SnuggleBot the Companion

Exploring In-Home Robot Interaction Strategies to Support Coping With Loneliness

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We explored the use of three robot interaction strategies to support people living with loneliness (physical comfort, social engagement, requiring care), by building these into a robot prototype and deploying the robots into homes for long-term evaluation. We placed our original prototype, SnuggleBot, unsupervised into the homes of seven people for at least 7 weeks (optionally up to 6 months), with bi-weekly interviews, to investigate how people engage with our three robot interaction strategies. Our qualitative analysis illuminated how people engaged the robot based on all three interaction strategies. Further, some participants showed signs of bonding with the robot as well as self-reported wellbeing benefits, while some participants failed to achieve sustained use over time. Our results provide strong support for future research into robots developed with our interaction strategies, and general potential for supporting wellbeing.

CCS CONCEPTS • Human-centered computing • Human computer interaction (HCI)• HCI Design and evaluation methods • User Studies

Additional Keywords and Phrases: Domestic Robots, Companion Robots

ACM Reference Format:

Danika Passler Bates, Skyla Y. Dudek, James M. Berzuk, Adriana Lorena González, and James E. Young. 2024. SnuggleBot the Companion: Exploring In-Home Robot Interaction Strategies to Support Coping With Loneliness. In Designing Interactive Systems Conference (DIS ’24), July 01–05, 2024, IT University of Copenhagen, Denmark. ACM, New York, NY, USA, 15 pages. https://doi.org/10.1145/3643834.3660702

1 INTRODUCTION

The ongoing global pandemic has highlighted loneliness as a public health concern [20][21], as living with loneliness is associated with negative wellbeing outcomes including reduced quality of life [4], lower cognitive function, depression, and cardiovascular disease [12]. Loneliness can be highly individual, based on a disparity between one's desired social connections and one's reality, making it challenging to design specific loneliness supports that work well for many; solutions can vary wildly between people [54]. However, there are general approaches (e.g., weighted blankets [10]) which can support people despite individual differences, highlighting the potential for broad solutions for many people. In this paper, we designed three robot interaction strategies inspired by loneliness mitigation techniques to support wellbeing, and conducted a longitudinal deployment to qualitatively study how people engage with these techniques in their daily lives.

Figure 1: A person cuddles with SnuggleBot: our companion robot we designed, prototyped, and deployed into homes to explore design strategies to support coping with loneliness.

Research has shown how social companion robots in general can support coping with loneliness, by using human- or animal- like interaction techniques that can impact people's feelings and behaviors, in similar ways to another person or a pet [52]. For example, research has demonstrated that social robots can increase motivation to exercise [18,29] or children's engagement in education [31], provide emotional support [33], can improve social engagement of people living with dementia [33] or children with autism [36], and overall generally improve quality of life [46]. However, these works are primarily in laboratory or highly controlled settings, and the field is still exploring how to design robots that successfully leverage these techniques while being deployed into people's homes (e.g., see [2,30]). For example, people regularly disengage after initial interactions [22,24]. Thus, in our work we focus on qualitatively exploring how people may engage with supportive robot interaction strategies in their homes and daily lives, to learn about use patterns and problems, to inform interaction designs that may garner sustained use and potentially support coping with loneliness.

We selected a set of three robot interaction strategies to support coping with loneliness and, using these, designed and implemented a novel robot prototype and interaction designs. Drawing from wellbeing literature, we selected the following three robot interaction strategies: have the robot provide physical comfort, social engagement, and require care. We drew on these to design novel robot behaviors, and implemented a novel prototype, SnuggleBot (Figure 1). Following, we deployed SnuggleBot into the homes of people who identify as lonely (seven people for 7 weeks, optionally up to 6 months), conducting a qualitative analysis to investigate how (and if) people engage with our designs within their daily lives, and if this sustained over time.

Our results indicate the overall success of our prototype and underlying interaction design strategies, in that they garnered our desired interactions and engagement with the robot. Our data demonstrated that people will engage in physically comforting activities (e.g., cuddling) with a home companion robot, generally interact socially with the robot, and will provide care. Further, people will readily embed a social robot into their lives (at least initially), and report it to be calming and reduce stress. This serves as an early step in a larger program of designing in-home companion robots to support coping with loneliness, providing specific designs and insightful data from in-home use that researchers can incorporate into companion robot designs.

2 RELATED WORK

A body of work has explored technology for improving mental health, supporting people who have clinical conditions such as anxiety [56,60], depression [6,14,51,56], and bipolar disorder [1,56]. Similarly, social robots have been leveraged to support wellbeing. We refer to wellbeing as "a positive state experienced by individuals and societies" that "encompasses quality of life and the abilities of people and societies to contribute to the world with a sense of meaning and purpose"[64]. Much of this work targets demographics with specific needs that can be less generalizable to other populations [52] such as children and older adults, or people in institutional settings such as in care homes and pediatric hospitals (e.g., [13,18,35,36,38,46,48,62]). For example, in one study hospitalized children showed more positive affect interacting with the teddy bear robot Huggable than a stuffed animal [40]. Engagement with the Huggable robot within homes over longitudinal use has not yet been studied, and this robot has not been studied with otherwise healthy adults, or in people's homes. We expand on the success of such projects by deploying our robot into the homes of healthy people who feel that they are lonely and by exploring a range of explicit design strategies.

In care homes, interactions with companion robots have been successful in increasing measurements of pleasure [39] and positive moods [33], as well as lowering levels of depression and loneliness [11] among residents. Social robots have also increased engagement among care home residents with other people [33,47]. This includes work with robots such as the social robot PARO developed for therapy for dementia patients [62], the Sony AIBO robotic dog, and the robotic cat NeCoRo. In our work, we draw on the successes from HCI and social robotics by designing and deploying a novel companion robot to provide comfort and engagement to members of the general public who identify as lonely.

Some wellbeing-oriented companion robot interventions are designed to be cuddly, such as the PARO robotic seal and the robotic cat NeCoRo which both have soft fur [39,62] and have shown to be engaging [39,41,43]. They can further support people living in care homes including dementia patients with various wellbeing measures such as increased positive moods and levels of pleasure [33,39], improved quality of life [11], and lower levels of depression and loneliness [11]. The soft pillow-like TACO robot was developed to support the mental health of hospitalized children, who hold the robot while it heats up and moves to simulate breathing for successful therapeutic effects when holding it [48]. Early successes of robots like PARO, NeCoRo, and TACO in controlled settings highlights the potential for a physically comforting companion robot like our design to provide comfort and engagement for the broader population, in less controlled and more natural home environments than studied with these devices.

While the Sony AIBO robotic dog has shown some success integrating into people's lives [34], and some work reported companion-like interactions with the iRobot Roomba vacuum cleaner [59], this has not emerged as a widespread phenomenon. Overall, the reasons for lack of widespread in-home companion robot use are not entirely clear. Perhaps it is because many support robots are research prototypes in care homes and hospitals that require support structures to facilitate the therapy [33] or teleoperate the robot (e.g., [40]). Robots such as PARO are further quite expensive [33] and difficult to repair [33]. There are also concerns that robots may not meet high expectations that people have, resulting in disappointment [30]. For example, some users of the Jibo robot [2] reported being disappointed in comparison with expectations based on marketing [2]. Our work contributes to these inquiries by providing longitudinal data on robot use, unsupervised in home environments and daily lives, highlighting potential avenues for eventual adoption and use.

