MALTE F. JUNG, RESEARCH OVERVIEW

My research aims to extend our understanding of Human-Robot Interaction (HRI) and Human-Robot Collaboration (HRC) from dyadic interactions (one robot and one human) to groups and teams of people (Fig. 1). Recent advances in safe human-robot interaction, AI, and computation have led to an increased deployment of robots in complex social contexts such as hospitals, homes, schools, airports, and manufacturing floors. All of these contexts involve multiple people, yet research has been focusing almost exclusively on understanding and enabling interactions between a single robot and a single human. To extend our understanding in HRI from dyads to groups my research integrates understanding about small work groups and teams into our broader understanding and design of human-robot interactions.

In three key threads of work, my research team and I combine research on human-robot interaction (HRI), the dynamics of work groups and teams, and emotion to not only build basic understanding about how robots influence groups of people and their interactions with each other but also to design techniques for robots to deliberately shape a group's interaction as well as its social and emotional processes. Our work shifts the focus in HRI, computer supported cooperative work (CSCW) and human-computer interaction (HCI) from focusing on interactions between people and a technology to questions of how technology affects the way people interact with each other (Fig. 1). Our work can be described by three major threads. As the first thread of this work, we combine behavioral research in the laboratory with observational studies in the field to build basic understanding and theory about human robot interaction and a robot's impact on groups and teams. The second thread focuses on developing understanding and techniques for designing robots that function effectively in teams and that can improve team dynamics and team effectiveness. The third thread focuses on expanding the methodological toolkit that HRI researchers have at their disposal by introducing experiment tasks that facilitate the systematic study of a robot's impact on groups and teams.

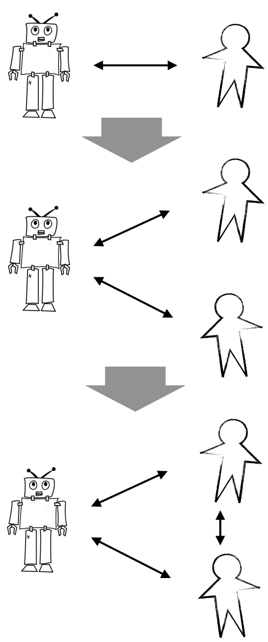

Fig 1. My research shifts the focus from interactions between a single person and a robot (top_ towards questions of how groups of people interact with a robot (middle) and robots influence the way people interact with each other in groups and teams (bottom).

BUILDING THEORY ABOUT ROBOTS IN GROUPS AND TEAMS

While existing work in HRI has helped establish fundamental understanding about people as they interact with robots, we have a limited understanding not only about how people respond to robots in group settings but also about how robots influence group dynamics and what the consequences of such influence are (Jung and Hinds, 2018). As soon as more than one person interacts with a robot, interactions between the people have to be considered and with every member added to a group the number of possible interactions increase polynomially. Through studies in the laboratory and in the field my build the fundamental understanding and theory necessary to understand a robot's impact on a group or team of people.

Understanding how a robot influences how people interact with each other in teams. Building on my dissertation work which found that interpersonal exchanges of emotional expressions accounted for up to 91% of a team's ability to perform (Jung, 2016; Jung, Chong, Leifer, 2012), a large part of our work focuses on understanding a robot's impact on interpersonal interactions and especially a team's emotional interaction. To gain insight we have conducted laboratory studies that engage two or more participants in a range collaborative tasks with a robot. We found that robots can impact basic group processes such as conflict (Jung, Martelaro, & Hinds, 2015; Stoll, Jung, &

Fussell, 2018), decision making (Hou, Lee, & Jung, In Prep), or group participation (Tennent, Shen, & Jung, 2018). These studies formed the empirical basis for our efforts to synthesize what we have learned into general theoretical frameworks on robots in group settings (e.g. Shen, Tennent, & Jung, 2017).

