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Signalling Emotions with a Breathing Soft Robot

Troels Aske Klausen^{1,*}, Ulrich Farhadi^{1,*}, Evgenios Vlachos², and Jonas Jørgensen³

Abstract—A novel abstract non-humanoid soft robot with four pneumatically actuated chambers was developed with the aim to signal specific emotions by altering its shape, movements, and breathing rates. Through a user study we investigated how observers perceived the robot’s emotional state at different breathing rates. An online questionnaire utilizing the Self-Assessment Manikin scale was used to evaluate pleasure, arousal, and dominance. Our findings show that a slow breathing rate between 7-12.5 breaths per minute corresponds to a high level of pleasure, whereas a high breathing rate of 40 breaths per minute corresponds to a high level of arousal. Participants’ gender, in addition, influences the perception of pleasure and arousal at different breathing rates. The findings demonstrate the possibility of signalling emotions through breathing patterns with a non-humanoid soft robot.

I. INTRODUCTION

When designing an interface for human-robot interaction (HRI) face-to-face communication between humans is often considered to be the ideal model. In human communication the interaction outcome is oftentimes determined not by what is being told, but by the way it is being told. According to Mehrabian [1], only 7% of the communicated message is due to spoken language, whereas 38% is due to paralanguage (the non-verbal audio part of speech), and 55% of it is transferred by facial expressions. Paralinguistic respiration (including sighing, ”a variably prolonged ingress of respiratory air followed immediately by a longer egression”, and gasping, ”sudden intake of air that actually interrupts breathing” [2]), as well as breathing patterns are two of the many nonverbal communication (NC) cues that exist. While robotic speech and robotic facial expressions are currently being extensively researched, the effects of breathing in robotic communication is an area that needs further investigation.

Respiration in animals is generally linked to inhaling oxygen and exhaling carbon dioxide. Breathing is, in addition, linked to several higher brain functions like emotions and feelings [3, 4]. There is a connection between respiratory rate and arousal, as well as auditory, olfactory, and visual stimuli [4, 5]. Internal and external changes in the environment can affect the autonomic functions involving breathing [4]. It has been known for a long time that breathing can alter a person’s state of mind and be used to regulate emotions [4, 5, 6], but

only recently was a cluster of neurons discovered in mice linking breathing to relaxation, attention, excitement, and anxiety [7]. Breathing practices and techniques to regulate well-being date back to at least 200 B.C. where Buddhists practiced Yoga breathing (*pranayama*) [3]. Deep breathing has been shown to reduce stress and anxiety [7, 8], and is used clinically to prevent excessive arousal and stress in panic attacks [9]. Changes in respiratory patterns have been found to be correlated with activation in the amygdala, which is thought to play an important role in human emotion and behavior [4]. A study found that test subjects did not have any changes in their heart rate, oxygen consumption, and carbon dioxide production when experiencing anticipatory anxiety and changes in respiratory rate [10].

Breathing is, unlike the heartbeat, not just a rhythm with a frequency that fluctuates between fast and slow. There exist many different types of breathing patterns expressed as, e.g., sequenced chest or belly breathing, gasping, yawning, or sighing. Within the traditional Japanese performing art *Noh* performers wear masks and cannot convey emotions through facial expressions, but use faster breathing rhythms when expressing negative emotions [11].

In the present work, we investigate attribution of emotions in human interaction with soft robots. More specifically, we focus on how altering the frequency of a cyclical inflation and deflation pattern, which we refer to as ”breathing”, affects people’s impressions of a soft robot’s emotional state. The study focuses on the feasibility of using breathing as a nonverbal means of expression and communication and examines if different breathing rates are perceived as expressing distinct emotions on the dimensional scales of pleasure, arousal and dominance. Extending recent work [12, 13, 14, 15, 16, 17, 18] showing that pneumatically actuated soft robots can be perceived as socially communicative agents, we developed a non-humanoid soft robot capable of altering its shape and movements to signal emotions. *Signalled emotions* are emotions that the robot engineer wants to show to the robot’s interaction partner via the robotic interface, and intends the interaction partner to recognize as displayed [19]. Within social robotics, signalled emotions are commonly used to facilitate, ease, and enrich HRI. Using robotic ”breathing” for signalling and facilitation of interaction with soft robotics holds great potential, as pneumatic actuation is the most commonly used actuation technology within soft robotics [20]. Most pneumatically actuated soft robots can generate ”breathing” motions (cyclical inflation and deflation), and breathing is thus already built into them as a possible communicative means. Moreover, pneumatically actuated soft robotics parts capable of ”breathing” could be added to

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humanoid and android robots to increase their lifelikeness and affective expressivity.