Prior work on domestic robot adoption has identified factors that may lead to adoption such as hedonic gains [22,26,65], robot sociability [25,26], and privacy. We incorporate this work into our design of our novel companion robot for lonely people by making a robot that is enjoyable to use, sociable and maintains user privacy by remaining offline. Our project further draws from the successes of prior work that demonstrates the potential for companion technologies to support wellbeing, by designing a novel social robot companion for healthy adults living with loneliness. We focus on user engagement to encourage interactions and deploy our robot for long-term use in less controlled home environments, to gather early feedback on our design strategies.

3 PROTOTYPE DESIGN

The primary goal of our prototype design was to develop initial candidates that enable our longitudinal in-home qualitative inquiry, to gain real-world in-use data. Thus, we opted for a less formal design process to quickly generate candidate designs that we can deploy and iterate on, rather than more time-intensive and formal methods which would delay deployment. For our exploration we aimed to discover and incorporate potential interaction designs that may support coping with loneliness while being physically and technically robust enough for unsupervised long-term deployment into homes. Further, for privacy reasons we avoided solutions that would require remote monitoring or cloud computing, and restricted our exploration to solutions that would be completely offline.

We first explored loneliness and general wellbeing support from psychology and wellbeing research to identify candidate avenues to support people, and then engaged with informal (but structured) brainstorming exercises with our research group (e.g., sketching, paper prototyping), to discover potential implementations that met our technical and deployability needs. We built and informally tested several physical prototypes for robustness and usability as we worked toward our deployment model. Early prototypes appeared in workshops and poster sessions [49,50].

3.1 Wellbeing Support Techniques

We conducted an informal online survey on wellbeing literature (e.g., via Google, Mendeley, university library, etc.) by searching for "wellness" and "wellbeing". Our goal was not to do a formal or complete survey, but rather, to identify mechanisms to support wellbeing that show promise for use by a robot, including technical feasibility. This resulted in three overarching candidate robot interaction design strategies: the robot should be physically comforting, socially engaging, and require care from people.

Physical comfort – Wellness literature has established that providing physical comfort can improve wellbeing. A classic study demonstrated how infant monkeys prefer to spend time with a physically-comfortable mother proxy (cloth-made, warm) than with a non-comfortable proxy that provided food (cold, wire construction) [27], highlighting the importance of comfort compared to sustenance. Similarly, weighted blankets can reduce a person's anxiety [16], and physical warmth can proxy social warmth and promote wellbeing [5]. Lonely people tend to take more warm baths and showers, and holding a warm pack can provide comfort while recalling a negative social experience [5]. In therapy, people holding and hugging something can improve wellbeing and serve attachment needs (e.g., doll therapy for dementia [44]). For robots, people may prefer to hug soft, warm robots rather than cold, hard robots [7], and physical comfort has been prominent in companion robot designs that support coping with loneliness [11] and provide comfort [48] as with PARO, TACO, and Huggable. As such, we selected physical comfort as a target strategy in our design, and incorporated elements of physical comfort we identified from our informal wellbeing literature survey into our robotic prototype: soft materials, weight, and physical warmth.

Social engagement – Social engagement can invoke empathy and attachment [57]. Perhaps because of this, social robots commonly use anamorphism: life-like attribution, encompassing both people (anthro-) and animals (zoomorphism) to encourage social interaction [65], including the design itself (e.g., [62]), and how the robot behaves. For example, people may pay more attention to a robot that uses gestures [58]. Social robots are engaging (e.g., [31]), even compared to other technologies or simulated robots (e.g., [57]), and in one study perceived robot sociability was a major factor in continued use [25]. Further, lonely people appear to have a particular tendency towards anamorphism of nonhuman agents [15] and robots [17]. Thus, to support attachment we target social engagement as a key strategy of our robot design. We design the robot to be animorphic and to have attention-grabbing features and movements, building on the design of other social robots.

Requiring care – Pet ownership is a strategy for supporting wellbeing, providing a source of social support [42] and companionship [9], and daily life structure and purpose; pet owners tend to be less lonely [42]. Caring for "virtual pets" such as the Tamagotchi product can also promote emotional engagement, with children developing attachments and even asking parents to care for it while the children were in school [61]. To emulate similar effects, we target the robot requiring care as a design strategy.

Following this, we design for physical comfort, social engagement, and requiring care. We expect that the combined effects of our design strategies will result in an engaging robot that people interact with, perhaps bond with, and serves as a source of social interaction and support that can promote wellbeing.

3.2 Robot Interaction-Strategies Prototype

Physical Comfort –We built our robot into a soft stuffed animal format to provide a comfortable experience for holding. We purchased (and informally tested) a range of existing stuffed animals, avoiding branded designs (e.g., Disney characters) to reduce people applying existing impressions to the robot. We settled on a design (Figure 2) that was "cute," zoomorphic, and large enough to support both cuddling and embedding electronics (approximately 19 inches long and 10 inches wide).

We created a foam assembly to insert into the robot that holds and covers the rigid electronics. Through experimentation we settled on dense memory foam as it feels comfortable to hold and hug like a typical stuffed animal, adds weight to the robot, and is rigid to both mask electronics and wires from being felt during hugging, and to provide leverage for actuators to push against when moving limbs. We added weighted beads to further mimic the heavy feel of a weighted blanket. Finally, we placed a heated compress in the robot (explained below) to provide warmth to the user. Thus, we achieved our comfort strategy completely through design, without any mechanical or processing requirements.

Socially Engaging – We used a zoomorphic narwhal toy and created animal-inspired movements to leverage anamorphic tendencies to encourage social and pet-like interaction. To try and catch a user's attention and encourage social engagement SnuggleBot communicates when it wants attention by flipping its pectoral fins (arms) and using its glowing horn (Figure 2, changes colour depending on needs). Further, SnuggleBot reacts to receiving hugs by flipping its caudal fin (tail), to display happiness and encourage hugs. SnuggleBot is only active from 9am-9pm, outside of which it is "sleeping" to avoid bothering users (the horn is off, and it will not move). We liberally selected the long 12 hour

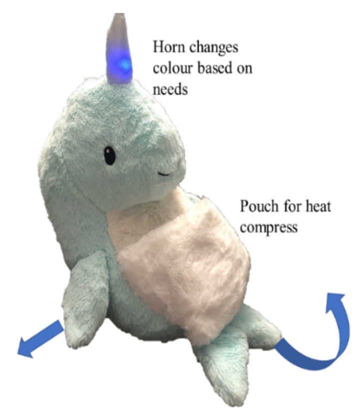

Figure 2: Robot with a glowing horn and a pouch for a heat pack, and actuated flippers and tail.

sleeping window to capture general expected sleeping or quiet times of our participants.