An important aspect of this work has been to expand our focus in HRI from understanding interactions between a person and a robot (e.g. Tennent, et al., 2017; Strait et al., 2017; Kwon, Jung, & Knepper, 2016) towards understanding the impact that a robot has on interactions between people. For example, we found that a standard industrial robot arm could introduce interpersonal tension into a team collaborating with a robot just by the way it performs a basic action to pick up and place a wooden block needed to complete a building task (Jung et al., 2018). This finding was significant, as it extends our established understanding in HRI that even robots without any social design features (e.g. a roomba) can not only elicit social reactions from people towards the robot but also that such robots can shape social reactions of people towards each other. My interest in a robot's impact on groups has led to a fruitful collaboration with Brian Scassellati and his student Sarah Strohkorb Sebo at Yale University. Together we designed a study that demonstrated that a robot's expressions of vulnerability led to increased expressions of interpersonal support by members of a group when one person made a mistake (Strohkorb Sebo, et al., 2018). A deeper analysis of the data revealed how profoundly interpersonal interactions can be shaped through simple changes in a robot's verbal utterances (Traeger et al., under review).

Understanding how robots transform teamwork in an organizational setting. During my postdoc I learned about robotic surgery with the DaVinci surgical system (Fig. 2). I learned that the DaVinci surgical system is designed based on a conceptualization of surgery as a practice of cutting and joining tissue performed by only one person, the surgeon. However, surgery is performed by a closely knit team that is dependent on effective communication and interaction. The surgical robot displaces the surgeon from the rest of the team to operate a console typically placed in an isolated corner of the operating room. I got immediately interested in the question about how the use of such a robot influences those interpersonal and emotional dynamics in teams that I have come to understand as uniquely important for a team's overall effectiveness. Over the past 6 years I have secured initial funding from Cornell's institute of social sciences and built a line of work that attempts to develop understanding about a robot's impact on work teams in the field. Together with my colleague Steve Jackson and our students Amy Cheatle and Hannah Pelikan we conducted almost three years of fieldwork in the operating rooms at two hospitals comparing traditional laparoscopic with robotic surgeries. We have conducted 32 interviews and collected and analyzed more than 60 hours of video. We not only found that the robot drastically impacts teamwork and team communication through the mere reconfiguration of the physical space in the OR (Pelikan et al., 2018), but also by reshaping in fundamental ways the way a team deals with the rich sensorium during surgery (Cheatle et al., under review). A further careful conversation analytic investigation of the video records revealed that the robot dramatically influences the structure requests made by surgeons and how they are respond-

Fig 2. Surgical team performing a surgery with the DaVinvi surgical robot.

ed to (Pelikan & Jung, 2019). Motivated by the rich insights we gained from our field work we are currently exploring several other avenues to study the use of robots in teamwork in the field.

DESIGNING ROBOTS AS SOCIAL CATALYSTS FOR TEAMS

The second thread of my work focuses on the question of how we design robots that operate effectively in teams. I have been particularly interested in designing robots and systems that act as social catalysts for teams. Our goal is to design robots that use subtle social nudges to help teams perform at their best.

Designing robots to improve teamwork by acting on a team's social processes. Motivated by my early work that highlighted the importance of a team's interpersonal interaction, I became interested in exploring whether and how robots can help teams to perform better by merely acting on a group's interaction and social processes. This effort to improve human robot-collaboration and teamwork by acting on a team's social processes departs from established approaches in HRI that have largely focused on designing novel ways for robots to help people with the completion of the task at hand. In a series of studies we were able to show that robots can help teams perform better for example by exhibiting subtle back-channeling behavior (Jung, et al., 2013), by intervening in conflict (Jung, Martelaro, & Hinds, 2015), or by expressing vulnerability when mistakes are made (Strohkorb Sebo, et al., 2018). Across all of these studies we used robots that essentially acted as a human moderator or mediator and employed human-like modalities to interact with people. We found over the years that this design approach had three important limitations: First, introducing robots that act like people sets unrealistic expectations that when unmet can lead to a loss of trust in the robot. Second, building robots that can perform as effective moderators presents a large technical effort, and third, this approach places robots as an active team member which draws attention away from the group's interaction and task. Our recent design efforts have therefore departed from this approach. Instead we have started to explore the use of simple robotic objects that influence social processes in groups through subtle implicit behavior. For example, Hamish Tennent developed micbot, a robotic object designed to balance group participation by subtly signaling attention and encouraging non-participating group members to engage as the microphone turns towards them and tilts down. Our evaluation showed that the fully autonomous robot was effective at balancing group participation and improving group performance (Tennent, Shen, & Jung, 2019).

