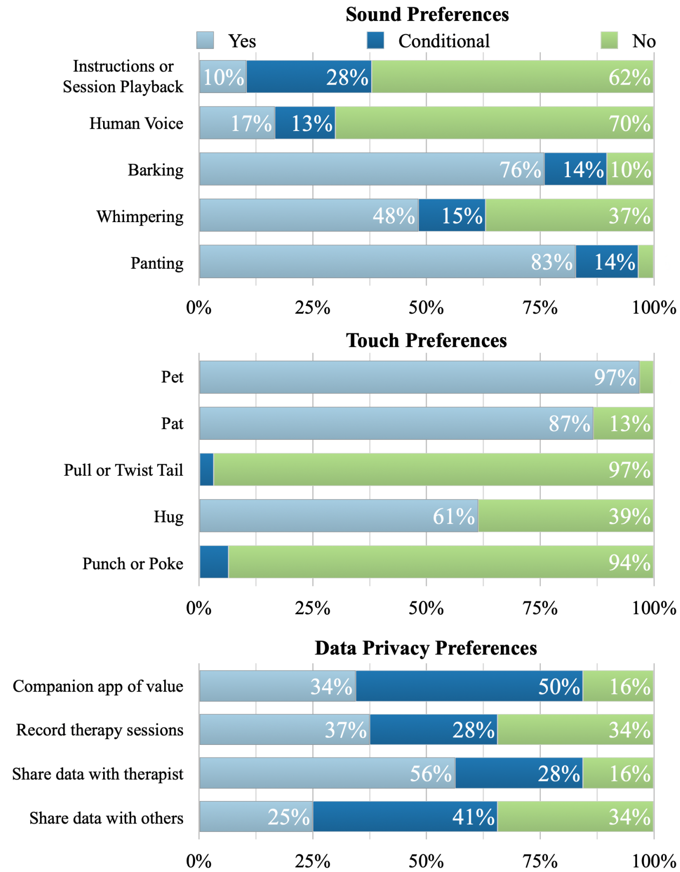

Fig. 3: Participant preferences for sound choice (top), type of touch (middle), and data privacy (bottom).

several imagined the robot having a distinct mode in which it might use a human voice for some purpose (e.g., to help guide a user), but that it would then return to using only dog sounds once the specific task was complete.

4) Touch: When discussing touch interactions with the robot, most participants indicated they would pet the robot (97%), pat the robot (87%), and abstain from twisting or pulling robot's tail (97%) or poking the robot (94%). Figure 3 indicates participant touch preferences. The two participants reporting they might poke the robot both indicated they would do this in an attempt to find its sensors. The participant who indicated that he/she would engage in tail pulling clarified that it would be in a gentle way. Participants were most divided on the idea of hugging the robot, with 61% reporting they would hug the robot and 39% not wanting to engage via a hug. Those responding that they would not hug the robot mostly felt it did not afford hugging, while a few were worried squeezing it might cause harm to the robot.

Among other desired touch interactions the most frequently reported were: rubbing the ears (7), touching the neck (4) and touching the nose (2). One participant mentioned rubbing under the robot's chin, another rubbing its belly. Gentle biting (similar to a puppy's play biting) was also mentioned once as a potential good touch interaction.

5) Privacy and control: After discussing the potential features of a companion app, participants were asked about considerations related to user privacy regarding the robot and app. Figure 3 reports the privacy preferences participants provided relating to the robot and app's potential collection and distribution of data.

When asked if the robot should be able to audio record therapy sessions, participants' responses were evenly distributed between acceptance, conditional acceptance, and denial. Most participants who indicated this feature to be acceptable or conditionally acceptable expressed it would be useful or convenient for a therapist that already recorded therapy sessions, few felt the ability would provide value to the patient. Those indicating conditional acceptance indicated that recording should only be allowed with patient consent and assured confidentiality/protection of the recordings.

Most participants felt that a therapist should be able to access data about the patient's use of the robot. Many participants indicated they assumed the therapist would access the data with the patient's permission and would use the data to enhance treatment. Some participants felt that allowing access to usage data would be harmful to patients and a threat to the trust developed as part of the therapeutic alliance.

Considering the ability to share data with caregivers, family, and friends, most participants felt the functionality had potential value but wanted the ability to control access. Most participants indicated this functionality would be helpful provided it was accessed by those committed to the patient's welfare. Among participants feeling the feature should not be included, many expressed concerns that data about the patient could be used against them by those with access.