In the following sections, we describe the design and fabrication of our breathing robot, present the study methodology and hypotheses and our results and, finally, discuss our findings.

II. DESIGN AND FABRICATION

A. Design considerations

Considering the technologies and materials available for pneumatically actuated soft robots, the following design criteria were established. The robot should:

- be approx. 10-20 cm in size;
- be perceived as resembling a living organism, yet be non-representational;
- not fall into the uncanny valley;
- be able to perform asynchronous two-part breathing similar to human breathing that activates the chest and the stomach regions independently.

Various sketches of design ideas were executed to end up with the selected robot design (Fig. 1).

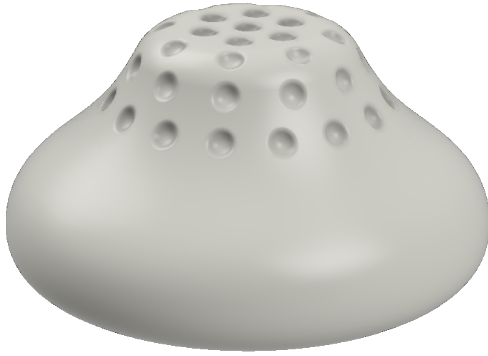


Fig. 1. CAD rendering of the soft robot morphology.

The morphology consists of a rounded, organic abstract shape with vague resemblances to a mushroom or a jellyfish. We chose this design, as we did not want the robot to directly resemble a human torso, yet it should have two inflatable layers that operate independently to emulate the asynchronous movements of the human chest and belly during breathing. The morphology consists of two parts. The bottom part of the robot is split into three separate air chambers that can be controlled individually. This allows the robot to tilt towards every direction within a full circle of 360 degrees. The bottom chambers enable upward movement if they are all inflated simultaneously. The top part of the robot consists of a smaller air chamber. Inflation of the top chamber makes the robot expand upwards but also makes it increase in width. A structure of small indentations in the silicone material were added to the surface of the top part to give it a more textured skin-like appearance. The robot is 12 cm in diameter at the bottom and has a height of 6.2 cm.

B. Fabrication

We used molds designed in Autodesk Fusion 360 and 3D printed in PLA to cast the robot. Ecoflex 00-30 silicone degassed in a vacuum chamber at -1 bar for 15 mins. was used for the casting. A multi-step casting technique was used (Fig. 2).