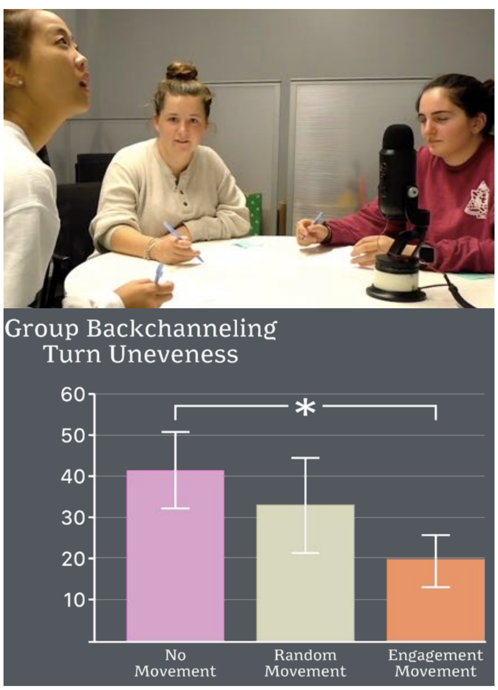

Fig 4. Micbot, a peripheral and automated robotic object to shape conversational dynamics during group interactions (top). The robot as designed lead to a significantly more balanced group interaction than a motionless microphone.

This approach of using non-anthropomorphic robotic objects that act from the periphery on a team's social processes in subtle yet effective ways has sparked several other design projects we are currently pursuing.

DEVELOPING METHODS FOR HRI RESEARCH WITH GROUPS

Efforts to combine small group research with research on HRI are both rare and fairly new in HRI. It is complicated by the realization that many established group tasks that are widely used in social psychology and communication studies do not easily translate to HRI contexts. The often do not account for the unique capabilities that a robot can bring to a group context. My students and I have thus directed a substantial effort of our work towards advancing the methodological toolkit HRI researchers have at their disposal when pursuing studies with groups and teams. This involves developing a range of novel human-robot group interaction tasks for laboratory and online studies.

Laboratory based group tasks. We have developed several tasks that have allowed us to study the effects of physically embodied autonomous robots on people in collaborative group contexts. Some tasks were designed for fully autonomous robots (e.g., Jung et al., 2013; Tennent, Shen, & Jung, 2019) and others for robots with simulated autonomy, i.e. Wizard of Oz operation (e.g. Jung, Martelaro, & Hinds, 2015). A key goal in this effort has been to design tasks that place a robot in a role that allows it to draw from unique robot-specific strengths, rather than being a mere replacement of a human team member. With that goal in mind we designed a complex task that allowed us to study teamwork between one participant, a human drone operator, and two fully autonomous mobile robots during my postdoc at the center for Work, Technology, and Organization at Stanford University (Jung et al., 2013). For later studies we developed a range of group problem solving tasks that allowed us to study a robot's impact on interpersonal interactions in teams (e.g. Jung, Martelaro, & Hinds, 2015; Strohkorb Sebo, et al., 2018; Stoll et al., 2018) and between children (Shen, Slovak, & Jung, 2018). Our most recent efforts have focused on designing a task that would allow us to study the social impact of a a standard industrial robot on a group of people collaborating with the robot in completing a task. We developed a novel tower construction task that allows us to systematically examine the impact of a robot's resource allocation behavior on group interaction (Jung, under review). Groups of human participants build a structure out of building blocks in collaboration with a standard robot arm (Fig. 3). The robot is tasked to allocate resources (blocks) to group members by picking blocks up from a stack and placing them in front of a team member. The task is complete once all blocks are placed. This task models typical assembly or building tasks that are used in many other human-robot collaboration studies but extends those tasks to groups of people. In a pilot study with N=62 teams of two human participants each (124 participants overall), we found that how a robot distributes resources among team members impacts interpersonal interaction. Our work on this task has attracted increasing attention and also formed the basis for a collaboration with Noshir Contractor at Northwestern which is being funded by the Army Research Lab.