Participants provided several important privacy concerns to be addressed in the design of the robot and companion app. Most frequently, participants indicated that users must consent to usage of the data being collected and shared. Participants felt that users should be informed of what data would be captured, where it would be stored, who would have access to it, and how it would be used. Participants also felt that significant efforts were needed to ensure the confidentiality and security of the data. Some participants mentioned the importance of visible indicators and understandable controls around capturing data. Two participants emphasized the importance of no video recording. One participant felt there should be a delay between the time data was recorded and able to be reviewed.

6) Comparison to a real dog: After viewing a short video of a living dog, participants were asked to compare and contrast the dog in the video to the robot dog they were holding. After making comparisons, participants were asked to indicate the biggest benefits and drawbacks to using the robot as a support companion.

Among the most frequently cited benefits of the robotic support companion were: low care demands (11), controllable / predictable nature (11), useful when real animal was not possible (7) and calmness (5). Participants also highlighted the added abilities, lack of feelings, and exemption from biological death.

The most frequently reported drawbacks to the robotic support companion were: non-realistic behavior (8), limited mobility (7), worry about damage and repair (5), lack of biological life (4), too reactive (3), lack of connection (2) and potential loss of interest (2). Participants also mentioned privacy concerns, tail sounds, battery charging, and potential expense.

7) Companion app: Participants were asked to consider the idea of a companion mobile application (companion app) that would allow users to communicate with and/or control features of the robot. Half of the participants (50%) felt the app might provide value to some but not all users, 34% indicated it would be uniformly valuable, and 16% felt a companion app should not be used.

Further discussing a companion app, participants were asked what features would be useful for patients using the robot. The most frequently reported features were: adjusting robot settings (9), messaging the robot remotely (3), direct control of the robot's movement (2) and interacting with the robot's character over long-term (2). One participant thought the app should allow the user to set reminders, and another indicated it should help the user track their own therapeutic progress. Among participants interested in configuring the robot, the specific settings mentioned consisted of: mood, tone, comfort level, volume, and mode (playful, relaxing, company).

Thinking of a therapist with a patient using the robot, participants were asked to describe features a therapist version of the companion app might include. The reported features included: viewing robot usage information (13), accessing patient health data (6), configuring the robot's settings (5), setting reminders (3), delivering therapy homework or surveys (2), communicating with the patient (2), and receiving alerts if the patient is in distress (2). Participants reported a similar set of possibly useful features regarding a version of the companion app for use by caregivers, family, and friends. The reported features included: monitoring the patient's condition (7), updating the robot's settings (5), viewing robot usage information (4), receiving notifications if the patient's condition is poor (4), remotely controlling the robot (3) and communicating through the robot (3).

8) Almere Model Survey: An analysis of responses to the Almere Model Survey conducted at the end of each study session indicated statistically significant differences between study conditions for four items. Differences were identified through a one-way ANOVA and post-hoc tests (Tukey) were conducted to identify the specific conditions with significant differences with effect sizes reported as Cohen's d (all large

Item	None	Stuffed	Robot	F(2,29)	p	Effect Sizes
It is good to make use of the robot.	4.55 (0.52)	4.8 (0.42)	4.09 (0.7)	4.29	.02	d=1.22
It would be convenient for me to have the robot.	4.09 (0.54)	3.8 (1.03)	3.18 (0.75)	3.78	.03	d=1.39
I think family/friends/therapist would like me using the robot.	3.73 (0.65)	3.8 (0.42)	2.91 (0.94)	5.21	.01	d=1.01, d=1.2
I think it would give a good impression if I should use the robot.	3.45 (0.82)	3.5 (0.53)	2.55 (0.52)	7.6	<.01	d=1.31, d=1.81

TABLE III: Means and (Standard Deviations) for Almere Survey items with significant differences ($p < .05$) between conditions. Shaded cells were significantly different compared to the Robot condition.

effects). Table III provides the means, standard deviations, main effect F-ratio, and post-hoc effect statistics for each item.

VI. Implications

The insights provided by participants in the design evaluation have implications for Therabot™, animal-like therapeutic robots, and therapeutic robots in general.