Requires Care – Our robot requires three forms of care to maintain its "happy" state: people need to keep it warm, give it hugs, and charge its battery. Users must keep the heat pad warm (Figure 3) by microwaving and returning it to the robot's tummy pouch (Figure 2). The horn turns blue when SnuggleBot is cold. Further, users must hug the robot, or SnuggleBot gets lonely, and the horn turns purple, and it intermittently flips its arms. When both lonely and cold the horn alternates between the colors (once per 0.75 seconds). The robot has an internal battery, charged via a port on its belly (resembles a navel); the horn stays red when the battery is low. For horn color interpretation, we embroidered a legend on the heat pad (Figure 3). These designed methods of caring for the robot aim to provide benefits of providing care, while supporting our comfort strategies of hugging the warm, heavy robot, and encouraging people to socially engage with it.

Figure 3: Embroidered heat pad explains the horn colours and warms the robot.

Implementation – We instrumented the stuffed animal using microcontrollers and custom circuitry. We built a hug sensor by using two pieces of conductive fabric, separated by pieces of velostat [1], where electrical resistance changes with applied pressure; we measured using a voltage divider. We further used a thermometer (embedded in a Wishiot DS3231 time module). We actuated the arms and tail using HiTec HS-422 servos, attaching wooden dowels to extend into the stuffed animal appendages. We embedded three RGB LED lights (in parallel) in the horn; the horn stuffing acts as a diffuser for the directional lights, making it viewable from all angles. All sensors and actuators were connected to a Pro Micro form factor Arduino clone (KeeYees) with a 4GB SD module for logging. This device is sufficient for all computational needs (basic sensing, state machine, and clock) and has low power demands. We added an off-the-shelf 6000maH, 12vDC battery pack (Talentcell), with a custom power harness (with regulator) to power the lights, motors, and Arduino. The robot can last for about two days on a full charge.

We placed the Arduino, modules, and voltage regulator in a project box to keep components away from the foam and stuffing. We mounted everything carefully within the robot to maintain the softness for hugging, using spray epoxy to affix the servos to the foam core (Figure 4). We placed the temperature sensor at the front near the heat pack. We placed the battery in a cut-out at the back and the weighted beads at the bottom to balance weight distribution and keep a low center of gravity for easy holding.

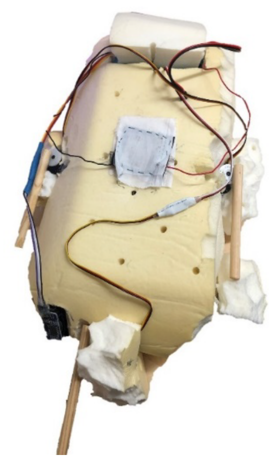

Figure 4: Foam skeleton to house the motors and circuitry of the robot.

We programmed a state machine (Figure 5) that monitored sensors and time to change the actuators and lights as needed. The robot enters a low power state based on a low voltage threshold (measured via a voltage divider to the Arduino) and will not leave this state until the battery is fully charged. The robot monitors the ambient temperature and assumes any rapid temperature gain means it was heated, and becomes cold when the temperature became near it was when it was last heated; it will not require heating more than once per 1.5 hours. The robot enters the lonely state if it has not recognized a hug in the past 1.5 hours, exiting this state as soon as a hug is received. We arbitrarily chose 1.5 hours as the period between the robot requiring hugs or heating, confirmed through informal

[1] Our sensor was inspired by https://www.instructables.com/Flexible-Fabric-Pressure-Sensor/

State Selection (evaluated from top 4/s)

Sleeping if time between 9pm and 9am

else:

Being hugged if detect hug
Low Battery if battery is low (hysteresis 9.4V-11.9V)

else one of:

Lonely if no hug in past 1.5 hours
Cold if no rapid temperature change in past 1.5 hours
Lonely and Cold if both above

else:

Content

State	Light	Tail	Pectoral Fins
Sleeping	X	X	X
Low Battery	Red	X	X
Lonely	Purple	X	Flips every 3 min
Cold	Blue	X	X
Lonely and Cold	Alternates blue and purple 1/0.75s	X	X
Content	White	X	X
Being hugged	No change from previous state	Flip at end of hug	x

Figure 5: Pseudocode indicating state selection of robot, and table indicating the outputs of the light, tail, and pectoral fins at each state.

experimentation within our group. We felt this duration represented a reasonable choice such that there would be frequent, but not constant, demands for attention from the robot. We logged all state transitions and outputs. This robot operates completely offline, which helps maintain the privacy of the user and lowers power demands.

4 DESIGN STRATEGY EVALUATION

The primary goal of our evaluation was to reflect on how people engage with a social robot in their homes with regards to our three novel robot interaction design strategies. We deployed our robot into homes to learn about participants' interactions with, reactions to, and thoughts regarding our robot interaction designs. We further evaluated the extent to which our design strategies encouraged their targeted behaviours (cuddling and holding the robot, repeatedly interacting with it, and caring for it) within a real-world context, to inform iteration on these behaviors. From these results, we aim to learn more about how to employ these strategies in robot design, and how practical they may be for supporting people. Successful results, and evidence of engagement and use, would support future exploration into concrete impact on loneliness outcomes. This would require a fundamentally different study design focused on quantitative robustness and not qualitative inquiry.

Instead of eliciting participant input as the first step in our design process, we design our initial prototype based on literature to enable us to involve people using a real robot within their homes, in a longitudinal study, to gain data grounded in real-use environments and contexts. Further, this allows us to gain insights based on current robot capability and mitigate issues relating to people's inflated expectations of robots that can cause disappointment [22,32] given current technical limitations [30].

We built five SnuggleBots, deployed them for 7 weeks (optionally longer, explained below) each into homes of people who self-identified as being lonely, and conducted a series of interviews and questionnaires to reflect on our design strategies.

4.1 Tasks and Robot Interaction

The core task of the study was for people to interact with the robot as if it were their own, so that we could gain grounded data as to how our robot is used in a real-world context. As such, we put careful attention to highlight to participants that they should feel free to interact with the robot as much or as little, and in whatever context or fashion, they would like. We introduced the robot to participants as a cuddly companion that they can interact with in their daily lives but provided little guidance beyond explaining the core robot purpose and designed interaction patterns. We explained that the robot will, on occasion, wiggle its fins, the meaning of the different horn colors, and how to care for the robot. We highlighted the instructions on the heat pack (Figure 3), and had participants try plugging in the charger and giving the robot a hug. However, we did not explain to participants exactly when (how often, etc.) the flippers or the tail would move, to explore freely how participants responded to these movements, given that they were designed as a social engagement strategy. If participants asked about behavior details such as precisely why or when the robot would move, we told them that the robot behaves depending on a range of factors including how and how often they interacted with it, and that it might move if it wants attention.

4.2 Measures

The primary author conducted and recorded scheduled semi-structured interviews (Zoom video as it was during the pandemic) where we inquired about designed-for behaviours such as generally engaging the robot, cuddling and hugging it, and caring for it, and opinions of the design (see Appendix A.1 for interview questions). The interviews were approximately 30 to 90 minutes long. We further asked participants for diary entries once a week via an online form (paper provided upon request).

We measured self-report levels of participant loneliness, state anxiety, and mood at regular intervals to assess trends in level of wellbeing, via the UCLA Loneliness scale [53], State-Trait Anxiety Inventory [63], and participants' mood with the PANAS questionnaire [8]. We present these results to provide insight into potential impact on loneliness, although our sample size and study design (e.g., no base case for comparison) does not enable us to make generalizable conclusions from this data.