Fig 3. Tower construction task that allows the exploration of the impact of a robot's resource allocation behavior on group interaction and performance.

Online group tasks. Running studies with robots is highly costly in terms of resources and time. To facilitate the faster exploration and evaluation of novel ideas, we have developed several web-based tasks that allow us to build understanding about how people interact with robots individually and in group settings. With support from NSF funding, we introduced a novel task that provided online participants with a constrained, yet realistic experience of piloting a telepresence robot (Shen et al., 2018). Participants were shown a video that replicated a typical view of a teleoperating interface. Using cursor buttons, participants were able to seemingly control a telepresence robot forward and backward by advancing a pre-recorded video forward and backward. My student Tung-Yu Hou designed a survey based task that allows us to study the relative impact of information provided by a robot vs a human on decision making in groups. Both the robot and the other human are simulated which allows us to scale data collection requiring minimal effort and resources. Finally, building on our resource allocation task for the laboratory, we developed a web-based task that synchronizes two participants to play a game of Tetris with a virtual robot as a team member. The task shares essential characteristics with our laboratory based resource allocation task. Teams collaborate in scoring points but only one participant at a time has control over a block. Much like in our physical task, the virtual robot allocates the Tetris blocks to the person who gets to place it. The advantage of this task is that it can draw from participants online and that it provides immediate performance metrics through the Tetris scores. The possibilities of this task led to a collaboration with Stefanos Nikolaidis at USC. My student Houston Claure used the task for an initial study that explored the effects of different types of allocation algorithms on team performance and perceptions of the robot (Claure et al., 2019). We are currently working on a range of other tasks that let us examine the impact of algorithms (e.g. smart replies: Hohenstein & Jung, 2018) on interpersonal and team interactions more broadly.

REFERENCES (IN REVERSE CHRONOLOGICAL ORDER)

Cheatle, A., Jackson, S. J., **Jung, M. F.**, & Pelikan, H. R. (Under Review). Sensing (co)operations: Articulation and compensation in the robotic operating room. Under Review for the Proceedings of the ACM on Human-Computer Interaction, no. CSCW.

Hou, Y. T.-Y., Lee, W. Y., **Jung, M. F.** (In Preparation). My robot leader is better than any human: the Influence of Power in Human-Robot Mixed Teams, In preparation for the Computers in Human Behavior Journal.

Jung, M. F. (In Prep). Group Affective Exchange in Conflict. Manuscript in preparation to be submitted to Organization Science.

Jung, M. F., DiFranzo, D., Stoll, B., Shen, S., Lawrence, A., & Claure, H. (Under Review). Tower Construction - A Platform for Research on Human-Robot Collaboration with Groups of People. *Under Review for the ACM Transactions on Human-Robot Interaction (THRI).*

Traeger, M. L., Strohkorb Sebo, S., **Jung, M. F.**, Scassellati, B., Christakis, N. A. (Under Review). Vulnerable Robots Positively Shape Human Conversational Dynamics in a Human-Robot Team. *Under Review for the Proceedings of the National Academy of Sciences* (PNAS).

Xie, H., Howell, A., Schreier, M., Sheau, K., Manchanda, M., **Jung, M. F.**, Reiss, A., Saggar, M. (2019) Finding the neural correlates of collaborative improvisation using 3-person fMRI hyperscanning. P*oster presented at the 2019 Annual Meeting of the Organization for Human Brain Mapping (OHBM).* Rome, Italy. June 9-13, 2019.

Costa, J., Guimbretière, F., **Jung, M. F.**, & Choudhury, T. (2019). BoostMeUp: Improving Cognitive Performance in the Moment by Unobtrusively Regulating Emotions with a Smartwatch. *Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies*, 3(2), 40.

