“It Was Not Your Fault” – Emotional Awareness Improves Collaborative Robots

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ABSTRACT

We have conducted a user study to investigate the importance of emotional awareness and the underlying affect-driven processes during a human-robot collaboration. The goal of this user study was twofold: (1) Investigating the overall functionality of the mechanisms and the underlying algorithms in our architecture, (2) Evaluating human's willingness and assessment of collaboration with an emotion-aware and an emotion-ignorant robot. We designed a simple table top game to simulate the collaborative environment in which a participant and the robot were “installing” a solar panel together. The result of our user study shows a significant difference between humans' preference of working with an emotion-aware robot during collaboration.

CCS Concepts

•**Computer systems organization** → **Embedded systems;** *Redundancy;* Robotics; •**Networks** → Network reliability;

Keywords

Human-Robot Collaboration, Affect-Driven Processes, Emotion-Awareness

1. INTRODUCTION

The idea of robots or other intelligent agents living in a human environment has been a persistent dream from science fiction books to artificial intelligence and robotic laboratories. Collaborative robots are expected to become an integral part of humans' environment to accomplish their industrial and household tasks. In these environments, humans will be involved in robots' operations and decision-making processes. The involvement of humans influences the efficiency of robots' interaction and performance, and makes the robots sensitive to humans' cognitive abilities and internal states.

We believe that collaborative robots need to take into account humans' internal states while making decisions during collaboration. Humans express emotions to reveal their internal states in social contexts including collaboration [4]. Due to the existence of such expressions robot's emotional-awareness can improve the quality of collaboration in terms of humans' perception of performance and preferences. Hence, collaborative robots require to include affect-driven mechanisms in their decision making processes to be able to interpret and generate appropriate responses and behaviors. Our aim in this work was to study the importance of emotional awareness and the underlying affect-driven processes in human-robot collaboration. We examined how emotional-awareness impacts different aspects of humans' preferences by comparing the results from our participants collaborating with an emotion-aware and an emotion-ignorant robot.

This work is implemented as part of a larger effort to assess affect-driven collaborative robots which are capable of generating and recognizing emotions in order to be better collaborators. This work is based on the development of *Affective Motivational Collaboration Theory* which is built on the foundations of the *SharedPlans* theory of collaboration [8] and the *cognitive appraisal* theory of emotions [7].

2. RELATED WORK

There are many research areas, including robotics and autonomous agents, that employ the structure and/or functions of emotions in their work with a variety of motivations behind modeling emotions [27]. In [4] authros surveyed some of the principle research in social robotics and its applications in Human-Robot Interaciton. We can see the application of emotion theories in designing robots capable of learning from humans [3], robots capable of expressing emotions [5] [20] and social behaviors [18], as well as robots which can convey certain types of emotion products, e.g., empathy [12]. There are also several works in which researchers have explored the human's affective state as a mechanism to adapt the robot's behaviors during the interaction [2] [14].

Many of the computational models of emotions and their applications are derived from appraisal theories of emotion making appraisal as the central process in their architectures [1] [16] [17] [21]. Appraisal is usually modeled as the cause of emotion being derived via simple rules on a set of appraisal variables. In robotics,