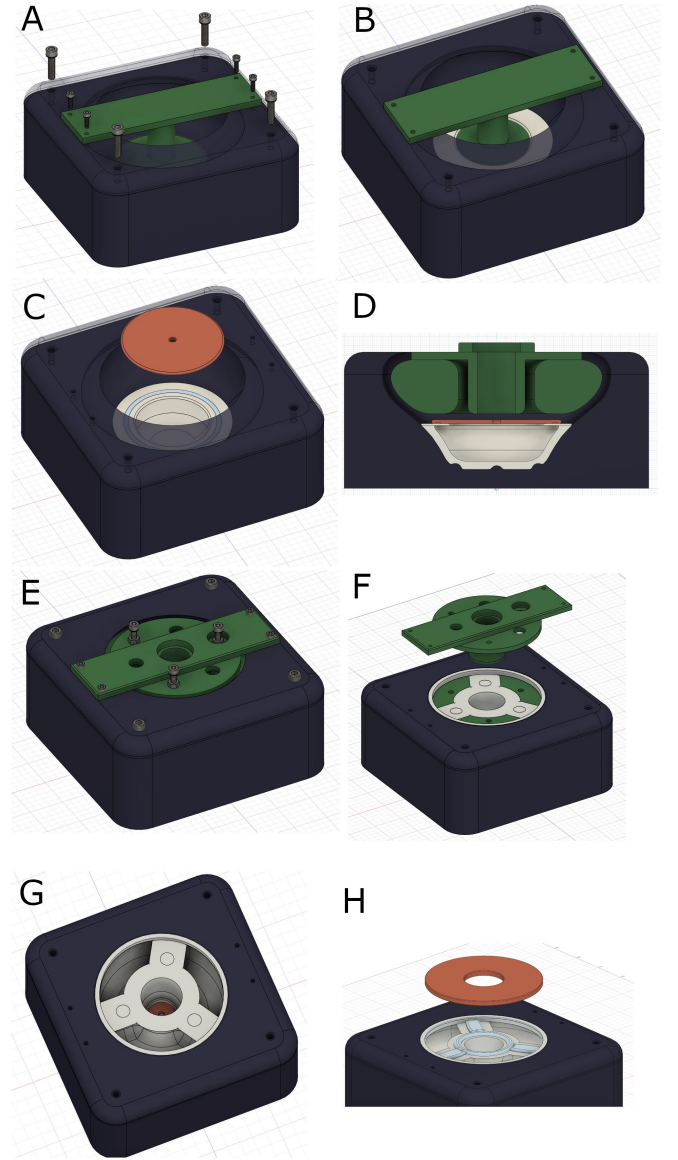


Fig. 2. Overview of the fabrication process. The following color coding is used: anthracite is used for the main mold; dark green for parts used to create internal chambers (inner mold parts and holders); light blue (C, H) represents liquid prepolymer silicone, white is cured silicone, and orange is silicone-coated fabric.

1) *Casting the top chamber:* To cast the top chamber, a holder and an inner mold part were screwed into place with bolts (A). 60 g of silicone were poured into the mold to just cover the top part of the inner mold part (B) and left to cure for 4 hours at room temp.

2) *Removing inner mold and sealing top chamber:* The inner mold part was taken out. Liquid silicone was applied manually with a brush to the lip at the top. A disc of silicone

coated fabric was placed on top to close the hole (C) and left to cure for 4 hours. The disc was perforated in the center and pneumatic supply tubing inserted and glued in place with SilPoxy glue.

3) *Casting the bottom chambers:* To create the 3 bottom chambers a similar procedure was used. A rectangular and a tubular inner mold holder and 3 inner mold parts were assembled and fixed in place with bolts (D-E). The tubing for the top chamber was pulled through the middle hole. 180 g of silicone was mixed, degassed, and poured slowly through the 3 outer holes (E) and at the edge, and left to cure for 6 hours.

4) *Removing inner mold and sealing bottom chambers:* The bolts for the holders and inner mold parts were unscrewed and the holders removed from the mold (F). Afterwards the 3 inner mold parts were removed (G). The 3 bottom chambers were closed off by adhering another disc cut from silicone-coated fabric, using liquid silicone as a glue (H). Finally, each of the 3 bottom chambers were perforated and tubing inserted and adhered.

5) *Finished robot:* The finished robot can be seen in the accompanying video of this paper¹.

C. Software and Hardware

An Arduino UNO R3 with a custom 8 channel motor shield was used to control 4 electrical pumps and 4 solenoid valves for actuation using pneumatic supply tubing with 1.5/3mm ID/OD. The following parts were used.

- Vacuum air pump 5DC (3-6DC) / 250mA (3,2L/min.) (unbranded)².
- ZQDZC FA0520D 6.0V DC Valves.
- Excellway YC668 6.0V DC Power supply.

The real-time operating system FreeRTOS (202107.00) for microcontrollers was used with the microcontroller to run multiple tasks concurrently³. FreeRTOS was setup to use a round-robin scheduling algorithm. A task was created for each chamber or group of chambers, which could be suspended or delayed with precise time intervals.

III. METHOD

The user study was designed to interrogate the following three hypotheses.

- **Hypothesis 1:** *We hypothesized that breathing rate is correlated with pleasure and that participants perceive slower breathing as signalling a higher level of pleasure.* Prior research has shown that respiration is slow and deep when test subjects experience positive emotions, and fast when they experience negative emotions such as anxiety, fear etc. [21]. Happiness and excitement can, however, also induce increases in respiratory rate [22].
- **Hypothesis 2:** *We hypothesized that breathing rate is correlated with arousal and that a faster breathing rate is perceived as signalling the robot is more aroused.*

Prior work has shown that there is a connection between respiratory rate and arousal in humans [21, 4].

- **Hypothesis 3:** *We hypothesized that breathing rate is correlated with dominance, and that a faster breathing rate is perceived as the robot being dominated.* Faster respiratory rates have been linked to feeling afraid and anxious [10, 11], which may result from the experience of being dominated and unable to control a situation.

