On the causality between affective impact and coordinated human-robot reactions

Morten Roed Frederiksen[1] Kasper Stoy[2]

Abstract— **In an effort to improve how robots function in social contexts, this paper investigates if a robot that actively shares a reaction to an event with a human alters how the human perceives the robot's affective impact. To verify this, we created two different test setups. One to highlight and isolate the reaction element of affective robot expressions, and one to investigate the effects of applying specific timing delays to a robot reacting to a physical encounter with a human. The first test was conducted with two different groups (n=84) of human observers, a test group and a control group both interacting with the robot. The second test was performed with 110 participants using increasingly longer reaction delays for the robot with every ten participants. The results show a statistically significant change (p<.05) in perceived affective impact for the robots when they react to an event shared with a human observer rather than reacting at random. The result also shows for shared physical interaction, the near-human reaction times from the robot are most appropriate for the scenario. The paper concludes that a delay time around 200ms may render the biggest impact on human observers for small-sized non-humanoid robots. It further concludes that a slightly shorter reaction time around 100ms is most effective when the goal is to make the human observers feel they made the biggest impact on the robot.**

I. Introduction

Creating robots that can understand and express emotions is a many-faceted problem. One of the many challenges lies in designing a relatable robotic behavior with which people will want to interact. If we disregard digital communication channels, robots convey information through simple means of expression that includes: Sound, appearance, movements, and gestures [1]. These means can improve how well the intentions of the robot are understood, and correctly timing when to use them can further improve the interaction and can influence how the robot is perceived [2]. A lot of research has focused on the expressive abilities of robots and have so far accomplished making people recognize robotic expressions of emotions using morphological attributes [3]–[5], facial features [6]–[13], movement [14]–[16], orientation [17], [18] sound [8], [19]–[24], and gestures [5], [13], [20], [25]–[32]. When it comes to expressing affective information and standard emotions, many projects focus on how to maximize comprehension. Relatively few projects in comparison focus on the impact of delaying when the expressive features of the robot are used, and how the causality between participant and robot reactions can affect how the affective information is conveyed. Michael 2010 proposes how perceived shared emotions can facilitate coordination between interacting humans without either of them possessing previous knowledge of intentions [33]. This paper focuses on whether this effect is equally present in human-robot-interactions and investigates the following:

- If there is a causality between reaction coordination and perceived affective impact on a robot. In other words: When humans and robots react to the same event, will the humans perceive the robots' reactions as stronger?
- Whether delaying the reactions of a robot in a physical conflict interaction can strengthen its perceived affective impact.

Gaining knowledge on these aspects of expression abilities is something all areas of robotics can benefit from. The investigation may provide an answer to when and how robots should behave in order to strengthen the affective impact of an interaction. This could be beneficial in situations where robots are required to convey vital information as efficiently as possible. E.g. Socially assistive robotics and rescue robots that operate in demanding working environments may be vastly improved if we, by altering how and when they use their communicative features, can make them communicate better in a critical situation.

Through each human-robot interaction, the timing dictates who initiates actions throughout the encounter. E.g. a swift reacting robot could make a human recipient hold back in the interaction or a robot that delays answering could make a human counterpart take charge of the situation. Among other aspects of communication, the timing encompasses both estimating when to perform movements (for robots to safely cooperate with humans) and controlling the flow of dialogue between humans and robots [34], [35].

When robots react to something, the reaction highlights the

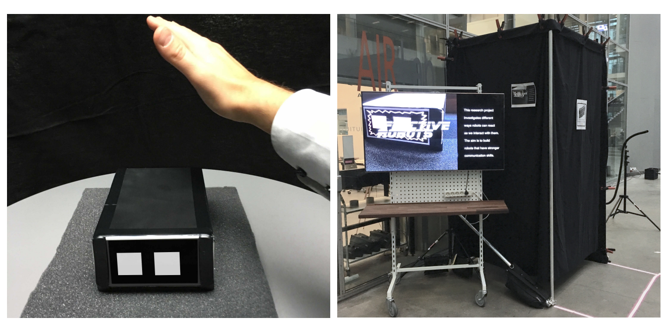

Fig. 1. Left: The "Affecta" robot. The robot was fastened to a soft foam pad to hinder it from moving as people interacted with it. Right: The test setup included an isolated room to let the participants interact with the robot undisturbed.

[1]Morten Roed Frederiksen mrof@itu.dk and [2]Kasper Stoy ksty@itu.dk are affiliated with the REAL lab at the Computer science department of The IT-University of Copenhagen, Rued Langgaards vej 7, 2300 Copenhagen S

connection between robot behavior and the context event, and it establishes the direction for the current communication. E.g. for a robot that is designed to portray being afraid of a dog in the vicinity, there is a timed frame of opportunity after the dog initiates an action where the robot can react. Any reactions applied in connection with the dog's actions will be perceived as connected to that event or that agent in the scenario. The robot's reaction will be interpreted in light of the event and if a human experiences the same event, the shared experience may be used to establish a connection between the human and the robot. The reaction time and response in the situation is influenced by the complexity and familiarity of the event information as outlined in Hyman 1953 [36]. Besides the complexity of event information to which the robot reacts, the hypothesis is that the following two things (among other factors) can influence how the expression of a robot's reaction is perceived:

- The time delay with which the robot reacts
- If the reaction is shared with someone.