4.3 Participant Recruitment

We recruited participants 18 years of age and above who self-identified as being lonely and who lived alone. We used social media posts and bulletin boards posted in general local online groups and public spaces to attract as diverse a participant pool as possible. Participants were asked to provide pseudonyms to use in dissemination for their privacy. To reduce the chances of adverse participant reactions (e.g., when taking a robot back) as required by our ethics board we noted on recruitment materials that we cannot include participants with a history, current diagnosis, or suspected mental health conditions. As a study finished we re-furbished the given robot (cleaned, tested, repaired as needed, etc.) and deployed to a new participant.

4.4 Procedure

Drawing from existing longitudinal robot studies we leveraged a phased approach (Figure 6) for our procedure [3,23], using the following phases:

Initial intake: Before deploying the robot, we conducted an interview and conducted wellbeing-related questionnaires to learn about participants' expectations of the robot.

First-encounter: We delivered the robot to participants homes and conducted a virtual (via Zoom) robot orientation and study session where participants interacted with the robot. Participants filled out the wellbeing questionnaires, and we conducted an interview to inquire about participants' first impressions.

Ongoing: We asked participants to complete the wellbeing-related questionnaires and diary entries weekly. We conducted virtual (Zoom) interviews every two weeks to monitor ongoing interaction and attitudes toward the robot. This phase lasted a minimum of 7 weeks, but participants were given the opportunity to stay in the study for longer, up to a total study length of 6 months.

Exit: We retrieved the robot from participants upon completion, followed by a virtual exit interview. We were more direct than in previous phases (e.g., "What did you think when you saw the robot flap its tail?") where we wanted to limit the impact of our questions on participant perceptions. Participants completed the wellbeing questionnaires.

Follow-up: One week after the robot was returned, participants completed the questionnaires, and we interviewed them about how they felt with the robot gone.

Participants were compensated $20 CAD every week for the first 10 weeks of the study. If participants chose to extend the study, they were not compensated beyond the initial study length, because we wanted to learn if participants wanted to keep the robot in their home, and for how long, without the potential variable of a financial incentive.

Our study protocol was reviewed and approved by our institution's research ethics board.

Figure 6: The study phases, with data collected at each phase.

4.5 Analysis

We conducted a thematic qualitative analysis [28,37] on our data to investigate our core research questions relating to participant engagement with our robot design. We employed a mix of inductive and deductive coding, starting with an initial set of focal points and related data codes based on or design strategies. We added new codes as salient novel points arose in the data. Following, we group the coded data to uncover dominant themes in our participants' behaviours and opinions. We included a time-based analysis, grouping reported interaction frequencies and reporting on changes in interaction observed across participants. Finally, we pay attention to themes that emerge amongst multiple codes to discover cross-cutting inquiry points.

5 RESULTS

We recruited 7 participants from a range of backgrounds, presented in Table 1 with participant self-selected pseudonyms. We present the results from our qualitative analysis, supported by numerical robot log data, detailing results specific to our three interaction-strategies as well as cross-cutting themes throughout all the data. We provide summary quantitative data at the end of the results.

5.1 Reflections on Robot-Interaction Designs

Our primary analysis focused on our strategies: the robot providing physical comfort, social engagement, and requiring care.

5.1.1 Design Strategy: Physical Comfort

Physical Comfort – All participants but Pester reported that they found the robot comfortable, liking the robot softness (Vanessa, David, Dancer) and size (Vanessa, David, Dancer); in contrast, Pester found the fake fur unrealistic in comparison to a pet.

Four reported liking the robot weight (Vanessa, Dancer, Sheila, Leslie), while one (Art) found it awkward to handle and expressed concerns over others being able to hold it. Most (Pester, David, Art, Sheila, Leslie) did not comment on robot warmth although one (Vanessa) found the compress comforting, and another (Dancer) found the robot warm and comforting overall:

"I feel more secure, I feel warmer and safer at least a little bit, especially when I'm hugging it." -Dancer, Ongoing during week 7

Although they noted the limited impact of the heat pack:

"You couldn't really feel it that much unless you were specifically touching its pouch…. maybe you'd feel it a little bit?"-Dancer, exit

Physically Comforting Behaviours – All participants reported physical comfort behaviors: cuddling, hugging, and holding the robot. Some reported interacting daily (Pester, David, Art, Dancer, Leslie) while others less frequently (Vanessa, Sheila). Overall reported average was 2-5 interactions on days engaged. Some reported brief hugs (Pester,

Table 1: Summary of Participants

Provided Pseudonym	Age Range	Occupation	Pronouns	Description	Deployment Duration
Pester	70-79	Commissionaire	he/him	Last partner was 23 years ago, reports that "there's a couple things that didn't go quite right in the love department." Pester misses the companionship of his deceased dog.	12 weeks
Vanessa	18-29	Nurse	she/her	Reports difficulty spending time with friends since school ended. Has a partner (not co-habitating) Moved out on their own at beginning of study and moved back with her mother and brothers during study.	25 weeks
David	40-49	Survey Interviewer, Tennis Instructor	he/him	Spends time with his family and non-cohabitating girlfriend often but works remotely and lacks companionship during the workday.	7 weeks
Art	30-39	Customer Service Representative	they/she	Had just gone through a break-up and was in between jobs. Living alone with a pet cat for one month before the study. Previously lived with their partner	7 weeks
Dancer	30-39	Statistician/Methodologist, Tutor	he/him	Recently moved to Canada and does not yet have close friendships despite meeting people. Works from home and wants to see more people during the workday.	16 weeks
Sheila	40-49	Primary Occupation unknown, Cleaning	she/her	Living alone with two cats for the past 3 years, single for the past 12 years. Likes having her own space but misses having someone to go out to do things with.	7 weeks
Leslie	18-29	Aerospace industry	she/her	Recently moved out of parents' place, doesn't see friends or her family often. Moving while working long hours (12-hour shifts plus overtime) has been stressful.	11 weeks

Dancer), or held from a few minutes to "quite a few hours" (Leslie). Four took the robot to bed at night (Vanessa, Art, Dancer, Leslie), 1-5 times per week, or cuddled during a nap (Vanessa, Sheila). While some cuddled while sleeping (Vanessa, Dancer, Sheila) others kept it in bed without cuddling (Art, Leslie).

Some noted decreased hugging and cuddling frequency through the study (Vanessa, Leslie), with one (Pester) noting that he only hugged to serve the robot's needs and stopped by the end.

The log data echoes what participants reported, where we find evidence that all participants but Pester gave the robots hugs or cuddled with the robot beyond what the robot required to satisfy the lonely need. We observe up to 381 hugs being recorded on a given day (David), where hugs within 10 seconds of each other were filtered out. We note that for one participant (Sheila), the number of hugs appears to increase towards the end of the study after the robot was repaired. The participant reported to us that the robot appeared to be responding more than before the repair. It is possible that the positioning of the hug sensor shifted accidentally during the repair and the robot became more sensitive to pressure, making the number of hugs the robot recorded higher. It is also possible that because the robot was responding more, she gave the robot more hugs.