A. The Self-Assessment Manikin scale

The Self-Assessment Manikin (SAM) scale is a validated self-report tool to measure emotions [23]. When a person is exposed to a stimulus, the SAM scale can be used to measure *pleasure*, *arousal* and *dominance* associated with the reaction. It is a pictorial scale, consisting of different figures visually representing the different measurement dimensions. When using the SAM scale, people are asked to choose one of 5 figures or in between two of these figures for each dimension. This results in a 9-point measurement scale for each of the 3 dimensions. For the 3 dimensions, the scale value of 1 corresponds to feeling displeasure, low arousal, and dominated respectively. The value of 9 instead corresponds to experiencing pleasure, high arousal, and dominating respectively. The SAM scale is frequently used to measure how people rate their own emotions associated with a specific stimulus. For this experiment, however, participants use the scale to rate the perceived emotional state of the robot. This use of the SAM scale has precedence in prior work [24, 25].

B. Experiment setup

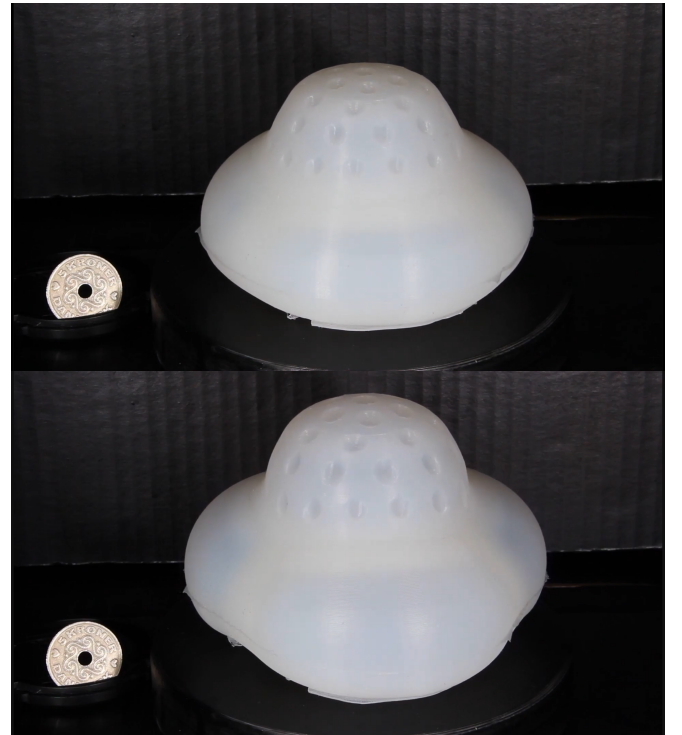


Fig. 3. Screenshots from the demonstration video.

¹Accompanying video: <https://youtu.be/TxFalZ7W0uc>

²Supplier: ELEXTRA.dk, <https://www.elextra.dk>

³FreeRTOS, <https://www.freertos.org/> (accessed Feb. 28, 2022)

Due to COVID-19 restrictions, it was impossible to invite participants physically. Instead, an online questionnaire was used (included under Supplementary Materials - see Appendix). Stimulus videos and rating questions were preceded by a short demonstration video of the robot (Fig. 3)⁴ showing the extremes of the breathing rates and various values lying in-between. The demonstration video was included for participants to become acquainted with the robot before rating and to compensate for lacking randomization of stimulus videos, as it was not possible to implement randomization with the survey system used (SurveyXact). By showing the extremes of the breathing rates before the experiment, we aimed to remove any potential ordering effect caused by the fixed sequenced of the videos. To give an impression of the robot's size, a Danish "5 krone" coin was shown beside it. In the present study, we only utilized inflation patterns wherein all three bottom chambers were inflated simultaneously followed by inflation of the top chamber, to simulate asynchronous chest and abdomen breathing movements. In all presets, inflation of the top chamber was offset to initiate when 40% of the total inflation time of the bottom chambers in a breathing sequence had passed. Other more varied movement presets with independent inflation of all 4 chambers have been studied in forthcoming work [26]. In the survey, participants were shown multiple videos of the robot and could watch each video as many times as they liked, to ensure proper observation before providing their ratings on the SAM scale. Stimulus videos⁵ with breathing rates of 7, 12.5, 20 and 40 breaths per minute (BPM) were created (links included as Supplementary Materials - see Appendix). These breathing rates were chosen based on a slow breathing rate being defined as being between 4-10 BPM [27] for humans and the human average respiratory rate in rest being 12-15 BPM [28] and around 40-60 BPM during exercise [22]. Due to limitations of the pneumatic system used, it was not possible to adjust the pneumatic flow rate and the video of the fastest breathing rate (40 BPM) had to be created by altering the speed of recorded footage. All videos were devoid of sound.

