A Social Robot for Anxiety Reduction via Deep Breathing

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***Abstract*— In this paper, we introduce *Ommie*, a novel robot that supports deep breathing practices for the purposes of anxiety reduction. The robot's primary function is to guide users through a series of extended inhales, exhales, and holds by way of haptic interactions and audio cues. We present core design decisions during development, such as robot morphology and tactility, as well as the results of a usability study in collaboration with a local wellness center. Interacting with *Ommie* resulted in a significant reduction in STAI-6 anxiety measures, and participants found the robot intuitive, approachable, and engaging. Participants also reported feelings of focus and companionship when using the robot, often elicited by the haptic interaction. These results show promise in the robot's capacity for supporting mental health.**

Fig. 1. A user practicing deep breathing with *Ommie*.

I. Introduction

Anxiety levels are on the rise. In a 2020 CDC study, 25.5% of American adults exhibited anxiety disorder symptoms, which was three times higher than in the year prior (at 8.1%) [1]. Among adolescents, a CDC survey revealed that 31.9% have had an anxiety disorder [2]. This rate increases into college, as a recent National Collegiate Health Assessment showed 37.4% of undergraduates as diagnosed or being treated for an anxiety disorder [3]. Many challenges exist in addressing this rise in anxiety, including access to treatment (e.g., therapy), cost of treatment, and compliance with behavioral therapy practices. Social robots have the capacity to help solve some of these challenges by providing distributed and consistent coaching, monitoring, compliance support, and companionship [4].

One effective behavioral method for anxiety reduction is a regular deep breathing practice, which consists of extended inhales, holds, and exhales. This practice has been shown to reduce heart rate and cortisol levels [5] as well as calm the autonomic nervous system [6]. Therapists treating anxiety patients often suggest at-home, daily deep breathing, however compliance with therapist-given practices is a known challenge [7]. Patients can have difficulty remembering to practice, practicing correctly, or sustaining motivation.

This paper presents a novel robot, *Ommie*, that provides support for practicing deep breathing for anxiety reduction. Our work is inspired by previous robotics research in supporting mental health, therapeutic haptics, and teaching new skills. We describe our core design decisions for *Ommie*, prototype construction, and the results from a usability study with participants of varying prior deep breathing experience.

II. Related Work

A. Social Robots for Anxiety and Mood Disorders

A number of human-computer interaction (HCI) projects explore deep breathing, often through wearable devices and biofeedback [8]–[10], but few robotics projects do so. As Rabbitt, Kazdin, and Scassellati outline, social robots have high potential to support mental health through their unique embodiment and interactions [4]. Closest to our work is *CAKNA*, a robot that verbally guides users through psychological techniques including deep breathing [11]. In a pilot study, *CAKNA* was shown to reduce anxiety levels moreso than a computer. Robots that support other mental health techniques include: (a) *PlantBot* [12], a robotic plant that reminds users with depression to perform certain activities; and (b) a modified *Jibo* robot [13] that delivers positive psychology interventions. While *Plantbot* has yet to show therapeutic impact, the *Jibo* robot provided measurable improvements in well-being. Our work expands these efforts by utilizing research-through-design [14] to create a social robot with haptic feedback to guide a deep breathing practice.

B. Therapeutic Haptics in Human-Robot Interaction (HRI)

The design of social robots to provide therapeutic calming effects, particularly through haptics [15], has been studied with multiple robots. *Paro* has been shown to provide therapeutic benefit via stroking the soft robot [16]. The *Haptic Creature* is another interactive animal-like robot, which also features breathing motions relevant to our work. Sefidgar et al. [17] have shown that holding and stroking the *Haptic Creature* stimulates a physiological relaxation response. Two other haptic robots feature breathing motions: *TACO* [18], a robot designed for anxiety and social isolation in children; and *Somnox* [19], a commercially available robot for adults with insomnia. Both robots feature abstract geometric forms. While *TACO* has yet to be tested for therapeutic benefit, the *Somnox* team reports successfully slowing down a user's breathing rate when held. Our work expands research in therapeutic haptics to an anthropomorphized robot that also supports practicing a skill (i.e., deep breathing).

