Involuntary Motion in Human-Robot Interaction: Effect of Interactive User Training on the Occurrence of Human Startle-Surprise Motion

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***Abstract*— In human-robot interaction (HRI) high relative velocity between robot and human at collision may lead to severe injury. Human rapid involuntary motion (IM) may therefore be a safety hazard resulting from startle or surprise (StSu). The arousal that may cause such motion can be reduced by habituation effects, indicating that user application training leads to improved safety in HRI. We suggest using an introductory hands-on user training and investigate whether it can influence the occurrence of IM. An exploratory experiment was performed with 21 participants. During the experiment a robot frontally approached the human six times. The experiment was repeated before and after a hands-on training session. We observe whether the participants show cues of StSu at the approach and compare the quantity of these cues occurring before and after hands-on robot introductory training. Our findings show promising results for the hands-on introductory training to positively effect the psychological and physical safety in HRI.**

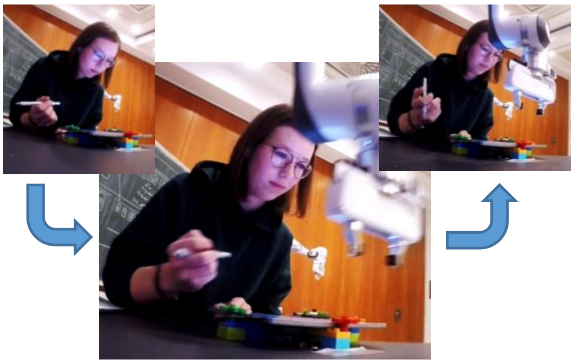

Fig. 1. Facial reaction and avoidance motion of a participant during the experiment where IM is observed when a robot frontally approaches the human to varying distances.

I. INTRODUCTION

In human-robot interaction (HRI) human and robot are sought to work in close proximity. One of the major safety hazards in such collaborations is rapid, unexpected movement. This does not only apply for the robot but also for human motion, which contributes to injury just as well as the one of the robot [1], [2]. Fast human motion therefore may be a threat to successful safety strategies. Involuntary motion (IM) is a rapid hormonal reaction resulting in a fast and uncontrolled movement [4] [5]. This movement can be a consequence of startle or surprise (StSu) and is therefore strongly connected to experience [4]. In HRI unexpected robot motions can cause IM [6]. The level of haptic user experience with a robot can be assumed to have a significant influence on this IM occurrence. Also fear-potentiated startle reflexes can be caused by pure anxiety towards a stressor [7]. Studies on anxiety in HRI show that the degree of anxiety can be influenced by habituation [8]. This suggests that due to training the quantity of IM occurrence can be reduced and endangering situations in close HRI can be prevented. While in industry training is required for all kinds of HRI [3], in the emerging field of social robotics focuses on robots in every day life only few training strategies exist [9]. Short training sessions for habituation and hands-on experience are performed such as introductory sessions between user or patient and robot e.g. by Robokind Stiftung [9].

In this paper, we investigate, whether a short period of around one hour of habituation by an introductory robot training already influences the occurrence of IM in HRI. Therefore, we conduct an exploratory experiment displayed in Fig. 1, which investigates the occurrence of social cues on StSu when a Franka Emika Panda robot-arm frontally approaches a human before and after training. The aim of this experiment is to determine whether the quantity of StSu cues among the group of participants significantly changes after hands-on robot training and habituation.

II. STATE OF THE ART

A. *Effect of human velocity on human injury in HRI*

The effects of velocity and mass on injury occurring in HRI was investigated in e.g. [12]. Based on the energy transmitted at a collision both velocity and mass have an influence on injury probability. [12]. As in HRI human injury is to be avoided, a safety strategy was introduced, relating the effective mass, curvature, and the maximum relative velocity at a collision, denoted as safe motion unit (SMU) [1]. As stated in [15] the average velocity a human hand voluntarily reaches when asked to hit one target as fast as possible is 4.43 m/s. This is significantly faster than collaborative robots typically operate at, e.g. Franka Emika Panda's maximum end effector speed is 2.0 m/s[1], ABB Yumi's 1.5 m/s[2] or

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[1] https://www.generationrobots.com/media/panda-franka-emika-datasheet.pdf

[2] https://library.e.abb.com/public/9f12ffd26ff749e1992b54e557b20a35/YuMi_Datasheet_US%20Letter.pdf

Yaskawa's HC10 and Universal robot's UR5e's 1.0 m/s[3] according to the robots' datasheets. Reflexes are known to occur with rapid IM caused by startle or surprise (StSu) [4] and can be caused by robots' approch motion [5]. Those motions could increase the relative velocity and thus potential hazard during collisions. Hence, we argue that unforeseeable IM should be prevented if possible.