To investigate this, we used two experiments. The first test was a standard A-B test aimed at isolating the effects of coordinating human-robot reactions to a context event, while the second test focused on how reaction delays affected the shared experience in a physical interaction. Our findings show a causality between human-robot reaction coordination and the perceived arousal level of the test robots, with a statistically significant ($p<.05$) difference between the main group and the control group. The results further indicate that the reaction times of the robots in physical interactions influence the affective state of the humans interacting with it. We argue that near human-like reaction reflexes overall have the biggest affective impact on the test participants, while a slightly lesser delay time (˜100ms faster) should be used when the aim is for the test participants to feel they made a big impression on the robot. The results also indicate that the perceived affective impact of the robot is strengthened slightly by delaying the reaction.

The presented findings are novel in that they present a new context for using shared experiences to gain emotional coordination in human-robot interaction scenarios. The new approaches are based on using non-humanoid robots and by placing participants on the opposite side of the robot in a high-intensity conflict situation. The results introduce many opportunities for further research on the topic. As a whole, they suggest investigating to what extend shared reactions could strengthen the affective expression abilities of rescue robots and improve the reception of critical messages in high-intensity contexts.

II. Other approaches

The timing aspects of cooperative interaction was investigated by Pan et al. 2019 [37] by in- and decreasing the reaction times of a robot that was handed an object. The study, which used a humanoid torso robot with a head and arms, found that the people preferred reaction time equal to normal human reaction time when interacting with the robot. Their test scenario was different than the scenario investigated in this paper, as it contained a low-intensity interaction, a humanoid robot, and a cooperative task to accomplish in the tests, whereas this project focuses on non-humanoid robots in a high-intensity scenario and a test task that emphasizes the conflict between the interacting human and robot participants.

Previous robot projects have investigated increasing the understanding of affective communication in their research. Brazeal et al. 2003 employed an emotional subsystem for the robot Leonardo and controlled realistic employment of several affective means of expression making it easier to understand [10]. Gunes et al. 2011 used a LEGO-based custom robot to convey the emotional intentions of classical music. The robot employed several affective means of expression including movement and onboard gestures to communicate the affective status [38]. The timing aspects were the focus of Huber et al. 2008 in which they investigated different ways of letting robots hand over objects to humans. Successfully handing over the objects requires both parties of the interaction to agree on a common timing for the involved movements. The study found that the less jerky the movement was, the safer they felt around the robot. [39].

Bing and Michael 2012 investigated how sharing a stressful experience with a humanoid robot can potentially help humans overcome the uncanny valley effect [40], [41]. The 2012 paper found that their test participants preferred familiar humanoids with whom they had shared a stressful experience with rather than familiar robots that they had shared a pleasant experience with. This paper aims to extend the results found in that paper on two different levels. It investigates whether the results are similar for a non-humanoid robot that bears no resemblance to a person, and it attempts to discover whether the result is isolated to people that are on opposite sides of a conflict- and stressful situation. This paper emphasizes how humans perceive robot specific nonverbal behavior which is also the focus in Putten et al. 2018 [42]. In this paper, the robot-like specific behavior is found less effective than using human-like familiar behaviors to convey affective information. Both Bing & Michael 2012 and Ptten et al. 2018 indicate the strengths of using human-inspired behaviors and morphology in their studies which make a good contrast to the experiments performed in this paper using non-humanoids and strictly robot-specific behaviors.

III. Method

The first test aims at investigating changes to the general composition of emotions, while the second test expands the investigation into a physical and confrontational scenario to see how that influences the perceived intentions of a robot. The second test also focuses on the immediate delay between the context event and the subsequent robot reaction to see how delaying the robot's reaction influences how the robot was perceived. As stated in Bing et al. 2012, a shared stressful event works stronger using humanoid robots, which is why a conflicting scenario with a non-humanoid robot was interesting for the second test in this paper [40].