Attitudes Towards Physical Comfort – Two participants indicated pre-study that they were open to cuddling the robot (Pester, Art), and three expected that this may help reduce loneliness (Vanessa, David, Dancer). One (Leslie) initially expressed hesitancy:

> *"I would have to be more comfortable with it for me to do that ... like maybe in a few more days." -Leslie, First-encounter*

Concerns over embarrassment and social norms continued to emerge through the study (Pester, Dancer).

> *"I'm not going to take it to couch with me and wrap my arms around it, sorry….Because if I were to die and they found me like that I'd be embarrassed."-Pester, Ongoing during week 11*

5.1.2 Design Strategy: Social Engagement

Anamorphism Towards Robot – The zoomorphic design encouraged anamorphism, shaping how all participants interacted with the robot, e.g.,

> *"It feels like there's someone else present with you in your home… I feel like I'm very drawn to go like interact with the robot and pick it up and hold it and I feel like it's very therapeutic. It feels like a pet or like a baby or something." -Vanessa, ongoing wk 3*

most participants used animorphic language to talk about it, e.g.,

> *"he wagged his tail so it was almost like he was answering me you know what I mean?"-Pester, Ongoing during 5*

Although one used mechanical language throughout the study:

> *"I guess there's a timer on it that sets it to retrigger itself…" -Art, exit*

In contrast, some did behaviors not typical with living pets, such as putting the robot in the fridge to test its cold sensor and horn colour (Pester). Two (Vanessa, David) discovered that the robot tail would move if they forcefully manipulated the pectoral fins.

Robot Attracting Attention – All noted the horn and tail movements as easy to notice. In contrast, most (Pester, Vanessa, Art, Dancer, Leslie) often did not notice the arms moving:

> *"definitely expecting like the arm flippers to move a little more… I think I caught it doing it once, I'm not a hundred percent sure."-Art, ongoing wk1*

Two (Pester, Vanessa) thought this possibly meant the robot was broken (although logs indicated it was not). One (Pester) augmented the robot to increase arm-movement saliency.

> *"I left the plastic bag on… it makes a little bit of noise what I was thinking of doing was adding a couple of bells to his tail so I could cheat from my bed and hear him ding ding ding" -Pester, Ongoing wk 7*

Participants reported varying sense of urgency to respond when the robot wanted attention, with some (Pester, Dancer, Sheila, Leslie) reporting it was hard to ignore , responding quickly, while others found it easy to ignore (Vanessa, David, Art).

Once it attracted attention, we noted variation in response based on modality. Some (Pester, Dancer, Sheila, Leslie) found the horn color prompted them to attend to the robot, while two (Pester, David) noted more pressure from arm movements, e.g.,

"There's probably more of a sense to nurture it when it's actually making the noises or flapping its arms a little bit more."-David, ongoing wk 3

This may partially be due to the sounds that the robot made when it moved, with three participants (Pester, Leslie, Vanessa) noting that the sounds of the robot were more effective at attracting attention than the motion itself.

Tail Movement Feedback – Most (Pester, Vanessa, David, Dancer, Sheila, Leslie) noticed tail movement feedback when the robot received attention, and found it affirming (Pester, Vanessa, Leslie) and made them feel good (Pester, Vanessa, David, Dancer, Leslie).

"I sort of look forward to the tail wag because then it sort of tells me that I've done everything right you know?"-Pester, ongoing wk 5

Some (Vanessa, Dancer, Sheila) noted that this encouraged them to interact with the robot more, for example:

"It made me kind of giddy sometimes and it made me want to hug it more. Like just seeing that it was happy or trying to get my attention." -Dancer, exit

Desire for More Engagement – Most (Pester, David, Dancer, Sheila, Leslie) expressed a desire for more engagement such as more complex interaction, more needs, or more time awake:

"by forcing you to take care of it more, you would develop that bond quicker and it would have more of a presence in your life, as opposed to I guess it's easy to just like let it sit around sometimes. It would make it harder to forget about if it needed more attention"-Dancer, exit

"an animal might respond differently to different people depending on if they like the person or how excited they are whereas the robot you can just sort of make it react the way you want it to react by you know wiggling its arms or touching and it will react the same way…. There is a reaction but it's more of a consistent doing the same thing reaction than where an animal might react differently in different situations and take more of a lead role in initiating contact with a human"-David, ongoing wk 3

Some (Pester, David) noted that the robot was too predictable:

"I had a couple of dogs, you can kind of predict almost their every move sometimes, but they still might do some things out of the ordinary… they might surprise you from time to time, react spontaneously whereas the robot is probably too predictable."-David, exit

5.1.3 Design Strategy: Requiring Care

Caring Behaviours – All participants reported engaging in care through the study, including hugging, warming, and charging the robot. Some (Vanessa, Sheila) found this encouraged more interaction than, for example, a toy. All but one (David) expressed interest and enjoyment from the care, although frequency varied.

All responded to the robot when it needed a hug, self-reporting responding up to 8 times per day, typically with a hug but also holding (Vanessa, David, Sheila), cuddling (Vanessa, Dancer, Sheila), petting and touching (David, Art, Leslie), or carrying the robot around (Vanessa, Leslie). Others did non-social actions such as pushing on the robot (Pester) or manipulating its flippers (Vanessa, David) to register a hug.

All participants reported warming the robot, which we confirmed with robot log data, up to 5 times per day, although some missed days. Instead of heating the pouch some held to use their body heat (Vanessa, Art). Participants reported typically keeping the robot charged, although most reported leaving it uncharged for a day or longer at least once (Pester, Vanessa, Art, Sheila, Leslie), citing forgetting (Vanessa), being busy (Leslie), or no power source (Pester) while travelling. From the robot log data, we also observe that some participants left the robot uncharged at the very end of the study (Pester, Vanessa, Art, Leslie), ranging from the very last day (Pester, Vanessa), to the last 15 days (Leslie).

Some reported taking care of the robot less as the study progressed, for example, some (Pester, David) reported not hugging the robot by the end, instead using alternatives. Perhaps this was due to becoming accustomed to it:

> *"at the start I was trying to like interact with the robot a lot to learn about the robot and yeah take care of the robot a lot but now I feel like I kind of know the robot and <laughs> I feel like it's more chill now than trying to always like get the heat pack"-Vanessa, ongoing wk 11*

Or a dwindling sense of responsibility, even after three days:

> *"the initial start of feeling the responsibility to tend to it was fairly strong. But has dwindled over time." -Art, diary 1*

Impact of Care – Some found that caring contributed to companionship (Vanessa, Dancer, Leslie), increased lifelikeness (Pester, Art, Sheila) and sense of intelligence (Vanessa, Leslie); most compared the robot to a pet (Vanessa, Dancer, Sheila, Leslie). Care sometimes contributed to anamorphism, with some (Vanessa, Art, Dancer) discussing the robot's feelings:

> *"I do get a vague sense that I'm like disappointing it."-Art, ongoing wk 3*

> *"he needs me to charge him and he's probably cold, I feel bad, his light's probably flashing and he's wondering where I am." -Sheila, ongoing wk 3*

Some further found that care helped establish a routine (Art, Dancer), provide a sense of purpose (Pester, Vanessa, Dancer, Leslie), or made them feel needed (Vanessa, Dancer, Sheila).