A. Aliveness and Realism

Many participants discussed the importance of the robot providing a sense of aliveness. The persistent heartbeat, panting sounds, warmth, and weight of the robot were noted as positive elements that created a sense of aliveness. A consistently reported deficit was that the robot did not fixate on the user's face, a behavior many felt was essential to demonstrate the robot's awareness of its surroundings and of the person during interactions.

1) Heartbeat and Breathing: Participants responded positively to the robot's heartbeat feature, noting that it created a sense of aliveness for the robot. One participant felt the rate was too fast and another thought an adjustable heart rate could be useful in helping the user relax. Since prior work has examined using artificial heartbeats to influence the state of a user [23] with some success, a more focused investigation on therapeutic applications of this feature merit further investigation. Though the heartbeat is produced using an audio surface transducer, few participants considered it a sound and two classified it as actuation. Additionally, a few participants thought additional persistent vibration or haptic aliveness would be helpful.

Related to heartbeat, prior work has shown that actuation mimicking breathing is an effective way to communicate aliveness and arousal levels via breathing rate [24]. While Therabot did not perform any actuation to mimic breathing, some participants interpreted the panting sound that played at randomized intervals to suggest breathing or aliveness. Platforms like the Haptic Creature and Cuddlebot have incorporated mechanisms for breathing [25], [26], but integration of similar mechanisms is difficult to achieve while maintaining Therabot's size and soft/squeezable characteristics.

The audio surface transducer (shown in Figure 4) was used exclusively for the robot's heartbeat sound, The audio surface transducer was used exclusively for the robot's heartbeat sound, but it may also be useful in creating fuller sounds that feel rooted in the structure of the robot, including sensations similar to breathing or purring. Additional surface transducers, small vibration motors, or subtle actuator movements could add a greater sense of aliveness.

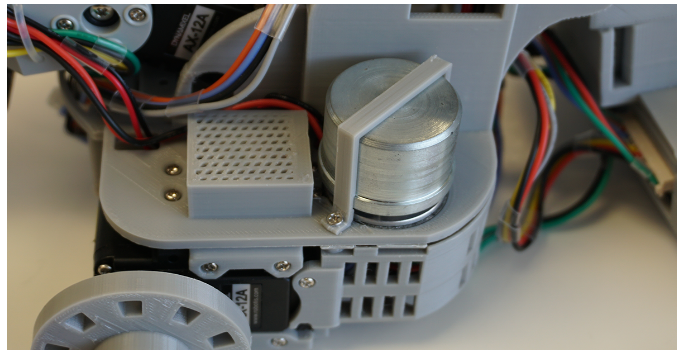

Fig. 4: An audio surface transducer mounted to the front structure of the robot provides playback of the robot's heartbeat.

When comparing the effects of study condition on heart rate, a significant difference was observed between those in the no support condition and those in the robot condition. In comparison to the no support condition, those with the robot experienced decreases in heart rate between baseline measurement and the first five minutes of the talk session. On average, participants in non-robot conditions experienced an increase in heart rate between baseline and the first five minutes of the interview. This finding indicates the presence of the robot during the talk session was beneficial in terms of heart-related measures. Further examination is needed to better understand what aspects of the robot contribute to these benefits. For example, would any novel interactive device produce similar results? This effect was not observed for the stuffed animal version of the robot, but there are many potential reasons (e.g., novelty, movement/aliveness of the robot, warmth of the robot, etc.). Future work should examine which aspects of the robot may contribute most to the differences observed in heart-related measures.

2) Warmth: Several participants noted the robot's body temperature as being important to providing a sense of aliveness, indicating an appreciation for its warmth. This insight was also provided from the opposite direction by two participants who experienced the robot immediately after its startup (prior to it becoming warm) spontaneously expressing that the experience would be improved if the robot was warm. Prior work with different robots and comfort devices have also found warmth to be a well-received feature [27].

3) Looking at the user: Participants advised that their experience with the robot would be better if the robot communicated social attention by looking at their faces (like a real dog). The evaluated implementation did not make any attempt to detect the user's position, instead, the robot simply moved in reaction to touch stimuli and internal timers with set probabilities.

While prior work has established the importance of head gaze in human-robot interaction [28], Therabot's limited sensing abilities pose a challenge to creating a spatial map of those interacting with the robot. The privacy-driven requirement that the robot not include cameras prevents computer vision approaches used on platforms like the Huggable and Probo [14], [29].