C. Participants

Participants were a convenience sample recruited through the Facebook social networking site by posting a link of the survey in groups for students at the University of Southern Denmark and local college dorms. Participation was voluntary and participants were not compensated for their participation.

IV. RESULTS

A total of 49 participants completed the questionnaire. Of all participants, 31 were male and 18 were female. 16 of the participants belonged to the age group of 18-23, 17 to the age group 24-30, and 16 were of age 31 or above. 11 of

the participants worked with, had worked with, or studied robotics.

Analysis of variance (ANOVA) showed that the robot's BPM had a significant effect ($F(3; 192) = 14.34; p < 0.0001$) on how participants perceived the pleasure level of the robot (see Fig. 4). Post Hoc analysis (Tukey's honestly significant difference - TukeyHSD) showed a significant difference in the perception of pleasure between 7 BPM and 20 BPM ($p < 0.0001$), 7 BPM and 40 BPM ($p < 0.0001$), 12.5 BPM and 20 BPM ($p = 0.0008$), and 12.5 BPM and 40 BPM ($p = 0.0011$). Participants scored the low breathing rate of 7 BPM high on the pleasure scale (mean 6.204, std. 1.732). A higher breathing rate resulted in a lower score on the pleasure scale: 20 BPM (mean 4.163, std. 1.875), and 40 BPM (mean 4.204, std. 2.282). No significant difference was found for the perception of pleasure between 7 BPM and 12.5 BPM ($p = 0.4449$), or 20 BPM and 40 BPM ($p = 0.9996$).

The analysis (ANOVA) also showed that the robot's BPM had a significant effect ($F(3; 192) = 11.94; p < 0.0001$) on how participants perceived the arousal level of the robot (see Fig. 4). Post Hoc analysis (TukeyHSD) showed a significant difference in the perception of arousal between 7 BPM and 40 BPM ($p < 0.0001$), 12.5 BPM and 40 BPM ($p < 0.0001$), and 20 BPM and 40 BPM ($p = 0.0011$). Participants scored the low breathing rate of 7 BPM lower on the arousal scale (mean 4.878, std. 2.128) compared to a higher breathing rate of 40 BPM (mean 6.836, std. 2.211). No significant difference was found for the perception of arousal between 7 BPM and 12.5 BPM ($p = 0.8793$), 7 BPM and 20 BPM ($p = 0.7249$), or 12.5 BPM and 20 BPM ($p = 0.2802$).

The analysis (ANOVA) showed that the robots' BPM had no significant effect ($F(3; 192) = 1.26; p = 0.289$) on how participants scored the dominance level of the robot (see Fig. 4). Table I summarizes these significant findings.

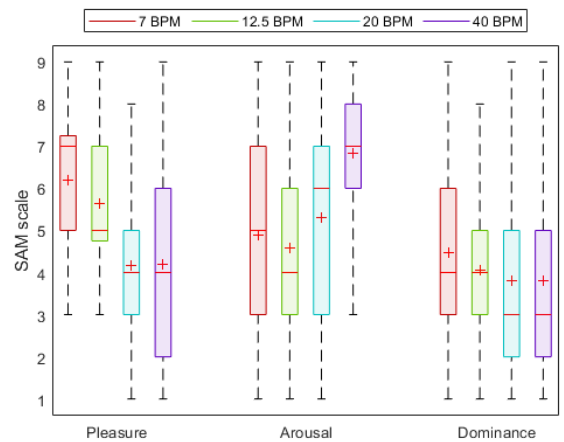


Fig. 4. Box plot for emotional perception of the robot's different breaths per minute rated on the SAM scale from 1 to 9. The "-" sign shows the median for each box plot. The "+" sign shows the mean for each box plot.

Exploratory analyses (ANOVA) showed that the participants' gender had significant influence on the perception

⁴Demonstration video of the robot: <https://youtu.be/xI2RGWL6cXI>

⁵Example video: Video 1 (7 BPM), <https://youtu.be/gT-UORmFug> (accessed Feb. 28, 2022)

TABLE I
SUMMARY OF SIGNIFICANT FINDINGS

Variable	Pleasure	Arousal
7 BPM	Above neutral	Medium
12.5 BPM	Above neutral	Medium
20 BPM	Below neutral	Medium
40 BPM	Below neutral	High

of pleasure ($F(3; 188) = 4.13$; $p = 0.0072$) and arousal ($F(3; 188) = 3.3$; $p = 0.0217$) at different breathing rates. The participants' gender had no significant influence on the perception of dominance ($F(3; 188) = 0.15$; $p = 0.9299$) at different breathing rates. Male and female participants generally scored in the same way, but female participants scored more toward the extremes of the pleasure scale (see Fig. 5). They also showed that prior experience with robots had no significant influence on the perception of pleasure ($F(3; 188) = 0.11$; $p = 0.9559$), arousal ($F(3; 188) = 0.82$; $p = 0.4852$), or dominance ($F(3; 188) = 0.18$; $p = 0.9097$) at different breathing rates.