> *"Makes you feel like needed or appreciated when you take care of the robot, it makes you feel like you did something good for the robot."-Vanessa, ongoing wk 19*

Some reported that, by the end, the care demanded too much attention and could feel like a chore (Pester, Art, Sheila), particularly when it interrupted tasks (Pester, Art) or when the participant was tired or sick (Pester, Art, Sheila).

> *"Because I've been so sluggish, it's been like flapping for attention and it's like 'I'm right here, I'm just not moving'"-Sheila, exit*

Lack of Care Urgency – There was some discussion on the fact that the robot was not alive, limiting impact of actions and bonding potential (Pester, David, Sheila):

> *"it's not life or death like a plant or a pet, like the light turns red... it's fine. Warm up his pouch or plug him in and he'll bounce right back so it's not like high stakes."-Sheila, ongoing wk 5*

Although one noted they performed care despite this:

> *"it has programmed stimuluses … but you know, that doesn't change the fact that I want to take care of it."-Dancer, ongoing wk 1*

5.2 Overall Interaction

We analyzed for general interactions with the robot beyond reflecting on the specific design strategies.

5.2.1 Integration Into Homes and Lives

All participants reported an initial positive outlook, for reasons including curiosity, a desire to help with research, and belief that the robot would be helpful to them. For home integration, some kept the robot next to them on a couch or chair while relaxing (Pester, Vanessa, Art, Dancer, Sheila, Leslie) or on a desk or TV nearby (Pester, David, Dancer). Placement was generally due to enjoying being near the robot (David, Art, Dancer, Sheila, Leslie):

> *"I actually put it on my desk next to my computer, so it was just kind of there hanging out with me while I was in training"-Dancer. Ongoing wk 9*

or to enable monitoring and responding to robot (Pester). While some moved the robot throughout the day to keep it near (Vanessa, Leslie), such as from the bed to the couch (Dancer), others (Pester, David, Art, Sheila) generally kept the robot in the same location. Participants reported interacting as often as "one thing per hour" (Dancer) and as rarely as no interaction for a week; interaction frequency decreased over the course of the study.

The robot log data further supported this decrease in interaction frequency for some participants (Art, Leslie), with some (Art, Sheila), interaction decreased sharply between the first and second week. Others (Pester, Vanessa, David) appeared to have variable but steady interaction throughout the study.

For daily interaction some cared for the robot while taking care of themselves (Vanessa) or pets (Art, Sheila), or when passing by (Pester, Dancer). Some cuddled or held the robot while relaxing, such as watching TV (Vanessa, David, Dancer, Sheila) or reading (Leslie). Work-from-home participants reported interacting during their workday, for example, caring and giving hugs, or holding it, as a break from work (Vanessa, David, Dancer). David reported interacting with the robot less on non-work days. Most left the robot home while on trips (Vanessa, David, Dancer, Sheila); although Pester took the robot to a vacation property.

David, Art, and Sheila continued the study until the 7 week scripted point, while Vanessa continued for 6 months. Leslie, Pester, and Dancer returned the robot after 11, 12, and 16 weeks, respectively. Withdrawal reasons included not feeling companionship with the robot (Pester, David), not having new things to say in interviews (David, Dancer), and inconvenience (Dancer) or a lack of time (Sheila, Leslie). One participant (Art) reported relief at no longer having the robot in their home, citing that it took up too much space in their apartment.

5.2.2 Bonding and Wellbeing

Participants overall reported that the robot promoted wellbeing, that it was comforting or calming (Vanessa, Art, Dancer, Leslie), had the potential to help (Pester) or helped with loneliness (Vanessa, Dancer), distracted from negative thoughts (Art, Dancer, Leslie), or reduced stress (Vanessa, Dancer, Leslie) or anxiety (Dancer, Vanessa). Some noted this as a potential result of robot-created structure and companionship.

> *"Living alone, my days can be a little unstructured beyond work, so having the robot to take care of has helped provide some routine and companionship in my day to day life." -Dancer, diary, wk 4*

One noted that caring provided an opportunity for self-reflection:

> *"how's the robot feeling? It's feeling lonely or cold. And I'm like do I have energy to take care of the robot, do I have like how am I feeling? Like maybe if I'm feeling stressed maybe I should take some time to cuddle with the robot because it will be good for me too"-Vanessa, Ongoing during week 23*

Some reported a sense of responsibility, with one (Pester) delaying going on an errand to wait for the robot to require a hug (Pester) or returning early from a social gathering to take care of the robot:

> *"wasn't paying any attention to him [the robot] you know? Felt a little bit, just for a couple of seconds but I remember that, ooh should I leave [the social gathering] now?"-Pester, ongoing wk 1*

Some (Pester, Art, Sheila) noted the conflict between feeling guilt and knowing that the robot was not alive.

> *"Honestly, it would feel bad, and then it was kind of like annoying because I'm just like 'it's a robot, like it's fine.'"- Sheila, exit*

When we asked participants if they felt that the robot was a companion, some (Vanessa, Dancer, Leslie) responded positively, while others reported a sense of companionship that faded over time (Pester, Art), or difficulty bonding altogether (David, Sheila).

> *"I was curious to see if it would develop into more of a bond. So, I mean it hasn't yet. It could maybe but um... since it hasn't happened yet, it probably won't happen but... at the same time I try to keep an open mind with it so." -David, ongoing wk 3*

Four of the Seven Participants (Pester, Vanessa, Art, Sheila) named their robot, but general signs of identity attribution did not emerge in our analysis.

At the end, of the study, most reported that they expected to miss the robot after giving it back.

> *"...actually kind of sad... it's been a constant companion for a few months so it's kind of tough seeing it go so. But I wasn't taking care of it anymore"-Leslie, exit*

Some did report missing the robot during the follow up interview while others noted they did not think about the robot much. One (Leslie) noted that they would miss the robot, despite lack of use.

We summarize the wellbeing-related questionnaires in Figure 7. Variation is high on the STAI and PANAS results, with patterns varying between participants. The UCLA Loneliness scale appears to show a slight decrease over time for many participants, and overall, given the sample size we did not conduct statistics.