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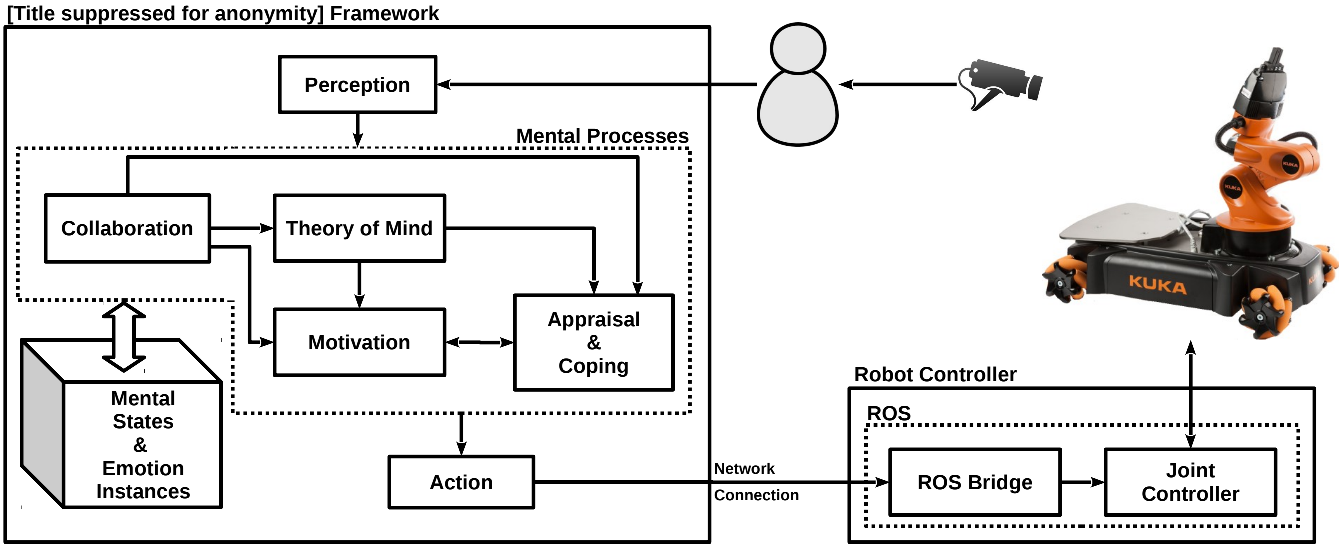

Figure 1: Computational framework based on [title suppressed for anonymity] theory (arrows indicate primary influences between mechanisms and data flow).

appraisal theory has been used to establish and maintain a better interaction between a robot and a human [6] [10] [19] [26]. There are other models of emotions that have been also used in robotics and human-robot interaction [11] [13] [28].

There are also other examples that researchers focus on the applications of emotions in human-robot collaboration. For instance, in [9] researchers use robot's emotional expression as a feedback to the human to improve the quality of collaboraiton. In [15] authors introduce some theoretical concepts that affective collaborative robots can enhance joint human-robot performance by adapting the robot's role and interaction to the human's affective state. This work does not provide any details of implementation and how these theoretical concepts can lead to a better human-robot collaboration. However, little effort has been put on development of functions of emotions and their applications in decision making and emotional-awareness processes of collaborative robots.

3. IMPLEMENTATION

The implementation of this user-study included two separated parts. The first part incorporated the [Title Suppressed For Anonymity] Framework consisting of all Mental Processes (see left-side of Figure 1) briefly described in Section 3.1. The second part was implemented to recieve action commands from the framework and forwarding them to the robot to control joints and actuators (see right-side of Figure 1).

3.1 [Title Suppressed For Anonymity] Framework

This framework is built based on [Title Suppressed For Anonymity] Theory which deals with the interpretation and prediction of observable behaviors in a dyadic collaboration [23]. The theory focuses on the processes regulated by emotional states [24]. The observable behaviors represent the outcome of reactive and deliberative processes related to the interpretation of the self's relationship to the environment. [Title Suppressed For Anonymity] Theory aims to explain both rapid emotional reactions to events as well as slower, more deliberative responses. The reactive and deliberative processes are triggered by two types of events: *external* events, such as the other's *utterances* and *primitive actions*, and *internal* events, comprising changes in the self's mental states, such as belief formation and emotional changes. The theory explains how emotions regulate the underlying processes when these events occur. It also elucidates the role of *motives* as goal-driven emotion-regulated constructs with which a robot can form new intentions to cope with events.

The framework includes the mechanisms depicted as mental processes in Figure 1 along with the mental states. The mental states shown in Figure 1 comprise the knowledge base required for all the mechanisms in the overall model. These *mental states* include self's (robot's) beliefs, intentions, motives, goals and emotion instances as well as the anticipated mental states of the other (human). The details about all these metal states are beyond the scope of this paper.

Each mechanism includes one or more processes in our architecture. For instance, the *Collaboration* mechanism includes processes such as *Focus Shifting* and *Constraint Management*, while the *Appraisal* mechanism includes processes to compute the values for individual appraisal variables [22] [25]. The *Collaboration* mechanism maintains constraints on actions, including task states and the ordering of tasks, and provides processes to update and monitor the shared plan. In this user-study, the *Collaboration* mechanism uses a hierarchy of goals associated with tasks in a the Hierarchical Task Network (HTN) structure depicted in Figure 2. The *Appraisal* mechanism is responsible for evaluating changes in the self's mental states, the anticipated mental states of the other, and the state of the collaboration environment. The *Coping* mechanism provides the self with different coping strategies associated with changes in the self's mental states with respect to the state of the collaboration. The *Motivation* mechanism operates whenever the self a) requires a new motive to overcome an internal impasse in an ongoing task, or b) wants to provide an external motive to the other (i.e. human) when the other faces a problem in a task. The *Theory of Mind* mechanism infers a model of the other's anticipated mental state. The self progressively updates this model during the collaboration.