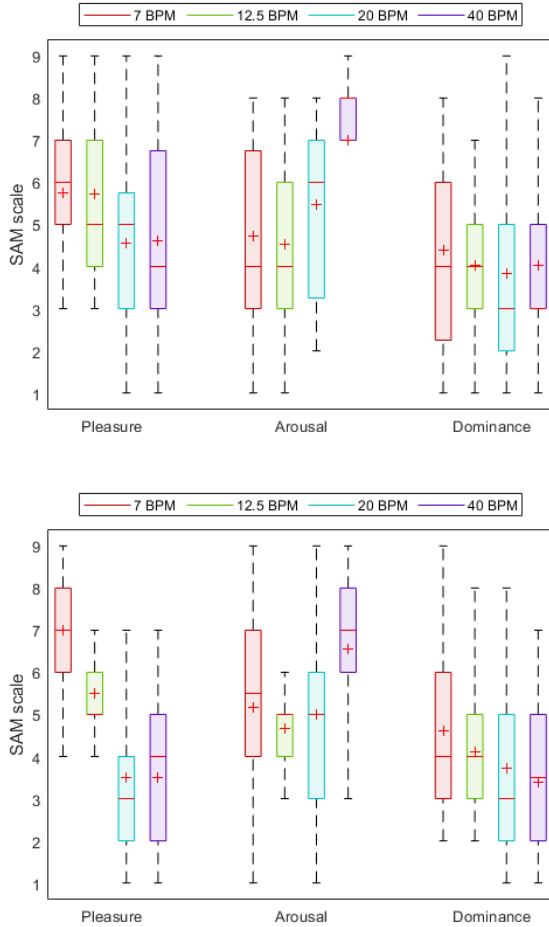


Fig. 5. Box plots of male (upper) and female (bottom) respondents for emotional perception of the robot's different breaths per minute rated on the SAM scale of 1 to 9.

V. DISCUSSION

The results show that different breathing rates influence how participants perceive the soft robot's level of pleasure and arousal. There was a significant difference in the participants' perception of pleasure between 12.5 BPM and 20 BPM. As no significant differences were found between the slow breathing rates (7 BPM and 12.5 BPM), or between the faster breathing rates (20 BPM and 40 BPM) the results indicate that a breathing rate < 12.5 is needed to express the emotion of pleasure with the robot. Therefore, Hypothesis 1 is partly satisfied, as we discovered only two levels of breathing rates that make a difference.

We hypothesized (Hypothesis 2) that a high breathing rate is perceived as a high level of arousal. There was a significant difference in the participants' perception of arousal between 40 BPM and all of the three lowest breathing rates (7 BPM, 12.5 BPM and 20 BPM). As there was no significant difference in how the arousal level was perceived between the three lowest breathing rates, the results indicate that a breathing rate > 40 is needed to ensure expression of arousal. Thus, hypothesis 2 is also partly satisfied.

We expected that a faster breathing rate corresponded to the robot being dominated but was not able to confirm this from the results of the analysis. Dominance seemed to be difficult for the participants to score, and there was no significant difference on the score between the different breathing rates. The appearance, shape, and relatively small size of the robot perhaps might have had an impact on how participants scored dominance on the SAM scale. This could explain the fact that the score overall was more to the dominated side (< 5) of the scale. Hypothesis 3, therefore, is rejected.

Results of exploratory analyses showed that gender had an influence on the perception of pleasure and arousal at different breathing rates. Overall, female participants responded more similarly to the perception of the robot's level of pleasure, whereas male participants had larger variance on the score within each breathing rate (5). There was a common agreement among male respondents regarding arousal in the 40 BPM video, otherwise male respondents scored with a higher standard deviation than females. This outcome is expectable, as several studies report evidence that females exhibit higher rates than males in various forms of empathy [29, 30].