C. Social Robots for Teaching New Skills

The efficacy of social robots in skills acquisition and behavioral compliance is well established, and coaching and tutoring robots abound [20]. For instance, Leyzburg et al. [21] showed that a physically-present social robot increases learning gains. Kidd and Breazeal [22] have shown that a social robot can have a measurable effect on compliance in calorie tracking and exercise. These results encouraged us to study an embodied social robot for developing another health skill: deep breathing. Our work explores the usability and feasibility of nonverbal haptic interaction for practicing this skill, with the longer-term goal of skill acquisition.

III. Robot Design

Over the course of 11 months, we utilized a research-through-design process [14] to design and test our robot. The core concept, a user placing their hands on a robot that expands and contracts, was initially validated by two clinical researchers with experience treating anxiety patients. They supported this concept for its clinical applicability, improvements over verbal instruction for deep breathing, and the known calming effects of tactile interactions.

We developed four design goals for the robot:

- **Calming**: The robot should provide a comfortable and calming experience to promote anxiety reduction.
- **Engagement**: The robot should inspire use and hold users' attention during interactions.
- **Haptic Experience**: Users should feel comfortable placing their hands on the robot and be able to tangibly feel the robot's breathing.
- **Instruction**: The robot should help users perform deep breathing in the correct sequence and cadence.

We applied these goals through the iterative development and testing of low-fidelity prototypes, such as foam mock-ups. This process led to a number of core design decisions:

1) ***Anthropomorphism****:* The question of whether to anthropomorphize a robot, or how much, is common to social robot design [23]. We knew that the body of our robot should feature a spherical form to avoid over-anthropomorphization [23] as well as invite familiarity with other objects people typically place both hands on (e.g., sports balls). However, the robot could remain purely ball-like (better facilitating cradling and suspected calming effects) or become more agent-like (likely affording more expressivity for engagement and guidance). Robots in the skills acquisition domain tend to feature anthropomorphized forms (e.g., [24]), while prior robots with breathing motions typically feature abstract or animal-like forms (e.g., [18]). We ultimately decided in favor of anthropomorphizing the robot with a distinct neck and head in order to optimize for interactivity. User testing of foam mock-ups of both modalities supported this decision.

2) ***Robot Scale****:* We chose the exact scale of the robot based on user testing with foam mock-ups of various sizes. It became clear that the smallest robot, at 7" body diameter, could potentially inspire care-giving tendencies that have been shown in other robots to enhance skills acquisition [12], [25]. Early testers commented on how they wanted to "*care for*" and "*felt more empathy for*" the smaller robot whereas larger ones felt "*intimidating*" or like they "*have the power*."

3) ***Tactile Breathing Experience****:* We prioritized the robot body's tactile quality as a way to invite haptic interaction with the robot. Past research on robot materials has shown a significant preference for compliant surfaces over hard ones [26]. We therefore decided to have the robot wear a soft "sweater" over a thick silicone skin covering moving plastic plates underneath (Figs. 1, 2). The silicone would provide cushioning and prevent finger-pinching, while the sweater featured a soft microfiber textile ideally reminiscent of clothing worn while relaxing.

4) ***Robot Expressions****:* We decided the robot head should have digital eyes, nodding head movements, and audio capabilities as these are well-known elements for social robot engagement [27], [28]. We designed these elements to be friendly and encourage the care-taking and empathy previously observed in testing. For the robot's eyes, we chose to imitate large googly-eyes used on early foam mock-ups, which were much-loved by users and provided an endearing "doe-eyed" look. For audio, we designed two sets of audio effects in Garage Band and Audacity software: chimes to signal different breath phases, and audio bites for different behavioral states. We created the latter by modifying recordings of human sighs, coos, giggles, and yawns.

IV. Robot Prototype

With foundational design decisions made, we built a fully integrated prototype for use with participants (Section V).

A. Mechanical and Electrical System

The prototype's body was formed from a series of Multi Jet Fusion 3D printed shells. The top shell is attached to a Dynamixel MX-64AT motor via a linkage mechanism to produce the robot's up-and-down breathing motion (Fig. 2). Each breath consists of approximately 2/3 of an inch of vertical displacement. A capacitive touch sensor is located on the robot's front plate for additional user interaction.

The robot head and neck were formed by Selective Laser Sintering 3D printing and feature one degree of freedom (nodding) from a Dynamixel AX-12A motor. The head also houses a USB speaker and two 2.2" TFT digital eye screens.