3.2 Robot Controller

The robot controller is comprised of two major components: ROS-bridge and joint controller (see Figure 1). Ros-bridge[1] pro-

[1]http://wiki.ros.org/rosbridge_suite

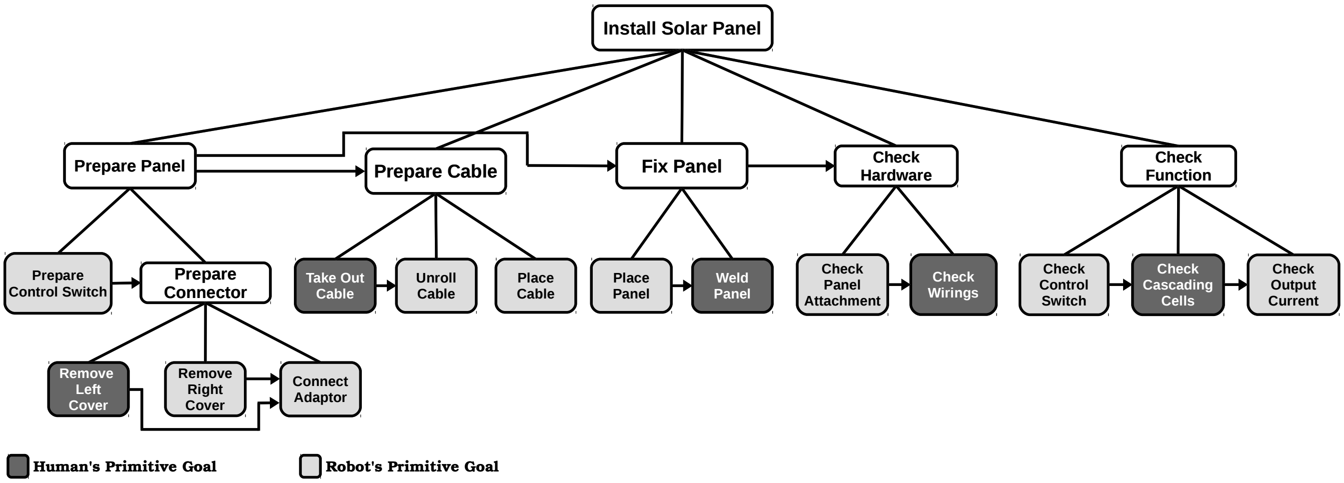

Figure 2: Collaboration structure used as the task model.

vides an API to ROS functionality for non-ROS programs which enables us to send action commands from our framework (implemented in JAVA) to the robot's joint controller. The joint controller receives action commands and translates them into actual joint and actuator commands and sends them to the robot.

4. EXPERIMENTAL SCENARIO

Our scenario was based on a table top turn-taking game that we designed to simulate installing a solar panel. Participants had to collaborate one-on-one with our robot to complete all the given tasks required to install the solar panel. All the tasks were simple picking up and placing collaborators' available pegs on predefined spots on the board (see Figure 3). Each pick-and-place was associated with the robot's or the participant's task. The robot and the participants had their own unique primitive tasks that they had to accomplish in their own turn. The final goal of installing a solar panel required the robot and the participants to accomplish their own individual tasks. Failure of any task could create an impasse during the collaboration.

4.1 The Robot

We conducted our experiment based on a KUKA Youbot (see Figure 4). The robot was stationary on top of a desk and was able to pick up and place avaiable pegs corresponding to the robot's task. The robot was operated based on Robot Operating System (ROS) and was receiving commands through the ROS-bridge from our [Title Suppressed For Anonymity] framework (see Figure 1).