The results also showed that prior experience with robotics had no significant influence on how participants perceived the emotional state of the robot throughout the experiment. This could suggest that the robotic emotions are signalled equally to experienced roboticists and naive interaction partners, supporting that breathing may be used for NC in several soft robotics application domains.

A parameter that may have affected the results of the study is that the survey was conducted online using videos due to COVID-19 restrictions. Even if HRI trials using video have previously reported similar results as physical experiments under controlled conditions [31], physical HRI experience is richer than that obtained from a 2D video without sound

and better allows a participant to perceive 3D movement and scale.

VI. FUTURE WORK

Further work is needed to capture the full potential of utilizing breathing as a nonverbal means of signalling emotions for different applications of soft robotics. Physical experiments should be conducted to validate the results obtained in our online study, and more studies are required to understand in more detail what the salient parameters of robot breathing for emotive transfer are, including, e.g., the effects of robot shape and size and of using bipartite asynchronous breathing as compared with using just one chamber. We plan to develop our novel soft social robot further to support multimodal interaction by adding sensors and additional expressive modalities including sound and light, to obtain clearer and more complex interactive NC with soft robotics.

APPENDIX

Supplementary materials (STL files for molds, robot code, questionnaire, experiment data) are available online at:

<https://doi.org/10.5281/zenodo.5565201>

<https://doi.org/10.5281/zenodo.5565177>

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REFERENCES

- [1] A. Mehrabian. *Nonverbal communication*. Nonverbal Communication. Taylor and Francis, 2017, pp. 1–226. DOI: 10.4324/9781351308724.
- [2] F. Poyatos. *Nonverbal Communication Across Disciplines: Paralanguage, kinesics, silence, personal and environmental interaction*. Vol. 2. John Benjamins Publishing, 2002.
- [3] R. P. Brown and P. L. Gerbarg. “Yoga breathing, meditation, and longevity”. In: *Annals of the New York Academy of Sciences* 1172 (2009), 54–62. ISSN: 1749-6632. DOI: 10.1111/j.1749-6632.2009.04394.x.
- [4] I. Homma and Y. Masaoka. “Breathing rhythms and emotions”. In: *Experimental Physiology* 93.9 (2008), pp. 1011–1021. ISSN: 09580670 (ISSN). DOI: 10.1113/expphysiol.2008.042424.
- [5] J. J. Arch and M. G. Craske. “Mechanisms of mindfulness: emotion regulation following a focused breathing induction”. In: *Behaviour Research and Therapy* 44.12 (2006), 1849–1858. DOI: 10.1016/j.brat.2005.12.007.
- [6] W. Zhang et al. “Breath-focused mindfulness alters early and late components during emotion regulation”. In: *Brain and Cognition* 135 (2019), p. 103585. DOI: <https://doi.org/10.1016/j.bandc.2019.103585>.
- [7] K. Yackle et al. “Breathing control center neurons that promote arousal in mice”. In: *Science (New York, N.Y.)* 355.6332 (2017), 1411–1415. DOI: 10.1126/science.aai7984.
- [8] V. Perciavalle et al. “The role of deep breathing on stress”. In: *Neurological Sciences* 38.3 (2017), pp. 451–458. DOI: 10.1007/s10072-016-2790-8.
- [9] R. P. Brown and P. L. Gerbarg. “Sudarshan Kriya Yogic breathing in the treatment of stress, anxiety, and depression. Part II—clinical applications and guidelines”. In: *The journal of alternative and complementary medicine (New York, N.Y.)* 11.4 (2005), pp. 711–717.
- [10] Y. Masaoka and I. Homma. “The effect of anticipatory anxiety on breathing and metabolism in humans”. In: *Respiration Physiology* 128.2 (2001), pp. 171–177. DOI: 10.1016/S0034-5687(01)00278-X.
- [11] I. Homma et al. “Breathing Mind in ‘Noh’”. In: *Breathing, Feeding, and Neuroprotection*. Springer Japan, 2006, pp. 125–134. ISBN: 978-4-431-28775-9.
- [12] L. Boer and H. Bewley. “Reconfiguring the Appearance and Expression of Social Robots by Acknowledging Their Otherness”. In: *Proceedings of the 2018 Designing Interactive Systems Conference*. DIS ’18. ACM, 2018, 667–677. DOI: 10.1145/3196709.3196743.
- [13] J. Jørgensen et al. “Is a Soft Robot More “Natural”? Exploring the Perception of Soft Robotics in Human–Robot Interaction”. In: *International Journal of Social Robotics* (2021). DOI: 10.1007/s12369-021-00761-1.
- [14] J. Jørgensen and M. B. Christiansen. “The Sounds of Softness. Designing Sound for Human-Soft Robot Interaction”. In: *Frontiers in Robotics and AI* 8 (2021), p. 274. DOI: 10.3389/frobt.2021.674121.
- [15] J. Jørgensen. “Leveraging Morphological Computation for Expressive Movement Generation in a Soft Robotic Artwork”. In: *Proceedings of the 4th International Conference on Movement Computing*. MOCO ’17. ACM, 2017, 20:1–20:4. ISBN: 978-1-4503-5209-3. DOI: 10.1145/3077981.3078029.
- [16] J. Jørgensen. “Interaction with Soft Robotic Tentacles”. In: *Companion of the 2018 ACM/IEEE International Conference on Human-Robot Interaction*. HRI ’18. Association for Computing Machinery, 2018, p. 38. ISBN: 978-1-4503-5615-2. DOI: 10.1145/3173386.3177838.
- [17] J. Jørgensen. “Appeal and Perceived Naturalness of a Soft Robotic Tentacle”. In: *Companion of the 2018 ACM/IEEE International Conference on Human-Robot Interaction*. ACM, 2018, 139–140.
- [18] J. Jørgensen. “Prolegomena for a Transdisciplinary Investigation into the Materialities of Soft Systems”. In: *ISEA 2017 Manizales: Bio-Creation and Peace: Proceedings of the 23rd International Symposium on Electronic Art*. Department of Visual Design, Universidad de Caldas, and ISEA International, 2017, 153–160.