B. Software Controls and Robot States

The screens, capacitive touch sensor, and speaker are controlled by a Raspberry Pi 4B in Python. This system also controls the robot's behavioral states and two motors.

We implemented a simple set of behavioral states: (a) *Sleep*: randomizing between various "sleep breaths" with

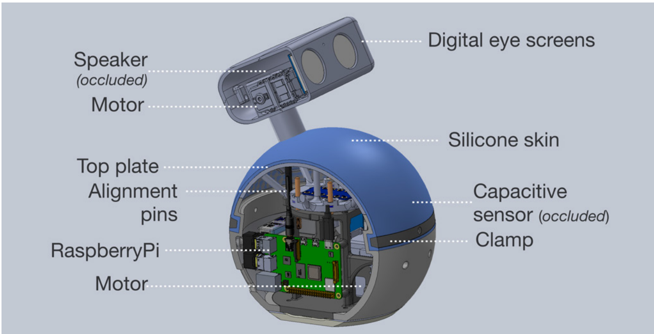

Fig. 2. A CAD model of the robot prototype. The moving top shell is constrained by a series of tracking pins as well as an overlaid silicone skin. The silicone is bound to front and back plates with a clamping mechanism.

audio coos and drooped eyes, (b) *Wake Up*: a transition state with audio and eye animations when the capacitive touch sensor is triggered, (c) *Idle*: micro eye movements while waiting to start a breathing exercise, (d) *Breathing*: moving the body upwards and downwards in a deep breathing cadence with closed eyes and audio chimes, and (e) *Celebration*: looking up at the user with joyful eyes and sounds before returning to *Sleep*. The breathing state was triggered via wireless SSH with specific breathing parameters (e.g., breath length, number of breaths, etc.).

V. Prototype Evaluation

We evaluated the *Ommie* prototype with a two-cohort usability study. Our goals included: (a) determining if we met our original design goals, (b) measuring the robot's ability to reduce anxiety states, and (c) gathering qualitative feedback on the robot interaction and imagined future use. All participant interactions were approved by our local Institutional Review Board.

A. Participants

We performed the study with two participant cohorts: a *wellness* cohort and an *anxiety* one. The *wellness* cohort consisted of 21 participants (12 female, 9 male) recruited through a local university wellness center. Participant ages ranged from 18 to 38 years with an average of 21.2 years. Fourteen participants (67%) had experience with deep breathing, with 6 (29%) having an active deep breathing practice at least once a week (of which 3 practiced everyday). The *wellness* cohort was not screened for anxiety and their results provided insight into any necessary study changes prior to testing with a more vulnerable population (i.e., those struggling with anxiety).

The *anxiety* cohort consisted of 22 participants recruited through the same wellness center and self-reported working with a therapist or doctor on anxiety reduction. Twelve identified as female, 6 as male, and 4 as non-binary. This male-to-female ratio is consistent with reporting on the prevalence of generalized anxiety in the United States [29]. Participant ages ranged from 18 to 29 years (average 20.9 years). All but one participant had prior experience with deep breathing, though only 8 actively practiced regularly at least once a week. None reported practicing daily. This distribution was not unexpected given deep breathing's prevalence in anxiety treatment but challenges with compliance.

B. Method and Measures

Each session lasted approximately 15-20 minutes in a private living room-like setting in the wellness center we partnered with for recruiting. The robot interaction consisted of: (a) being introduced to "*Ommie*" in its *Sleep* state on the table, (b) waking up the robot by rubbing it's "belly", (c) placing one's hands on the robot and being asked to match one's breathing to the robot's breathing, (d) breathing with the robot in a sequence of three 3-2-3 breaths (3 second inhale, 2 second hold, 3 second exhale)[1], and (e) observing the robot's *Celebration* and its return to *Sleep*. After the first breathing sequence and celebration, participants were given the option to breathe again with the robot in their lap.

For the *anxiety* cohort specifically, we measured pre- and post-interaction anxiety levels with a widely-used short-form version of the State-Trait Anxiety Inventory, the STAI-6. This short format features 6, four-point Likert scales (from "not at all" to "very much") on particular mood states (e.g., *relaxed* or *worried*). The short form has been shown to be comparable to the full-form survey for measuring current anxiety levels [30]. Participants completed the STAI-6 immediately before and after interacting with the robot.