5.2.3 *Emergent Interactions*

Participants reported interacting beyond our designed-for behaviors; all but one (Dancer) petted the robot, and some (Pester, Vanessa, Dancer, Sheila, Leslie) talked to it while caring for it:

> *"Typically when... it's cold or lonely. I'll baby talk it more like a dog, like it's a puppy that needs to be taken care of."- Dancer, ongoing wk 13*

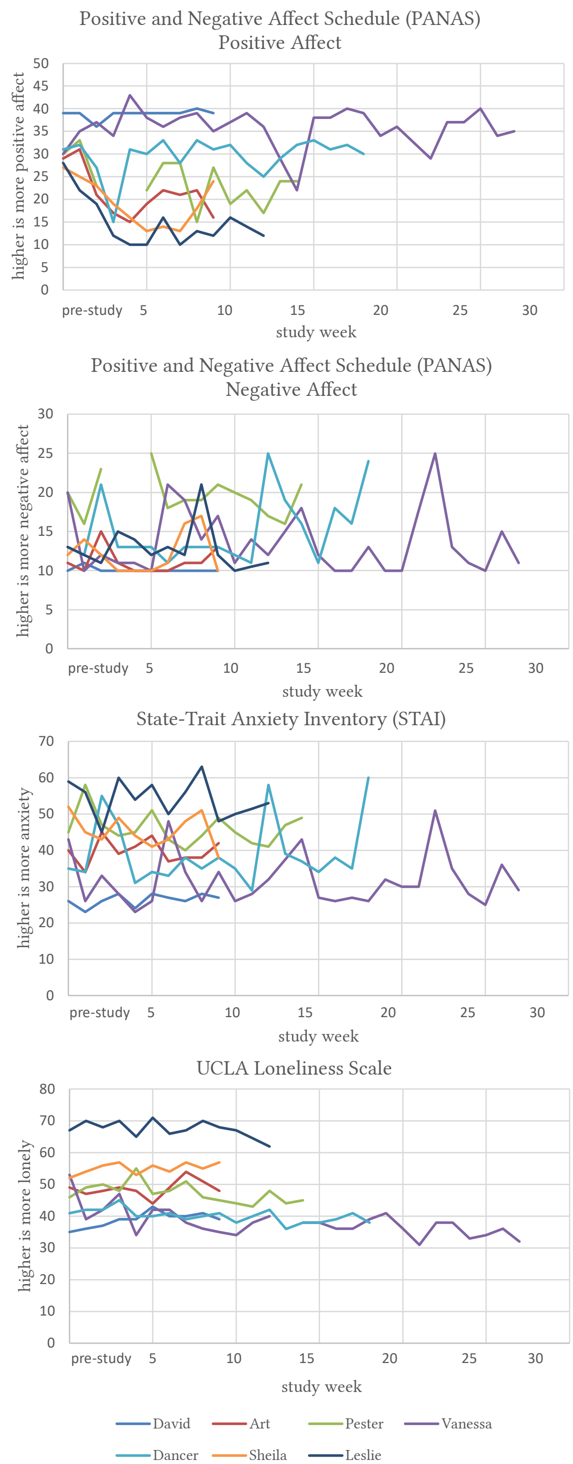

Figure 7: Summary of self-report wellbeing questionnaires results, by participant.

Some (Pester, Sheila, Leslie) further reported additional care such as trying to keep it clean:

“just in general wipe it down really and I try not to put it on the floor anymore I don’t like it getting dusty so”-Leslie, ongoing wk 7

Or modifications, such as adding plastic to make the movements easier to hear (Pester) or covering the horn to mask brightness (Vanessa, Sheila, Leslie).

“So I was reading, and I was holding it close <laughs> the light was a little too bright for me so I had to like cover it a little”-Leslie, ongoing wk 1

For most, the robot served as a social catalyst or served as a conversation topic (Pester, David, Dancer, Sheila, Leslie):

“It was definitely a conversation topic, …I think if there was a lull in conversation I could definitely bring it up for something to talk about”-Dancer, ongoing wk 3

Some shared pictures of the robot (David, Leslie), e.g., on social media (Vanessa), or showed the robot in person (Pester, Leslie, Vanessa, David). Pester invited people specifically to see the robot (Pester), although he noted potential stigma limiting this behavior.

“I don’t tell anybody about it other than neighbour across the back lane, or second cousin. I don’t really want to tell somebody I meet on the chinwag on the front street that I hug a little robot. You what? You’re how old? So I don’t.“-Pester, ongoing wk 5

5.3 Robot Log Data

We present the log data collected from the robot in figure 8, which indicates the number of hugs registered by the sensor, how often the robot was warmed, and how often the robot battery was depleted, as general indicators of engagement with the robot. We processed the hug data to filter repeat sensor triggers for a single hug by only registering one hug in a 10s window, and registered the robot battery being depleted by counting the subsequent boot indicators where the battery was still low (indicating the beginning of a charge from empty). Finally, we indicate days that a robot was being repaired on the graph. We note that the number of recorded hugs from the robot was often much higher than the number of times the participants reported responding to the robot’s need for hugs, with up to 100+ recorded hugs (David), but a maximum of 8 times a day of reported responding to the robot. We expect that this difference is due at least partly to cuddling or holding behaviour, as the robot will register multiple “hugs” if a person holds the robot for a period of time.

We excluded Dancer’s data completely due to ongoing technical errors with the logging system in that instance.

6 DISCUSSION

Our study results highlight the general success of our three robot interaction designs in encouraging their targeted behaviors. Participants found our prototype comfortable, noting the softness, weight, and size, and regularly held, cuddled, and slept with the robot. In terms of design, most did not comment on the robot warmth, suggesting that the heating power may not have been as effective as intended.

Our design successfully encouraged social engagement, with the overall zoomorphic design garnering anamorphism in how participants engaged and talked about the robot. Further, this led to peripheral behaviors such as having concern for the robot while away. A key point of this success was the robot movements, which participants responded positively to, particularly the tail motion. However, many failed to notice the arm movements, suggesting they were more subtle than intended.