Claure, H., Chen, Y., Modi, J., **Jung, M. F.**, & Nikolaidis, S. (2019). Reinforcement Learning with Fairness Constraints for Resource Distribution in Human-Robot Teams. arXiv preprint arXiv:1907.00313.

Fischer, K., **Jung, M.**, Jensen, L. C., & aus der Wieschen, M. V. (2019). Emotion Expression in HRI—When and Why. In 2019 14th ACM/IEEE International Conference on Human-Robot Interaction (HRI) (pp. 29-38). IEEE.

Pelikan, H. & **Jung, M. F.** (2019). "What's going on there?" Negotiating common ground in robotic vs. open surgery. *Unpublished Manuscript*, 2019.

Tennent, H., Shen, S., & **Jung, M.F.** (2019). Micbot: A Peripheral Robotic Object to Shape Conversational Dynamics and Team Performance. *In 2019 14th ACM/IEEE International Conference on Human-Robot Interaction (HRI)* (pp. 133-142). IEEE.

Jung, M.F., & Hinds, P. (2018). Robots in the wild: A time for more robust theories of human-robot interaction. *ACM Transactions on Human-Robot Interaction (THRI)*, 7(1), 2.

Costa, J., **Jung, M. F.**, Czerwinski, M., Guimbretière, F., Le, T., & Choudhury, T. (2018, April). Regulating Feelings During Interpersonal Conflicts by Changing Voice Self-perception. In *Proceedings of the 2018 ACM Conference on Human Factors in Computing Systems (CHI)* (p. 631). ACM.

Hohenstein, J., & **Jung, M.F** (2018). AI-Supported Messaging: An Investigation of Human-Human Text Conversation with AI Support. In Extended Abstracts of the 2018 CHI Conference on Human Factors in Computing Systems (CHI Extended Abstracts). ACM.

Pelikan, H. R., Cheatle, A., **Jung, M. F.**, & Jackson, S. J. (2018). Operating at a Distance-How a Teleoperated Surgical Robot Reconfigures Teamwork in the Operating Room. *Proceedings of the ACM on Human-Computer Interaction*, 2 (CSCW), 138.

Shen, S., Slovak, P., & **Jung, M. F.** (2018). Stop. I see a conflict happening.: A robot mediator for young children's interpersonal conflict resolution. *In Proceedings of the 2018 ACM/IEEE International Conference on Human-Robot Interaction (HRI)* (pp. 69-77). ACM.

Shen, S., Tennent, H., Claure, H., & **Jung, M.** (2018). My telepresence, my culture?: An intercultural investigation of telepresence robot operators' interpersonal distance behaviors. *In Proceedings of the 2018 ACM Conference on Human Factors in Computing Systems (CHI). (p. 51).* ACM.

Stoll, B., Reig, S., He, L., Kaplan, I., **Jung, M. F.**, & Fussell, S. R. (2018). Wait, can you move the robot?: Examining telepresence robot use in collaborative teams. *In Proceedings of the 2018 ACM/IEEE International Conference on Human-Robot Interaction (HRI).* (pp. 14-22). ACM.

Stoll, B., **Jung, M. F.**, & Fussell, S. R. (2018). Keeping it light: Perceptions of humor styles in robot-mediated conflict. *In Companion of the 2018 ACM/IEEE International Conference on Human-Robot Interaction (HRI Companion)* (pp. 247-248). ACM.

Strohkorb Sebo, S., Traeger, M., **Jung, M.F.**, & Scassellati, B. (2018). The ripple effects of vulnerability: The effects of a robot's vulnerable behavior on trust in human-robot teams. *In Proceedings of the 2018 ACM/IEEE International Conference on Human-Robot Interaction (HRI)* (pp. 178-186). ACM.

Gao, G., Hwang, S. Y., Culbertson, G., Fussell, S. R., & **Jung, M. F.** (2017). Beyond Information Content: The Effects of Culture on Affective Grounding in Instant Messaging Conversations. *Proceedings of the ACM on Human-Computer Interaction, 1(CSCW)*, 48.