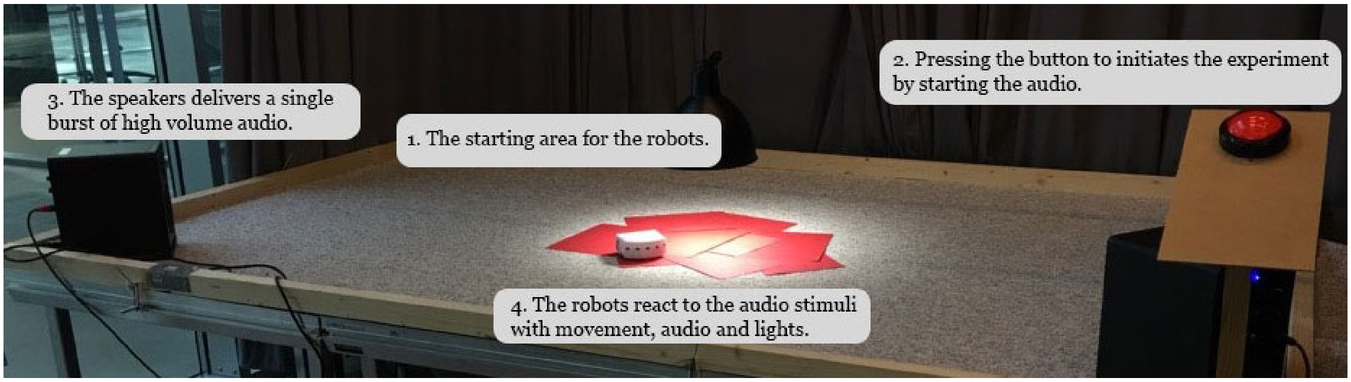

Fig. 2. The test setup for the initial experiment. The red center of the arena marks the starting position for the robots. The red button on the right side initiates the experiment in the first test. The same button was removed for the control test of the experiment in which the robots reacted with random intervals.

A. *Using standard descriptors*

In affective robotics research it is often the Pleasure, Arousal and Dominance (or PAD) scale that is used to describe emotional states [43], [44], while temporal aspects can be classified in the Traits, Attitudes, Moods and Emotions (TAME) architecture [45].

We quantify the affective impact by measuring the changes to the robot's perceived current emotion in PAD space. We measure differences between the two test groups on how the robot's affective state is perceived. If the test participants find it more or less pleasant, aroused, or dominant. E.g. if a person is angry during an interaction with a robot, and the robot emits a soothing sound to make the person change to a happier state, the angry emotion could move along the 'arousal' axis towards less aroused - which would be considered an affective change to the current affective state. This is what we use as a quantitative measure for the effects of coordinated reactions in the initial tests.

The tests followed a standard A-B pattern with two individual groups of test participants where one of them acted as a control group. The two groups would encounter the same scenarios, but the control group of participants would not experience coordinated reactions with the robots as they would react at random and out of phase with the participants. The test setup is depicted in Figure 2.

B. *Moving to a physical interaction*

Building upon the outcome of the first tests, the second test focused on how the shared reaction was perceived when the interaction context was changed to a physical and conflicting encounter with closer proximity between the participants and the robot. In this test, we asked the participants to physically strike the robot as much as they wanted and observe the reaction. We departed from using the standard PAD descriptor as we were not focusing on the composition of the affective impact, but rather on investigating where the interaction was perceived as making the largest impact - on the robot itself or the test participants. We also wanted to see how the delay time influenced the perceived size of the affective reaction and introduced delays between the physical interaction and the robot's reaction to highlight the connection between them. As the robot reacted in this context, the swiftness of the reaction made it more similar to a reflex than a prepared response. This approach was chosen as it matched the conflicting scenario. The sharing in the second test was solely the interaction, and we attempted to investigate how placing the participants and the robot on opposite sides of a conflict situation influenced the human-robot relationship.

IV. Experimental setup

In the first test, there were two groups with 42 people observing the robots in each of them. The overall gender distribution was 39 females and 45 males in ages from 10 to 50+. The majority of the participants were between 20 and 30 (71%) years old, and most of the participants either worked - or studied at The IT-University of Copenhagen (82.5%).

In the second test there were 110 participants distributed in 7 groups. The gender distribution here was 56% male and 44% female and the largest age group was 20-30 years old (33%) followed by people between 10-20 (20.2%). The initial test used a "Thymio 2" robot while the second test used and altered a custom-built "Affecta" robot designed to convey affective information.

A. *The first test: impact of reaction*

The setup of this test was comprised of three "Thymio 2" robots and a designated arena for the robots to move on. The arena was constructed from stage parts, forming a 220cm times 300cm surface, with floor carpets on top to create a smooth surface to easily maneuver on for the low-clearance Thymio 2 robots. The edges of the designated test arena were padded with a small wooden edge to prevent the robots from falling to the ground. The edges were fastened just high enough to trigger the proximity sensors positioned at the front, side, and back of the robots. The first test contained two experimental phases with different groups participating in each experiment. The tests were initiated in isolation from each other and followed this test outline:

Test steps:

1. The robots were initially placed at the center of the

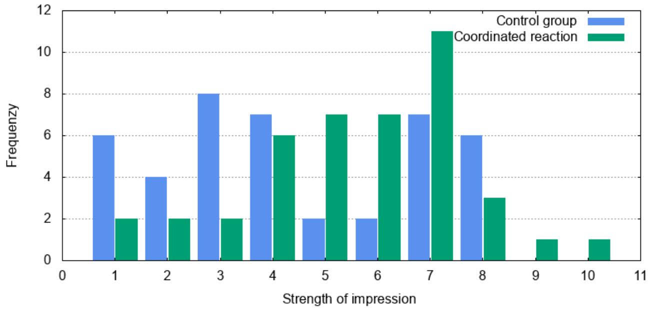

Fig. 3. The diagram shows the perceived arousal level of the robots. The blue-colored values are from the control test with uncoordinated human-robot reactions while the red-colored values are from the test group coordinated reaction between the participants and the robots.

arena. See Figure 2 for the initial position of the robots. 2. The participants were asked to start the experiment by pushing a button. 3. A high volume sound of an explosion was played as the button was pushed and the robots (and participants) reacted to the sound displaying fear. The robots used the following expression modalities: Sound, movement, and colored lights to convey the fear behavior. 4. The robots moved from the start area with maximum speed while displaying lights, and playing alerting audio signals in an attempt to show fearful behavior. 5. After 2 seconds of employing audio and lights, the robots continued to move but the audio and lights were turned off. This was done to enforce the connection between the reaction and the event that initiated it. 5. The robots moved randomly around on the surface while using front and back sensors to avoid the perimeter. 6. Once the robots encountered the center 'resting' area again, they stopped and waited until reacting again (start over from point 2).

The control group would go through the same steps. However, the robots would not react in coordination with the sound but at random intervals. After each experiment, the test participants were asked how *aroused* they perceived the robots were, how *pleasant* they perceived the robots found the experiment, and how *dominant* they perceived the current emotion for the robots was on a scale from 1 to 10 (1 meaning: not at all and 10 meaning: maximum possible). The participants were additionally asked to state their gender, and age.

B. The second test: the impact of specific timing

The second test used a custom-built robot as depicted in the left image of Figure 1. The robot was a small non-humanoid box-shaped robot that was designed to have implementations for a large variety of expression modalities, making it a great fit for this project. This specific robot design was 3d-printable, and suited the test setup. For the robot to remain stable for the physical interaction, only the top part of the robot was used and the bottom drive wheels not added. The robot consisted of two separate software architectures - a ROS based part to control the physical movement and gestures of the robot and a mobile application with access to all available sensors on a mobile smartphone. For this test, the mobile IOS based platform was expanded with a module for detecting physical movement using the onboard accelerometer. When the user would hit the robot the accelerometer sensor was triggered which informs the main robot controller to display a reaction using the mobile phone screen and audio capabilities of the robot (also supplied by the phone). The reaction consisted of a loud alert noise and jagged lines flashing at the edge of the screen. The second test was set up in a specially constructed and isolated test booth. The booth, which can be seen in the right image of Figure 1, contained a table with the robot at a raised position to facilitate a close proximity interaction, and it contained a poster with instructions for the test participants to strike the robot. One at a time we asked them to enter the test booth and hit the robot as much as they liked. They would interact with the robot by hitting it and observe how the robot reacted. When the test participants were finished with the physical interaction, they would step outside of the test booth and we proceeded by asking the following questions:

- How big an impact did your actions make on the robot?
- How big an impact did the robot's reaction make on you?
- How appropriate would you rate the robot's actions as being in light of how you interacted with it?

The participants were also asked to state their age group and their gender. The test was completed with 110 test participants. With each group of ten participants, the reaction delay of the robot's reactions was doubled starting from an initial reaction delay of 50ms ending at a reaction delay of 3200ms.

V. Results

The first test isolated the effects of coordinating human-robot reactions to a context event, while the second test used increasingly longer reaction delays to investigate how that affected the perceived affective impact of a human-robot physical interaction.

The results show three important findings:

- There is a causality between coordinating the reactions of humans and robots and the perceived arousal level of the test robots.
- The reaction times of the robots in physical interactions influence the affective state of the humans interacting with it and near human-like reaction reflexes (˜250ms) have the biggest affective impact on the test participants
- A slightly lesser delay time (˜100ms faster) is preferred when the aim is for the test participants to feel they made a big impression on the robot.

A. The influence of coordinating human-robot reactions

In the first test, we asked the participants to rate how *aroused* the robots seemed, and the difference between levels of perceived arousal was statically significant (Two-tail Wilcoxon signed-rank, $p<.05$). This shows a strong connection between experiencing a shared reaction with the robots and the interpreted level of arousal conveyed by the robots. The distribution of answers for the question on the perceived level of arousal can be seen in Figure 3, and the key figures for the same question can be seen in Table I.

We also asked the participants to rate the perceived pleasantness of the experience for the robots. The results for that question showed no relevant differences between the random group and the reaction group. The participants agreed that the experience was mildly unpleasant for the robots in both groups with key figures as seen in Table I. The last question regarded the perceived level of dominance for the current emotion, on which the participants rated each group with near similar scores. This indicated that there was no connection between the dominance level and sharing a reaction or not.