4.2 Interaction Paradigms

The robot interacted via a) speech, b) the corresponding utterance on the screen, c) negative, positive and neutral expression of emotion through an emoticon on the screen. The robot used neutral expression in case of the emotion-ignorance. The interaction was controlled autonomously by the AMC framework in case of the emotion-awareness, and Disco in case of the emotion-ignorance (see Section XYZ). The reasoning about which task should be done and controlling the robot was entirely autonomous. Only the perception of the task failure or achievement by the robot or by the participant was done by a wizard monitoring the collabortion outside of the test area. The interaction was structured based on the exact same goals in an HTN for both conditions. The robot was using the same utterances in both conditions. In emotion-aware condition only if the participant was expressing a negative emotion in case of a failure the robot was using a different utterance in compare to the participant's positive or neutral expression of emotion; i.e., the robot's utterances were identical in emotion-aware and emotion-ignorance cases if in the latter the participant reported (expressed) a positive or a neutral emotion. At the beginning of each collaboration the robot asked each participant to achieve the overall shared goal, i.e., "installing the solar panel". Then, before achieving a new goal, the robot informed the participant about the higher level non-primitive goal of which the primitives were going to be achieved. The same procedure was used by the robot if there was a decision for switching to another nonprimitive due to the failure of the task achieving the current goal. For example, . . . (see Figure 2). After achieving a new primitive goal, the robot either informed the human keeping the ground for the next goal to achieve, or informed and passed the ground to the human to execute the next task with repoect to the human's goal. In case of the human's turn, the robot waited for the human to do a task, then the wizard let the robot know whether the human's goal was achieved or not. Afterwards the robot was making a decision about which goal to pursue and was informing human accordingly. The same entire procedure was applied to both conditions.

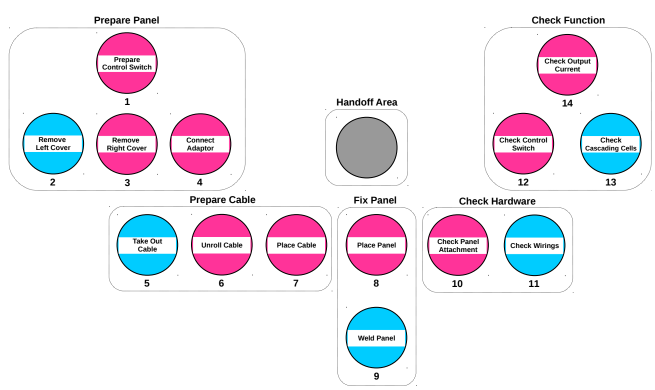

Figure 3: The layout of the available spots for the human and the robot to place their pegs during the collaboration.

4.3 Environment and Tasks

The environment was set up in Human-Robot Interaction lab. and included the robot, the collaboration board on top of a desk,

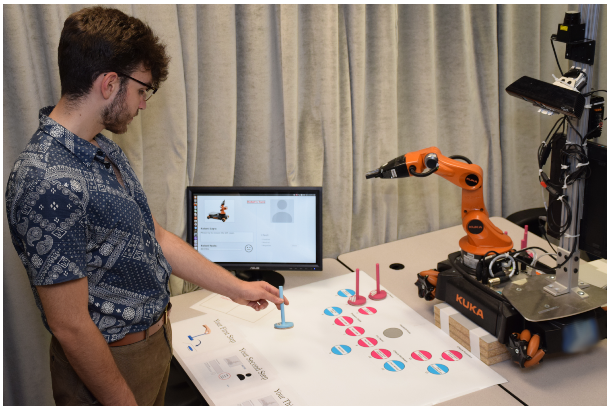

Figure 4: Experimental setup.

and the participant standing in front of the robot on the other side of the board (see Figure 4). One of the experimenters monitored the interactions using a live stream of a camera in a different room. The experimenter provided only the required perception, i.e., decision on success or failure of the tasks for the robot, through the entire time of the collaboration (see Section 4.2).

The tasks were defined based on the HTN structure shown in Figure XYZ and were executed in a turn-taking fashion by either of the collaborators. For each task either the robot or the participant was responsible to pick up one of the corresponding pegs from their own inventory and place it on the right spot which was colored and tagged same as the associated peg.