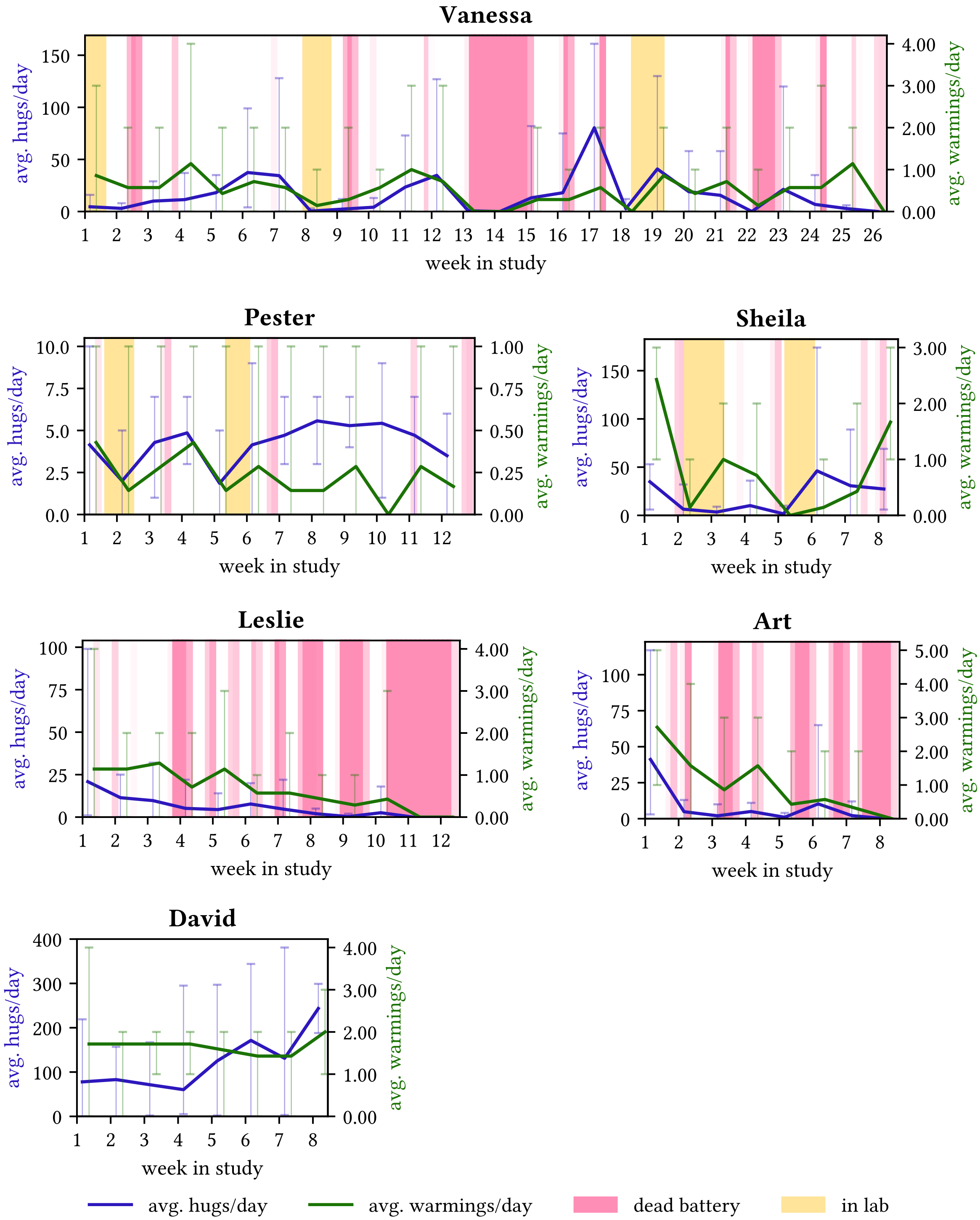

Figure 8: Weekly datapoints show average, min, and max for the week; trend lines highlight change between weeks. We note that the final week may contain less than 7 days worth of data as participants did not leave the study at exact weekly intervals. Shading: pink illustrates the robot died, with darker shade indicating higher proportion of day, yellow indicates in-lab robot repair days.

When noticed, the arms were effective at engaging people and created urgency to care for the robot, particularly in comparison to the light which some people covered to reduce visibility. Perhaps this is due to the light not fitting the animistic design; future work should continue to explore methods for lightweight attention-grabbing and communication, to support the animistic design while being salient yet not bothersome.

Our interaction strategy of requiring care was successful as all participants cared for the robot, and most participants reported wellbeing benefits because of caring for the robot. Some reported engaging in care not designed for, such as cleaning the robot, which is a promising avenue for future care-related designs. Some participants further exhibited signs of bonding due to the care activities, such as feeling guilt at neglecting the robot.

Care frequency varied and decreased throughout the study, with some reporting that the robot demanded too much attention and could feel like a chore. Some (Pester, David) found ways to care for the robot without demonstrating empathy (e.g., pushing on the robot instead of hugging it) - we note that these participants also report a lack of companionship by the end of the study. Thus, perhaps future work could investigate how to increase the stakes or importance of caring for the robot, to create a perception of sufficient benefits (vs. being a chore), as this may help develop companionship.

Combined, the care, comfort, and animorphic design resulted in many treating the robot similar to a pet or living thing and demonstrating signs of bonding and self-reported wellbeing benefits, including feeling an increased sense of purpose, improved structure, less anxiety, and leveraging the robot as a social catalyst. Further, while much of the numerical questionnaire data was noisy, suggesting individual patterns rather than general results, the UCLA loneliness scale suggests a potential reduction over time, which should be formally investigated with a larger sample size.

Overall, our three design strategies were successful in engaging participants, initiating bonding, and encouraging them to interact with it. In particular the widespread result of physical comfort is encouraging as a long-term use case, and participants keeping robots close supports existing research on how a common locus may support social engagement and attachment [45]. While our data provides avenues for improvement, in sum it supports the use of these behaviors in companion robots for homes.

However, our prototype had limited success with sustained interaction, reducing through the study. Most participants expressed a desire for more robot engagement and perhaps more complex interaction, suggesting continued exploration into increased interaction complexity or randomness, or to provide more avenues for engagement in future work. Our data highlighted that people who did not report engaging empathically with the robot (e.g., few or no hugs) also did not see the robot as a companion. This correlation provides an avenue for improving companion robot design as we should investigate how to encourage empathic behavior which may improve the sense of companionship. Perhaps one reason for this is that some participants were embarrassed about having a cute, cuddly robot; exploring alternative form factors to avoid this concern may improve engagement.

7 CONCLUSIONS AND LIMITATIONS

In this paper, we presented an exploration of robot interaction strategies for potentially supporting people who are lonely, using a longitudinal in-home deployment where people used the robot unsupervised in their daily lives. Our results provide strong support for the feasibility of our companion robot approach and our specific interaction designs –providing physical comfort, being socially engaging, and requiring care – and further provide insight into developing improved robot designs, while highlighting the ongoing challenge of sustained use over time. We further highlight that our robot was successful in achieving these interactions using simple technologies and without requiring online or other processing with potential privacy implications.

With our results that indicate that people generally engage with our three designed interaction strategies, and the graphs of our UCLA Loneliness scale indicating a slight decrease in loneliness over time, future work can now examine measurable impact on loneliness with larger sample sizes and controls in place. An initial power analysis [19] suggests a sample size of 20. Future work can further conduct a detailed analysis of participants' adoption patterns as they go through the process of adopting a robot with our interaction strategies, to inform the design of robots that will be more readily adopted. This work investigating adoption patterns is also needed to determine an appropriate study length to measure participants' change in loneliness over time.

Our findings indicate that future work should explore more avenues to encourage long term engagement, and methods of engagement that would allow for more complex interaction. Additionally, future work should investigate methods of reducing predictability, such as incorporating randomness into the robot's requests for attention.

We found that most participants named their robot, but we did not analyze participants' identity attributions in depth in this work. Future work can explore identities that participants attribute to the robot including gender and likes or dislikes.

Details of the robot circuit and build can be found on the project website[2], for use by future researchers and individuals who may want to build their own SnuggleBot robot.

A limitation of our study is that as participants frequently report on their interactions to a researcher, they may interact with the robot differently than they would outside of a study. Participants sometimes made comments that suggested that they were interacting with the robot for the sake of the study, indicating that they may have been trying to please the researcher. Additionally, the Hawthorne effect [55] may have impacted our data as the participants' behaviour may have changed as a result of being observed.

Overall, our work contributes to the growing field of technological interventions for wellbeing, and more specifically, for supporting people who are lonely. As social robots and companion technologies continue to advance, our findings provide novel approaches, an example feasible robot, and original nuanced feedback from participants who lived with our robot for 7 weeks to 6 months. We envision that our research will be useful to others to develop ongoing work in the area.

ACKNOWLEDGMENTS

This work was funded by the Natural Sciences and Engineering Research Council of Canada, through their Discovery Grants program, and was also supported by the University of Manitoba Graduate Fellowship from the University of Manitoba Faculty of Graduate Studies.

[2] https://hci.cs.umanitoba.ca/projects-and-research/details/snugglebot

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