An informational interview followed the robot interaction.[2] The interview began with open-ended questions on general impressions of the experience and continued with more targeted questions about topics such as physical handling of the robot and the robot's role. Following the interview, participants submitted an exit survey with a series of 7-point Likert scales of robot and interaction characteristics: *calming*, *approachable*, *engaging*, *desire to interact again*, and for just the *anxiety* cohort, *desire to use in the home*.

C. Quantitative Results

Overall, results showed positive regard for the robot in both cohorts and a measurable drop in anxiety measures with the studied *anxiety* cohort. All participants were successful in using the robot from start to finish and exit survey results show favorable rankings on all five characteristic scales (Table I). Overlapping exit survey data was analyzed between the two cohorts using Mann-Whitney U testing.[3] Notably, there was no statistically significant difference between cohorts on the four shared characteristic scales. We additionally split exit survey data into three experience-level groups: those with no deep breathing experience (7), those with an occasional practice (22), and those regularly practicing at least once a week (14). Between these groups, all scales had statistically similar results apart from *engagement*. *Engagement* scores for all groups were high: no experience averaged

[1]The 3-2-3 breathing cadence was the most accessible version of what our interviewed researchers use clinically. This specific cadence was not disclosed to participants prior to use, only what deep breathing is.

[2]The *wellness* cohort was offered the lap interaction during the interview.

[3]We used non-parametric tests as the exit survey and STAI-6 data were determined to be non-normally distributed with Shapiro-Wilks testing.

TABLE I

EXIT SURVEY RESULTS (7-POINT SCALE)

		Calming	Approachable	Engaging	DTI[1]	DTH[2]
Wellness	*mean*	6.05	6.19	6.10	6.24	n/a
Cohort	*std*	0.67	0.87	0.89	0.89	n/a
Anxiety	*mean*	6.32	6.09	5.68	6.00	5.36
Cohort	*std*	0.72	1.23	1.09	1.20	1.65
Δ	*p*	>.05	>.05	>.05	>.05	n/a
No	*mean*	6.14	6.00	6.43	6.29	n/a
Practice	*std*	0.64	0.76	0.49	0.70	n/a
Occ.	*mean*	6.14	6.05	5.91	6.09	n/a
Practice	*std*	0.81	1.26	1.08	1.12	n/a
Reg.	*mean*	6.29	6.36	5.57	6.07	n/a
Practice	*std*	0.45	0.72	0.90	1.03	n/a

[1] *Desire to interact again* [2] *Desire to use in home*

TABLE II

STAI-6 PRE- AND POST- INTERVENTION (ANXIETY COHORT)

		TA[1]	Calm	Tense	Upset	Relaxed	Content	Worried
Pre	*mean*	13.86	2.45	2.23	1.36	2.14	2.64	2.50
	std	2.92	0.60	0.75	0.66	0.64	0.73	1.06
Post	*mean*	10.27	3.23	1.59	1.05	3.00	2.86	1.73
	std	2.37	0.61	0.59	0.21	0.76	0.77	0.88
Δ	*mean*	-3.59	0.77	-0.64	-0.32	0.86	0.23	-0.77
	std	2.40	0.43	0.66	0.65	0.83	0.61	0.75
	p	<.001	<.001	<.001	<.05	<.001	>.05	<.001

[1] *Total anxiety, calculated with standard positive state reverse-scoring*

6.43 (0.49), occasional practice averaged 5.91 (1.08) and regular practice averaged 5.57 (0.90). However, those with no experience reported significantly more engagement than those with a regular practice ($p < 0.05$).

Anxiety cohort STAI-6 data was analyzed using Wilcoxon signed-rank testing (Table II, Fig. 3). All participants saw improvement in at least one anxiety state shift post-interaction. Reduction in total STAI-6 anxiety measurement was significant ($p < 0.001$), averaging 3.59 points (-25.9%).

D. *Qualitative Results*

We analyzed information from participant interviews by transcribing written notes and applying a modified affinity diagram technique [31] to distill patterns among individuals. Analysis revealed five core insight clusters.