B. Privacy

As everyday artifacts increasingly gain computation, transmission, and retention capabilities, concerns about user privacy have increased. Work by Al-Saif examined privacy regulations related to animal healthcare robots in the United States and identified a need for supplementary regulation to protect user privacy [30]. Though participants in our study were asked explicitly about privacy concerns, most conveyed concerns about privacy prior to direct prompting.

Most participants felt the robot should be able to record and share data with a therapist, caregiver, family, or friend, provided the user was informed of the data that would be recorded, who it would be shared with, and gave consent to share. When discussing data sharing, several participants emphasized the need to be able to easily see who had access to the data the robot collected. A minority of participants expressed concerns that access to the robot's stored data could be abused and used to cause harm. A majority also implied or explicitly indicated that data stored by the robot should be encrypted and safe from unauthorized access.

When examining responses it is important to note that participants were aware that Therabot™ lacks cameras and the type of information stored and transmitted would primarily be about the user's environment (e.g., time spent in a dark room), interactions with the robot, or information supplied intentionally by the user to the robot (e.g., daily mood tracking). Regardless, it was clear that visibility and transparency related to information sensed by the robot are necessary.

C. Condition Differences and Limitations

Though no major differences were observed between conditions for the design feedback phase, significant differences were observed in four of the items on the Almere Model Survey. The two items assessing social influence indicated that in comparison to both the "no support" and "stuffed animal support" conditions, those in the "robotic support" condition perceived lower social acceptance of the robot. In comparison to those in the "no support" condition those in the "robotic support" condition felt the robot would be less useful. Finally, those in the "stuffed animal support" condition had a more positive attitude toward the robot than those in the "robotic support" condition.

In general the significant differences from the Almere Survey indicate that participants using the robot in the interview portion of the study had less favorable perceptions of the robot than those in other conditions. Since participants in the robotic support condition interacted with the robot for roughly twice as long as those in other conditions, it is possible this captures a novelty effect.

In addition to the amount of time participants were exposed to the robot, several other sources of variability and limitations should be kept in mind while making inferences from the data. The robot was configured to operate in the same manner across participants, but details of its behavior differed between participants. For example, touch sensor sensitivity shifts caused more sound playback for some participants. Similarly, if any of the robot's actuators reached a high temperature, they would be disabled temporarily to allow cooling. The robot's temperature also varied depending on its run time prior to a session. Overall these differences did not appear to greatly affect participant feedback, but taken together with the small sample size prevent useful statistical analysis of individual design features. Finally, any analysis of the data collected should be mindful of the context of the study related to users' experiences with anxiety and stress.

D. Future studies

We are currently developing a sound localization subsystem to aid in localization (similar to approaches taken with platforms like Paro [10]), but even in combination with the robot's other sensors it is unknown if the robot will be able to perform localization of users at an acceptable level. In future studies, we plan to investigate the types of indicators to best communicate the specific types of information captured. For example, in the case of recording audio, similar to many popular consumer products (e.g., home voice assistants) a persistent unavoidable indicator (like changing the colors of the robot's collar LEDs) is appropriate. However other types of data, like interaction frequency and a list of individuals with access to this data might be better candidates for periodic review, similar to mechanisms used on mobile devices that periodically remind users which applications are accessing specific data. To help balance user privacy with the robot's need to understand its surroundings, we plan to investigate the use of emerging techniques that use ultra-wideband (UWB) radar sensing technology to facilitate reliable person and activity detection. Early efforts using this approach to monitor patients in assisted living facilities while maintaining privacy have shown promising results [31], though incorporating the necessary hardware into the robot's form factor is not trivial. Overall the development of more privacy-sensitive techniques for sensing is a pursuit that could greatly widen the acceptance of robots in particular domains, especially related to companion robots.

VII. Conclusion

The design of a therapeutic, robotic support companion is a nuanced process, requiring iterative cycles of revision and evaluation. This paper has described insights gathered from participants about the design of Therabot™; we have also discussed the physiological effects on participants and how they varied between conditions. On average, participants in the robot support condition experienced more favorable heart-related performance changes than those in the no support condition. We believe these findings highlight the importance of aliveness behaviors in the robot and offer many avenues for future research in developing a robot that has use in both companionship and therapeutic domains.

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