- [19] E. Vlachos. "Sustaining Emotional Communication when Interacting with an Android Robot". In: Ph.d.-serien for Det Humanistiske Fakultet, Aalborg Universitet (2015). DOI: 10.5278/vbn.phd.hum.00037.
- [20] N. El-Atab et al. "Soft Actuators for Soft Robotic Applications: A Review". In: *Advanced Intelligent Systems* 2.10 (2020), p. 2000128. ISSN: 2640-4567. DOI: 10.1002/aisy.202000128.
- [21] F. A. Boiten et al. "Emotions and respiratory patterns: review and critical analysis". In: *International Journal of Psychophysiology* 17.2 (1994), pp. 103–128. DOI: 10.1016/0167-8760(94)90027-2.
- [22] A. Bullack et al. "Psychophysiological Responses to "Happy" and "Sad" Music: A Replication Study". In: *Music Perception* 35.4 (Apr. 2018), pp. 502–517.
- [23] M. M. Bradley and P. J. Lang. "Measuring emotion: the Self-Assessment Manikin and the Semantic Differential". In: *Journal of Behavior Therapy and Experimental Psychiatry* 25.1 (1994), 49–59. DOI: 10.1016/0005-7916(94)90063-9.
- [24] M. Inderbitzin et al. "Expression of emotional states during locomotion based on canonical parameters". In: *2011 IEEE International Conference on Automatic Face & Gesture Recognition (FG)*. IEEE. 2011, pp. 809–814.
- [25] R. Peters et al. "Robots Expressing Dominance: Effects of Behaviours and Modulation". In: Institute of Electrical and Electronics Engineers Inc., 2019, pp. 461–467. DOI: 10.1109/ACII.2019.8925500.
- [26] U. Farhadi et al. "Exploring the Interaction Kinesics of a Soft Social Robot". In: *HCI INTERNATIONAL 2022 24th International Conference on Human-Computer Interaction*. Springer, (forthcoming).
- [27] M. A. Russo et al. "The physiological effects of slow breathing in the healthy human". In: *Breathe* 13.4 (2017), 298–309. DOI: 10.1183/20734735.009817.
- [28] K. E. Barrett et al. *Ganong's review of medical physiology (24th ed.)* E-Book, 2012.
- [29] L. Christov-Moore et al. "Empathy: Gender effects in brain and behavior". In: *Neuroscience & biobehavioral reviews* 46 (2014), pp. 604–627.
- [30] C. S. Löffler and T. Greitemeyer. "Are women the more empathetic gender? The effects of gender role expectations". In: *Current Psychology* (2021), pp. 1–12.
- [31] S. Woods et al. "Comparing human robot interaction scenarios using live and video based methods: towards a novel methodological approach". In: *9th IEEE International Workshop on Advanced Motion Control, 2006*. 2006, 750–755. DOI: 10.1109/AMC.2006.1631754.