B. *Reaction delays strengthen affective impact*

In the second test, the results indicate that there was a preferred reaction delay around 200ms for the question regarding the perceived impact of the robot's actions on the participants who interacted with it. The resulting averages for that question can be seen in Figure 4. This enforced the results found in by Pan et al. 2019 and extends the finding to also include non-humanoid robots and a conflicting scenario rather than a cooperative context [37]. The results show that the robot made the biggest affective impact on the participants when it reacted to the physical interaction with human-like reaction times (which we assume is approximately 250ms). It is important to state that although our number of participants is relatively high (n=91), using the arithmetic mean for smaller individual groupings could make the result more easily affected by outliers.

We asked the participants to rate how big an impression the test participants' actions made on the robot, and for that question, the relative highest rated delay time was 100ms. This and the previous result indicate the following:

- If the aim is for the robot to make a big impression on the participants, it should react with near-human reaction times.
- If the aim is for the test participants to feel they made a big impression on the robot, it could benefit from reacting with a slightly smaller delay. (˜100ms faster).

We also asked the participants to rate the appropriateness of the robot's action in relation to the actions performed by the test participants. The resulting ratings were near at par with each other with a reaction time of 100ms rated relatively highest. The resulting averages for the last two questions can be seen in Figure 4.

	No Reaction (avg/dev)	With Reaction
Agitatedness	4.40/2.42	5.55/2.04
Pleasantness	4.83/2.27	4.71/2.11
dominance	3.76/2.34	3.98/2.50

TABLE I

THE AVERAGES AND STANDARD DEVIATION FOR THE ANSWERS FOR THE PERCEIVED LEVEL OF AROUSAL, PLEASANTNESS, AND LEVEL OF DOMINANCE IN THE TESTS WHERE THE PARTICIPANTS SHARED A REACTION WITH THE ROBOTS AND THE CONTROL TEST IN WHICH THE ROBOTS REACTED AT RANDOM INTERVALS.

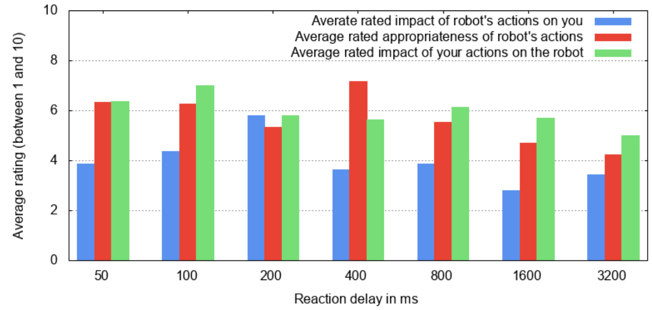

Fig. 4. The resulting average ratings in relation to the delay time in milliseconds concerning the rated impact of the robot's actions, the impacts participants made on the robot, and the rated appropriateness of the robot's actions.

Grouping the results by the age of the participants shows that most of the age groups prefer human-like reaction times. The top-rated of the average reaction time for the affective impact of the robot's behavior in regards to age group was 200ms. Our initial assumption was that the results would support a relationship between older age and slower preferred reaction times. However, this is not the case. The 200ms delay which corresponds to human-like reaction times is preferred even by the older test participants. The age group from 21 - 30 preferred the slowest reaction time of 3200ms, but a closer look at the data reveals that may be explained by a lack of proper age distribution for some delay times. It is vital to state that the age distribution across every delay group is not uniformly distributed. Some delay categories have very few examples for specific age groups. The results indicate that the age group of 41 - 50 prefers a slower-than-human robot with a preferred reaction time of 400ms and presents an opportunity for further research projects to focus more on each age group and the preferred reaction times.

VI. FROM MEASURES TO MEANING

The boundaries of each discrete state in models such as the PAD space are fuzzy, and a single 3d coordinate can rarely convey the rich sources of information that affective data is [38]. Because emotions are given significance by the words that express them, they differ between languages. In some cases with specific languages, certain emotions are not present or mean something different [46]. When the interpretation and comprehension of the affective states are culturally dependent the problem is that the interpretation of them change with each cultural context and group of human observers [47]. This paper acknowledges that it is difficult to create a test setup that provides clear answers, but attempts to work around it by using many participants. Our test setup had the two following drawbacks regarding the age of the participants:

1. The test was designed to measure the effect of the delay times. This meant that the age groups were not uniformly distributed within each tested delay times

and that some delay times had one or more age groups that were not represented.
2. As our delay time was doubled each time, it left out too many details of the interesting area between 200 and 400ms. It may be that the effect we were attempting to verify was smaller than anticipated and that we instead needed a test that expanded the knowledge on that specific delay interval.