B. *Habituation and training to increase safety*

With the rise of machinery and due to injuries caused by improper use first studies referred to methods increasing operator safety and also find human factors such as training to be important [14]. An overview of studies on the effect of training on safety in working environments can be found in [13]. Generally, all studies found improvement of performance behaviour after safety training. Notably, training where participants were able to gain real life experience in practical handling of hazardous scenarios showed most effect [13]. Those training methods are mostly developed for industrial setting. Nevertheless, in household and care-taking scenarios concepts for such training have hardly been considered [10]. In [9] hands-on training concepts are suggested for education of persons in social scenarios. We hypothesize that even short sessions of introductory hands-on user training with robots have a positive effect on safety in social robot settings. Therefore, we conduct a study observing whether safety-critical IM of inexperienced robot-users can be prevented with the help of an one hour hands-on user training.

III. METHODOLOGY

To observe whether IM can be reduced within a short duration of training and habituation, an experiment is designed and conducted with non-experienced robot users. We record the participants facial and upper body reactions to the approaching robot with a GoPro camera attached to the robot base and observe whether social cues on StSu appear. Generally, IM result from disappointed expectations [11]. In our case, the participant has a certain expectation regarding the robot's motion. This can vary with each person and also with time. Following, we decided to include all social cues on StSu are to the evaluation.

A. *Hands-on user training*

The training is held in teams of three people and consists of the following phases.

1) As a team the participants start a new program in the programming interface shown in Fig. 2 a).
2) Each person is individually asked to move the robot by hand and test its joint limits.
3) The first motion is programmed by each participant moving the robot to a certain pose and setting that pose, speed, and acceleration for the joint motion generator to move along this trajectory as in Fig. 2 b).
4) The group is asked to use the interface to program the robot to transport a pile of three wooden blocks from the one table side to the other shown in Fig. 2 c) and d). No restrictions on how to move the blocks are given.

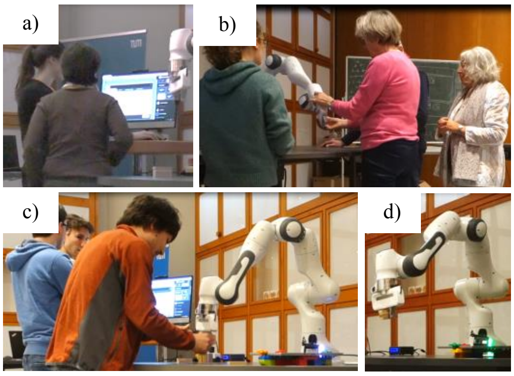

Fig. 2. Photographs of the training sessions displaying a) the start of the training by starting the programming interface, b) one group of participants testing the robots limits and programming the first motions, c) another group of participants programming the robot to place a pile of wooden blocks from on side of the table to another, and d) the robot finally conducting the piling task.

To solve problem 4) the participant group is asked to solitary get to know other applications given by the interface and ask for help when necessary. Also all participants are asked to equally contribute to the programming task. This short training session is designed to take approximately one hour.
After the habituation period during user training, the first experiment was repeated at the same velocity and again with randomized order of approaching distances.

B. *Experimental set up and procedure*

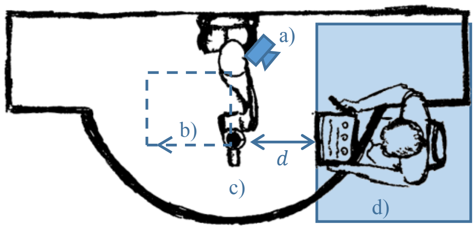

Fig. 3. Sketch of experimental set up with a) camera pointing towards the human, b) robot end effector motion path, c) start position of the robot with direction and distance d of the approach and d) the human workspace beginning at the corner of a tablet and the participant holding a pen for answering a quiz on the tablet.