Jung, M. F. (2017). Affective grounding in human-robot interaction. In 2017 12th ACM/IEEE International Conference on Human-Robot Interaction (HRI). (pp. 263-273). ACM/IEEE.

Shen, S., & **Jung, M. F**. (2017). A Benefit of Thinking Like a Robot. *In Proceedings of the Companion of the 2017* ACM/IEEE *International Conference on Human-Robot Interaction (HRI companion)* (pp. 283-284). ACM.

Shen, S., Tennent, H., & **Jung, M.F.** (2017). Robot chameleons and small group decision making: The case of conformity. *Paper presented at the 12th Annual Conference of the Interdisciplinary Network for Group Research (INGRoup 2017).* St. Louis, MO. July 20-22, 2017.

Strait, M. K., Floerke, V. A., Ju, W., Maddox, K., Remedios, J. D., **Jung, M. F.**, & Urry, H. L. (2017). Understanding the uncanny: both atypical features and category ambiguity provoke aversion toward humanlike robots. *Frontiers in psychology*, 8, 1366.

Tennent, H., Moore, D., **Jung, M.**, & Ju, W. (2017). Good vibrations: How consequential sounds affect perception of robotic arms. *In 2017 26th IEEE International Symposium on Robot and Human Interactive Communication (RO-MAN)* (pp. 928-935). IEEE.

Costa, J., Adams, A. T., **Jung, M. F.**, Guimbretière, F., & Choudhury, T. (2016). EmotionCheck: leveraging bodily signals and false feedback to regulate our emotions. In Proceedings of the 2016 *ACM International Joint Conference on Pervasive and Ubiquitous Computing* (pp. 758-769). ACM.

Jung, M. F., Kruzan, K. P., McLeod, P. L. (2016). Conflict in Work Teams: The Role of Emotion Regulation and Self-Esteem. *Paper presented at the 12th Annual Conference of the Interdisciplinary Network for Group Research (INGRoup 2016).* Helsinki, Finnland. July 14-16, 2016.

Jung, M. F. (2016). A Balance Theory of Intra-Group Conflict and Performance. *aper presented at the 12th Annual Conference of the Interdisciplinary Network for Group Research (INGRoup 2016).* Helsinki, Finnland. July 14-16, 2016.

Jung, M. F. (2016). Coupling interactions and performance: Predicting team performance from thin slices of conflict. *ACM Transactions on Computer-Human Interaction (TOCHI)*, 23(3), 18.

Kwon, M., **Jung, M. F.**, & Knepper, R. A. (2016). Human expectations of social robots. *In Companion of the 11th ACM/IEEE International Conference on Human-Robot Interaction (HRI Companion)* (pp. 463-464). IEEE.

Adams, A. T., Costa, J., **Jung, M. F.**, & Choudhury, T. (2015). Mindless computing: designing technologies to subtly influence behavior. *In Proceedings of the 2015 ACM International Joint Conference on Pervasive and Ubiquitous Computing* (pp. 719-730). ACM.

Jung, M. F., Martelaro, N., & Hinds, P. J. (2015). Using robots to moderate team conflict: the case of repairing violations. *In Proceedings of the Tenth Annual ACM/IEEE International Conference on Human-Robot Interaction (HRI)* (pp. 229-236). ACM.

Jung, M. F., Martelaro, N., Hoster, H., & Nass, C. (2014). Participatory materials: having a reflective conversation with an artifact in the making. *In Proceedings of the 2014 conference on Designing interactive systems (DIS)* (pp. 25-34). ACM.

Jung, M. F., Lee, J. J., DePalma, N., Adalgeirsson, S. O., Hinds, P. J., & Breazeal, C. (2013). Engaging robots: easing complex human-robot teamwork using backchanneling. *In Proceedings of the 2013 conference on Computer supported cooperative work (CSCW)* (pp. 1555-1566). ACM.

Jung, M.F., Chong, J., & Leifer, L. (2012). Group hedonic balance and pair programming performance: affective interaction dynamics as indicators of performance. *In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI)* (pp. 829-838). ACM.