1) ***Participants successfully completed deep breathing and felt comfortable with the robot****:* All 43 participants (including those with no deep breathing experience) were observed to successfully breathe in the same cadence as the robot's haptic instruction. When asked about their overall experience with the robot, many users commented on how "*natural*", "*easy*", and "*intuitive*" it felt. Their reasoning consisted of easy interpretability of the robot's breathing and similarities to other calming experiences, such as hugging a friend or petting a pet. All participants were also comfortable with the concept of placing their hands on the robot. A few described the first moments of feeling the robot's breathing as "*strange*" or "*odd*" but that they enjoyed it by the end.

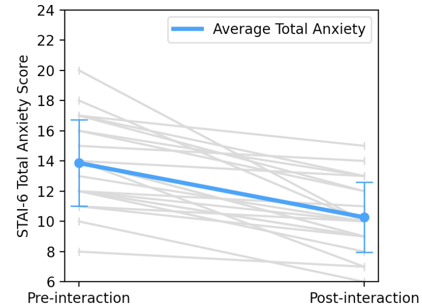

Fig. 3. STAI-6 Total anxiety measures of the *anxiety* cohort.

Nineteen *anxiety* participants (86%) closed or lowered their eyes when breathing with the robot, often a gesture of trust.

2) ***Participants tactically interacted with the robot in a wide variety of ways****:* All 43 participants opted to try the robot in their lap in addition to on the table. Overall, we observed 7 different variations of user hand placements with the robot on the table, and 10 variations when using it in a lap (Fig. 4). The preferred interaction modality varied: 23 participants preferred the lap, 12 preferred the table, 4 preferred the lap with certain modifications, and 4 had no strong preference. Those that preferred the lap cited physical comfort, better feeling the robot's breath, and the desire for a more "*intimate*" interaction. As one participant explained, "*[Ommie] felt alive and I wanted to be closer.*" Those that preferred table use similarly cited physical comfort and better feeling the robot's breath. They also shared wariness of the robot's fragility while on their lap or how using the robot on the table felt more "*filled with intent.*"

3) ***The haptic interaction provided focus, easy guidance, and connection****:* The vast majority of participants commented on the unexpected benefits they received from the robot's haptic breathing interaction. Both cohorts described it with such terms as "*focusing*", "*grounding*", "*anchoring*", and "*tethering*." A common reason for this focus was the ability to tune out thoughts and other distractions via the physical feedback. As one participant noted, "*I could let my hands guide me, not my thoughts.*" The easy-to-follow nature of the haptic guidance also contributed to feelings of focus. One participant elaborated, "*You don't have to process [the breathing]... it's just there. You know when to do it.*"

Multiple participants also preferred the robot's non-verbal guidance, inclusive of both the haptic movements and audio chimes, to verbal meditation. As one explained: "*one problem with meditation is focusing on words and the voice over focusing on yourself. With Ommie... I was focusing less on Ommie and focusing more on myself.*" Other participants commented that the haptic feature provided a closer relationship with the robot. Many compared the experience to "*embracing*" or close contact with a friend, with one participant sharing that "*feeling the motions of the robot brought a deeper level of connection.*"

4) ***Participants saw the robot's role as one of helpful companionship****:* While the exact terms they used to describe the robot's role varied, all but one participant in the *anxiety*

Fig. 4. Examples of participant hand placements during haptic interaction with the robot.

cohort and the majority in the *wellness* cohort spoke of the notion of companionship. This manifested in descriptions of the robot as "*pet*"-, "*friend*"-, "*child*"-, or "*companion*"-like and phrases like the "*tangible feeling of someone doing this with you*." Multiple participants also drew an analogy to the motivating social aspect of group meditation. Notably, 11 *anxiety* cohort participants (50%) spoke of a dual role of companionship combined with a more intentional and skilled level of help or instruction (such as from a "*teacher*", "*professional*", "*coach*", or "*therapist*"). Six specifically noted the duality with a pet-like companion, for example: "*[it was] like sitting in a therapist's room, but the therapist is a little cute animal.*" One user found the dual hierarchies strange, but the majority stated they were unphased by the combination. Instead, participants expressed the advantage of being guided without feeling commanded or bossed around. Rather, as one user put it, that the robot is "*someone trying to help me*."