The experimental setup is shown in Fig. 3. For the experiment a group of participants is chosen that have never worked in HRI with robotic arms like Panda and have few to no experience with the system. For the meaningful design of the interaction task with regard to everyday scenarios, we investigated which situations occur frequently in HRI and may cause significant damage in a potential collision. We found the approaching motion of a robot typically show the highest injury potential. Therefore, we focus on modelling

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[3] http://yaskawa.co.il/wp-content/uploads/2017/12/HC10-datasheet.pdf, https://www.universal-robots.com/media/50588/ur5_en.pdf

the approach of a robot towards the human, where the human can be distracted, surprised or startled by the system approach motion.

Starting the experiment, all participants were asked to sit on a chair next to the robot as depicted in Fig. 3 d). They are told, that the robot will move due to calibration tasks. For creating a mental distraction from the robot motion, the participants were asked to complete a quiz task on a tablet in front of them. The robot was moving in squares on the other side of the table at minimum 0.44 m distance from the tablet (Fig 3 b)) while the human conducted the quiz. After a random number of movements, the robot frontally approaches the human till reaching a certain distance d, which is measured from the outer edge of the tablet, see Fig. 3 c). The robot is hereby in peripheral view of the human and the approaching is slightly audible. The approach motion is repeated six times. It is designed to simulate a dynamic environment where the autonomous robot may change approaching behaviour and avoid the influence of velocity and distance of the approach by taking the following measures:

a) two groups are randomly assigned where in one group the approaching velocity is $v = 0.25$ m/s (G1) and for the other $v = 1.00$ m/s (G2)
b) for both groups all six approaches are targeted towards different distances to the outer edge of the tablet ranging from 0 m to 0.25 m in 0.05 m steps in randomized order from the outer edge of the tablet.

This procedure is followed by a hands-on introductory user training for programming and guiding the robot. Afterwards, it is repeated.

The entire group of participants consists of 21 participants 15 males and six females with an average age of 37.10 ± 17.75 years. 17 participants had an academic degree comparable to Bachelor or higher. Of those, three were students in STEM subjects, eight research assistants, five with no technological background and one is technician. The four participants without academic degree were one student in Bachelor's STEM course, a home maker, and two technicians. G1 consists of eleven and G2 of ten participants. This study was conducted under the approval of the Ethic Commission of Technical University of Munich under review number 395/19 S.

C. Hypotheses

To evaluate the effect of short-time habituation by interactive training we use the following hypothesis.

H1: The number of StSu cues occurring among all participants is higher before training than afterwards.

We also analyze whether the velocity of an approach was a potential factor to the success-rate of training in HRI by

H2: The change of number of StSu cues from pre- to post-training differs between G1 and G2.

To prove the feasibility of H1 and H2, a t-test for dependent samples is conducted for each hypothesis. Here we use the null hypothesis that no decrease in StSu cues occurs after training for H1. It is tested unilaterally. For H2 the null hypothesis states that no significant change of the number of StSu cues exists between both groups and is tested with a t-test bilaterally.

D. Evaluation of involuntary motion

To define whether a motion is caused involuntarily by startle or surprise, the sociometric coding scheme depicted in Table I is used, which is based on [16]-[19] and resulting from one session of sample training. An exemplary expression of StSu is depicted in Fig 4. Besides StSu cues observable in face and upper body motion, contact perception (CP) is annotated, which tells whether the human noticed the approaching robot prior to a reaction. This helps to evaluate whether a motion was caused by the robot. For all the non-verbal behaviour annotations we apply the MUMIN coding scheme [20] for multi-modal analysis in simplified form and use the ELAN software tool [21]. An experienced human coder from the social sciences evaluated the videos. For the inter-coder reliability test a second coder uses the same coding scheme to verify the results. Finally, the coding is repeated eight weeks later to check if the evaluation is consistent in time (intra-coder reliability). Both tests show high reliability.

Fig. 4. Exemplary expression of startle and surprise captured during the study.