The results of the first test indicate that there is a causality between the level of perceived arousal and the coordination of human-robot reactions to the context event. The robots were perceived as being more aroused when their reactions were coordinated with human observers. The results show that considering the timing aspects of conveying affective information and sharing a reaction with a human observer can be beneficial in those scenarios where the aim is to convey highly aroused affective states.

That the overall voted most suitable reaction delay time for the reaction to the physical interaction of the second test is 200ms, might for some scenarios be considered a positive result. Such a delay leaves a wide timeframe even for low hardware-driven robots to analyze the input and consider the proper reaction to a given situation. The physical properties in the second test also seemed to affect how the participants interpreted the overall pleasantness of the interaction. Some participants stated they felt bad about hitting the robot and did not want to interact with it because it seemed as if they punished the robot for no reason. The average ratings on appropriateness in relation to reaction time can be seen in Figure 4.

The resulting ratings for the different delay times fortify what Pan et al. 2019 found with humans and robots interacting in a cooperative setting [37]. Our common intuition would say that the Pan et al. test participants preferred a human-like response time because they used a humanoid robot and a human-to-human inspired context with a cooperative task. However, if we interpret the highest-rated suitable behavior as the preferred behavior, our result shows that these findings can be extended to non-humanoid robots as well. They also show that the same reaction time was found most suitable in high-intensity scenarios - in which people physically interact with the robot.

When we asked the participants to rate the emotional impact of hitting the robot, the highest average rating was given when the robot reacted with a delay time of 100ms followed by the second-highest ratings for 50ms. This could indicate that there is a measurable difference between how the participants wanted the robot to react in the different scenarios. When the aim is to convey to the participants that their actions had a large impact, the reaction time should be shorter than human reaction times (<250ms). When the aim is for the robot to make a large emotional impact on the participants, the robot should react similarly to humans (~250ms). It makes sense to consider to what extent the results are applicable in other contexts. The tested scenario portrayed a social context, and it may be that the highest-rated reaction speeds in this experiment would be found suitable for other social situations as well. However, the results do not per se extend to other robot types and or other domains. E.g. we don't necessarily prefer a manufacturing robot at a factory to work at the same speeds as humans.

Regarding the results grouped by age, we argue that the presented findings introduce many opportunities for further research on the topic. As one, we suggest investigating more specifically to what extend age influences the chosen most suitable reaction times in a finer interval between 200 and 400 ms - to see if age specific reaction times could strengthen the reception of affective information even further.

VII. Conclusion

The paper has investigated the causality between coordinating human-robot reactions and the perceived affective impact on robots. It has shown that we can use coordinated reactions to strengthen the way robots convey affective information. The emphasis was to see whether the perceived level of intensity in the behavior was increased when a robot was reacting to a context event in coordination with a human, and to test whether delaying the specific reaction times in physical interactions influenced how test participants viewed the affective state of the robot. We carried out two human-robot interaction tests to highlight these aspects of human-robot interaction.

The result showed that there was a significant difference between how aroused the human observers rated the robots as being in the first test when the human-robot reactions were coordinated. The results of the second test indicated that even for high-intensity scenarios with non-humanoid robots, the preferred reaction for the robots was similar to the reaction time of humans. Furthermore, they showed that a faster reaction time (~100ms faster) was preferred when the goal was for the test participants to feel as if they made a large impact on the robot.

The findings indicate that the concept of sharing reactions and using near-human reaction delays can be strategically used to influence how the current affective state of a robot is perceived.

References

[1] K. S. Morten Roed Frederiksen, "A systematic comparison of affective robot expression modalities," *IEEE/RSJ International Conference on Intelligent Robots and Systems*, 2019.

[2] G. Hoffman, M. Cakmak, and C. Chao, "Timing in human robot interaction," *2014 9th ACM/IEEE International Conference on Human-Robot Interaction (HRI)*, pp. 509–510, 2014.

[3] L. Boccanfuso, E. S. Kim, J. C. Snider, Q. Wang, C. A. Wall, L. DiNicola, G. Greco, F. Shic, B. Scassellati, L. Flink, S. Lansiquot, K. Chawarska, and P. Ventola, "Autonomously detecting interaction with an affective robot to explore connection to developmental ability," *2015 International Conference on Affective Computing and Intelligent Interaction (ACII)*, pp. 1–7, 2015.

[4] W. D. Stiehl, C. Breazeal, K.-H. Han, J. Lieberman, L. Lalla, A. Z. Maymin, J. Salinas, D. Fuentes, R. L. Toscano, C. H. Tong, A. Kishore, M. Berlin, and J. Gray, "The huggable: a therapeutic robotic companion for relational, affective touch," *CCNC 2006. 2006 3rd IEEE Consumer Communications and Networking Conference, 2006.*, vol. 2, pp. 1290–1291, 2006.

[5] A. Singh and J. E. Young, "A dog tail for communicating robotic states," *2013 8th ACM/IEEE International Conference on Human-Robot Interaction (HRI)*, pp. 417–417, 2013.