5) ***Participants could imagine using the robot at home and how it might solve existing challenges with practicing deep breathing****:* From the *anxiety* cohort exit survey, 16 participants had clear interest to use the robot in their home, 4 had little interest, and 2 were somewhat interested. Those with high interest described the robot as solving past challenges with sustaining a deep breathing practice such as: (a) remembering to practice (particularly when in a high anxiety state), (b) keeping count of their breathing, (c) getting distracted on their phones when using mobile apps, and (d) feeling "*alienated*" or overly "*commanded*" by a voice. They saw the robot as meeting these challenges with its physical presence, haptic interaction, ease of use, and companionship. Five *anxiety* cohort participants (23%) also commented on faster time-to-relaxation (*"I relaxed way quicker than my normal 5-10 minute exercises!"*). Those with little interest in home use cited existing expertise, mobile app preference, and worrying about possible judgement from others.

VI. Discussion

Overall, our results validated meeting our original design goals. We additionally obtained a few surprising findings:

A. Focusing Effects

We did not expect the haptic interaction to provide such a focusing experience in addition to instruction and haptic calming. One could have expected those with a regular breathing practice to be impervious to the robot's guidance; or, for those without one to lack the experience required to become so quickly focused. Instead, participants from varying experience levels among both cohorts reported the focusing effect. We suspect that this effect results from simultaneous sensorial enhancement and occlusion. Tactically feeling the breathing guidance likely allows users to block out the visual world, as well as reducing the need to be auditorily present. It additionally may allow participants to tune out their conscious mind by providing a new stimulus to focus on. Given that current technologies designed to support deep breathing (e.g., mobile applications, recordings, and certain robots) do not provide tactile feedback, we see *Ommie's* focusing effect as a unique characteristic.

B. Tactile Versatility

We were surprised at the multitude of ways participants managed to hold the robot. In mock-up testing, users always placed their hands on the robot's "shoulders." We suspected this felt like the most appropriate way to handle an anthropomorphized robot with a certain level of agency and imagined the same from the usability study. Results showed otherwise, as illustrated in Fig. 4. One participant statement made us consider a potential reason why: *"[the lap use] felt very intimate at first… am I invading something's personal space? But, Ommie seemed to want it."* We theorize that study participants felt comfortable customizing their hand placement because of certain invitational features: (a) an introductory haptic experience (rubbing the robot's belly), (b) the robot's sweater providing a soft feel and the notion of being clothed (versus a distinctly un-clothed foam mock-up), and (c) the robot's expressions providing the oft-stated *pet*- or *child*-like nature and affording care-giving touch.

C. Companion Role

We were not certain how participants would interpret the robot's role and found it notable that nearly all participants described it as one of companionship. One could imagine those with deep breathing experience seeing any sort of guidance as over-instruction, or those struggling to practice seeing mere companionship as not enough. We find the companionship result potentially beneficial, however, given that teacher- or coach-like relationships can sometimes introduce stress or pressure. Notably, even those participants using terms such as a "*coach*" or "*teacher*" always did so in tandem with describing a companionship component. We see this as evidence of a balancing act for mental health and HRI: providing enough guidance so that users know how to do a behavioral practice correctly, but with a gentle enough touch to retain feelings of closeness and partnership while avoiding those of judgement. We suspect that users felt this balance due to the robot's friendly, approachable nature as well as the haptic interaction, which afforded a level of intimacy similar to encounters with close friends or pets.

D. Limitations

Our study shows promise; however, there are certain limitations to our work. For instance, our usability study was performed with young adults and the results may not translate to other populations. Also, the wellness setting of our study had a relaxing ambiance, potentially contributing to reported feelings of calm and focus versus the robot alone. Additionally, testing sessions were relatively short per participant, rather than the longer and repeated sessions required for developing a daily deep breathing practice. We suspect long-term home use will bring additional challenges (e.g., novelty effects, sustained engagement) and see our results as warranting deeper investigation into these unknowns.

VII. Conclusion

In this paper, we introduced *Ommie*, a novel social robot to reduce anxiety by supporting a deep breathing practice. We described the development of the robot and key decisions in areas such as morphology, tactility, and expression. A usability study showed that our robot is easy to use and generates an approachable, engaging, and calming experience with measurable anxiety state reduction. Additionally, *Ommie* provides elements of focus, companionship, and guidance relevant to building a regular deep breathing practice.

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