TABLE I
CODING SCHEME FOR STSU CUES BASED ON [16]-[19]

CP	Face	Gestures/Postures
- gaze to robot - immediate StSu cue - irritated look at robot after approach - freezing	- rapid eye-blinks - lowered eyebrows - closed eyes - tightened eyelids - stretched lips - open jaws - widened eyes - raised eyebrows - delayed felt smile	- body freezes - shoulder jerk - body twitches - tightened neck - evasive trunk/ head motion

IV. RESULTS

In the exploratory study we found a decrease of StSu cues after the training session from 28 % to 19 %. We therefore accept H1.

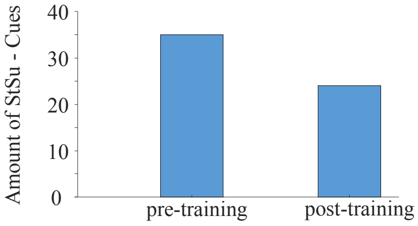

Fig. 5. Pre- and post-training occurrence of StSu cues

Before training, in average 1.75 ± 1.99 StSu cues occurred per person during the 6 approaches and after training 1.14 ± 1.53 per person. We applied a Kolmogorov-Smirnoff test for both data sets to check for normal distribution and found both to be normally distributed. The unilateral t-test for dependent samples gives $p = 0.02$, which proves significance to a level of significance $\alpha = 0.05$. We therefore reject the null hypothesis, which states that no decrease in StSu cues occurs from before to after the training session. We can state that our hands-on training session has a positive influence on the number of IM occurring.

For H2 we found the amount of StSu cues occurring within G1 and G2 shown in Fig. 6. For pre-training among G1, 7 cues on StSu were observed while for G2 18. Considering post-training, in G1 4 cues occur while in G2 it is 13. The number of StSu cues occurring after training decreases by 42.86 % in G1, while it decreases by 27.78 % in G2.

For each participant we calculate the percentage of decrease of IM from the first to the second experiment. Within G2 we observe an average of decrease of the number of StSu cues by 5 % ±25 % participant conducting the experiment. In G1 the average decrease is by 33 % ±42 % per participant. Result of the bilateral t-test is $p = 0.27$. With the level of significance $\alpha = 0.05$ the null hypothesis is therefore not rejected. The high standard deviations show a great difference in the decrease of IM per person after training. We suggest a larger study design to observe whether approaching velocity has an influence on the reduction of IM by hands-on training sessions.

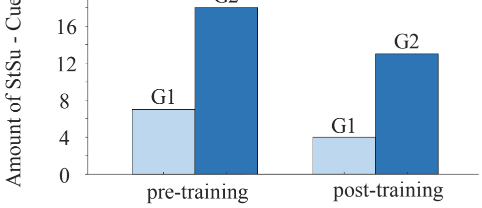

Fig. 6. Pre- and post-training occurrence of StSu cues among G1 and G2

V. CONCLUSION AND DISCUSSION

In this paper we investigate the question whether hands-on user training can increase cognitive and physical safety in HRI. We propose an exemplary training sequence consisting of a short introduction and hand guiding the robot, followed by programming a simple pick-and-place task. An exploratory study, in which a robot approaches a human was conducted to observe whether introductory robot lessons decrease human involuntary motion due to startle or surprise among our 21 participants. The result of this study shows a significant reduction of involuntary motion occurrence by 31.43 % using the proposed hands-on introductory user training. We investigated whether the robot's approaching speed has an influence on this decrease and found no significant effect. Generally, we conclude that hands-on user training has the potential to improve psychological and physical safety. Future work includes finding the most effective study designs and investigating the effect in a large scale study. As a contribution to psychological and physical safety in HRI, we suggest to design introductory hands-on trainings for robot users.

ACKNOWLEDGMENT

The authors would like to thank Jan Schreiber for supporting the experiments and Nico Mansfeld for proof reading. We gratefully acknowledge the funding of the Lighthouse Initiative Geriatronics by StMWi Bayern (Project X, grant no. 5140951) and LongLeif GaPa gGmbH (Project Y, grant no. 5140953), the European Union's Horizon 2020 research and innovation programme as part of the project ILIAD under grant no. 732737 and the funding of project KoBo34 (Verbundprojektnummer V5ARA202) by the BMBF (grant no. 16SV7985). The support by the Bavarian Institute for Digital Transformation is gratefully acknowledged. Please note that S. Haddadin has a potential conflict of interest as shareholder of Franka Emika GmbH.

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