[6] C. C. Bennett and S. Sabanovic, "Perceptions of affective expression in a minimalist robotic face," *2013 8th ACM/IEEE International Conference on Human-Robot Interaction (HRI)*, pp. 81–82, 2013.
[7] D. Benson, M. M. Khan, T. Tan, and T. Hargreaves, "Modeling and verification of facial expression display mechanism for developing a sociable robot face," *2016 International Conference on Advanced Robotics and Mechatronics (ICARM)*, pp. 76–81, 2016.
[8] C. L. Lisetti, S. M. Brown, K. Alvarez, and A. H. Marpaung, "A social informatics approach to human-robot interaction with a service social robot," *IEEE Transactions on Systems, Man, and Cybernetics*, vol. 34, 2004.
[9] G.-Y. Park, S.-I. Lee, W.-Y. Kwon, and J.-B. Kim, "Neurocognitive affective system for an emotive robot," *2006 IEEE/RSJ International Conference on Intelligent Robots and Systems*, pp. 2595–2600, 2006.
[10] C. Breazeal, "Emotion and sociable humanoid robots," *Int. J. Hum.-Comput. Stud.*, vol. 59, pp. 119–155, 2003.
[11] R. Gockley, R. G. Simmons, and J. Forlizzi, "Modeling affect in socially interactive robots," *ROMAN 2006 - The 15th IEEE International Symposium on Robot and Human Interactive Communication*, pp. 558–563, 2006.
[12] S.-I. Lee, G.-Y. Park, and J.-B. Kim, "Natural emotion expression of a robot based on reinforcer intensity and contingency," *Proceedings 2007 IEEE International Conference on Robotics and Automation*, pp. 2144–2149, 2007.
[13] J.-D. Yim and C. Shaw, "Designing cally, : a cell-phone robot," in *CHI Extended Abstracts*, 2009.
[14] J.-Y. Yang, B. K. Dinh, H.-G. Kim, and D.-S. Kwon, "Development of emotional attachment on a cleaning robot for the long-term interactive affective companion," *2013 IEEE RO-MAN*, 2013.
[15] G. Yoshioka, T. Sakamoto, and Y. Takeuchi, "Inferring affective states from observation of a robot's simple movements," *2015 24th IEEE International Symposium on Robot and Human Interactive Communication (RO-MAN)*, pp. 185–190, 2015.
[16] M. Saerbeck and C. Bartneck, "Perception of affect elicited by robot motion," *2010 5th ACM/IEEE International Conference on Human-Robot Interaction (HRI)*, pp. 53–60, 2010.
[17] C. L. Bethel, K. Salomon, and R. R. Murphy, "Preliminary results: Humans find emotive non-anthropomorphic robots more calming," *2009 4th ACM/IEEE International Conference on Human-Robot Interaction (HRI)*, pp. 291–292, 2009.
[18] C.-Y. Lin, L.-C. Cheng, C.-C. Huang, L.-W. Chuang, W.-C. Teng, C.-H. Kuo, H.-Y. Gu, K.-L. Chung, and C.-S. Fah, "Versatile humanoid robots for theatrical performances," *International Journal of Advanced Robotic Systems*, vol. 10, p. 1, 01 2013.
[19] B. Gonsior, S. Sosnowski, M. Buß, D. Wollherr, and K. Kühnlenz, "An emotional adaption approach to increase helpfulness towards a robot," *2012 IEEE/RSJ International Conference on Intelligent Robots and Systems*, pp. 2429–2436, 2012.
[20] I. D. Addo and S. I. Ahamed, "Applying affective feedback to reinforcement learning in zoei, a comic humanoid robot," *The 23rd IEEE International Symposium on Robot and Human Interactive Communication*, pp. 423–428, 2014.
[21] K. Winkle and P. Bremner, "Investigating the real world impact of emotion portrayal through robot voice and motion," *2017 26th IEEE International Symposium on Robot and Human Interactive Communication (RO-MAN)*, pp. 627–634, 2017.
[22] C. Becker-Asano and H. Ishiguro, "Laughter in social roboticsno laughing matter," *Intl. Workshop on Social Intelligence Design (SID2009)*, 01 2009.
[23] J. H. Lui, H. Samani, and K. yu Tien, "An affective mood booster robot based on emotional processing unit," *2017 International Automatic Control Conference (CACS)*, pp. 1–6, 2017.
[24] R. Zhang, Y. He, and Z. Liu, "Communication atmosphere in humans and robots interaction based on fuzzy analytical hierarchy process," *2017 36th Chinese Control Conference (CCC)*, pp. 6767–6772, 2017.
[25] I. Cohen, R. Looije, and M. A. Neerincx, "Child's recognition of emotions in robot's face and body," *2011 6th ACM/IEEE International Conference on Human-Robot Interaction (HRI)*, pp. 123–124, 2011.
[26] T. L. Chen, C.-H. King, A. L. Thomaz, and C. C. Kemp, "Touched by a robot: An investigation of subjective responses to robot-initiated touch," *2011 6th ACM/IEEE International Conference on Human-Robot Interaction (HRI)*, pp. 457–464, 2011.
[27] J. Xu, J. Broekens, K. V. Hindriks, and M. A. Neerincx, "Effects of a robotic storyteller's moody gestures on storytelling perception," *2015 International Conference on Affective Computing and Intelligent Interaction (ACII)*, pp. 449–455, 2015.
[28] J. Xu, J. Broekens, K. Hindriks, and M. A. Neerincx, "The relative importance and interrelations between behavior parameters for robots' mood expression," in *2013 Humaine Association Conference on Affective Computing and Intelligent Interaction*, 2013, pp. 558–563.
[29] W. Johal, S. Pesty, and G. Calvary, "Toward companion robots behaving with style," *Proceedings - IEEE International Workshop on Robot and Human Interactive Communication*, vol. 2014, pp. 1063–1068, 08 2014.
[30] L. Rincon, E. Coronado, H. Hendra, J. Phan, Z. Zainalkefli, and G. Venture, "Expressive states with a robot arm using adaptive fuzzy and robust predictive controllers," *2018 3rd International Conference on Control and Robotics Engineering (ICCRE)*, pp. 11–15, 2018.
[31] C. Park, J. Ryu, J. Sohn, and H. Cho, "An emotion expression system for the emotional robot," *2007 IEEE International Symposium on Consumer Electronics*, pp. 1–6, 2007.
[32] C. L. Bethel and R. R. Murphy, "Survey of non-facial/non-verbal affective expressions for appearance-constrained robots," *IEEE Transactions on Systems, Man, and Cybernetics, Part C (Applications and Reviews)*, vol. 38, pp. 83–92, 2008.
[33] J. Michael, "Shared emotions and joint action," *Review of Philosophy and Psychology*, vol. 2, pp. 355–373, 01 2010.
[34] V. V. Unhelkar, P. A. Lasota, Q. Tyroller, R.-D. Buhai, L. Marceau, B. Deml, and J. A. Shah, "Human-aware robotic assistant for collaborative assembly: Integrating human motion prediction with planning in time," *IEEE Robotics and Automation Letters*, vol. 3, pp. 2394–2401, 2018.
[35] L. Lucignano, F. Cutugno, S. Rossi, and A. Finzi, "A dialogue system for multimodal human-robot interaction," in *ICMI*, 2013.
[36] R. A. Hyman, "Stimulus information as a determinant of reaction time." *Journal of experimental psychology*, vol. 45 3, pp. 188–96, 1953.
[37] M. B. Matthew Pan, Espen Knop and G. Niemeyer, "Fast handovers with a robot character: Small sensorimotor delays improve perceived qualities," *IEEE/RSJ International Conference on Intelligent Robots and Systems*, 2019.
[38] H. Gunes, B. Schuller, M. Pantic, and R. Cowie, "Emotion representation, analysis and synthesis in continuous space: A survey," in *Face and Gesture 2011*, March 2011, pp. 827–834.
[39] M. Huber, M. Rickert, A. Knoll, T. Brandt, and S. Glasauer, "Human-robot interaction in handing-over tasks," *RO-MAN 2008 - The 17th IEEE International Symposium on Robot and Human Interactive Communication*, pp. 107–112, 2008.
[40] R. W. Bing and J. Michael, "Overcoming the uncanny valley through shared stressful experience with a humanoid robot," *Journal of Emerging Investigators*, 06 2018.
[41] M. Mori and K. F. MacDorman, "The uncanny valley: The original essay by masahiro mori," in *IEEE Spectrum*, 2017.
[42] A. M. R. von der Pütten, N. C. Krämer, and J. Herrmann, "The effects of humanlike and robot-specific affective nonverbal behavior on perception, emotion, and behavior," *International Journal of Social Robotics*, vol. 10, pp. 569–582, 2018.
[43] A. Mehrabian and J. Russell, "An approach to environment psychology," *Cambridge, MA*, 01 1974.
[44] J. A. Russell, "Core affect and the psychological construction of emotion." *Psychological review*, vol. 110 1, pp. 145–72, 2003.
[45] L. V. Moshkina, S. Park, R. C. Arkin, J. K. Lee, and H. Jung, "Tame: Time-varying affective response for humanoid robots," *I. J. Social Robotics*, vol. 3, pp. 207–221, 2011.
[46] B. B. de Mesquita and N. Frijda, "Cultural variations in emotions: a review." *Psychological bulletin*, vol. 112 2, pp. 179–204, 1992.
[47] H. Gunes and M. Pantic, "Automatic, dimensional and continuous emotion recognition," *IJSE*, vol. 1, pp. 68–99, 2010.