5. EVALUATION AND RESULTS

5.1 Hypothesis

The non/social functions of emotions impact a collaboration process. Human collaborators prefer to collaborate with others whose behaviors are influenced by these functions of emotions depending on the context. We developed seven hypotheses on positive influence of emotion-awareness and usefulness of emotion function during collaboration:

Hypothesis 1. Subjects will prefer to collaborate with the robot which is controlled by Affective Motivational Collaboration framework more than the robot which is controlled by Disco.

Hypothesis 2. Subjects will find a mutual understanding in the collaboration with the robot which is controlled by the AMC framework more than the robot controlled by Disco.

Hypothesis 3. Subjects will find working with the robot which is controlled by AMC framework less confusing than the robot controlled by Disco.

Hypothesis 4. Subjects will find the robot which is controlled by AMC framework understanding their goals more than the robot controlled by Disco.

Hypothesis 5. Subjects will find the robot which is controlled by AMC framework understanding their feelings more than the robot controlled by Disco.

Hypothesis 6. Subjects will find the robot which is controlled by AMC framework more helpful in compare to the robot controlled by Disco.

Hypothesis 7. Subjects will find the robot which is controlled by AMC framework more trustworthy than the robot controlled by Disco.

5.2 Procedure

Participants were first given a brief description of the purpose of the experiment. After the short introduction, they were asked to review and sign a consent form. Participants were then provided with a written instruction of their task and the rules for collaborating with the robot. Then, one of the experimenters lead them into the experiment room and asked the participants to asked to answer pre-experiment questionnaires. Afterwards, the experimenter went through all the important details of the instructions with the participants standing in front of the collabortion board and the robot. The experimenter confirmed participants' correct understanding of the tasks and informed them with type of task failures that might occur during the collaboration. Participants were told that researchers were developing a collaborative robot and would like their help in evaluating their design. Participants were provided with identical instructions and randomly assigned to the conditions in the experiment. They were told that, after their collaboration with the robot, they would be asked to answer a questionnaire on their experience. After completing the first round of collaboration, participants answered a post-experiment questionnaire that measured their perceptions of the robot, the task, and the collaboration procedure. After answering the first post-experiment questionnaire, participants were told that they were going to collaborate with the robot one more time and the robot might not necessarily have the same collaborative behavior. After completing the second round of collaboration, participants were asked to answer the second post-experiment questionnaire which included the same questions as the first post-experiment questionnaire. After all, participants were asked to answer an open-ended questionnaire which measured their perception of difference between two runs, their preference of collaborative robot between two runs, and thier reasons of preference.

5.3 Measurements

In our study two basic conditions of the robot were tested: a) controlling the robot using Disco, b) controlling the robot using AMC framework. The collaborative results were measured using objective and subjective measurements.

Objective – We measured participants' recall of the collaborative behaviors presented by the robot using an open-ended post-experiment questionnaire. We also specifically asked the participants what behavior of the robot did they like during their collaboration.

Subjective – We evaluated participants' levels of satisfaction, trust, confusion, goal achievement, as well as mutual understanding of goals, mutual understanding of feelings, mutual agreement, and also participants' beliefs about the efficiency of collaboration and their feeling of robot's collaborative behaviors. Seven-point Likert scales were used in all questionnaire items.

5.4 Participants

A total of 37 participants participated in the experiment in 74 trials. Participants were recruited from Worcester Polytechnic Institute's students and staffs as well as other civilians recruited from outside of the campus. The ages of the participants varied between 19 and 74 with an average of 34.2 years before our screening of 4 subjects based on our sanity check questions. After this screening the ages of the participants varied between 19 and 54 with an average of 30.8 years old. Of all the 33 participants, 21 were female and 12 were male. Each participant participated in 2 trials. In one trial the robot was controlled using Disco and in the second trial the robot was controlled using AMC framework. The order of these two trials were randomly assigned to each participant. In general we used Disco first in 16 experiments, and AMC framework first in

Question Category	Question	Question Number
Likability	I would like to continue working with the robot.	Q1
	I felt close to the robot.	Q2
Trust	I trust the robot.	Q3
	I trust the robot to perform appropriately in our collaboration.	Q4
Robot's Performance	The robot was repetitive.	Q5
	The robot's decisions improved my performance during the collaboration.	Q6
Robot's Understanding of Human's Emotions	The robot understood my emotions.	Q7
	The robot understands some of my feelings and takes them into account in our collaboration.	Q8
Robot's Understanding of Goals	The robot perceives accurately what my objectives are.	Q9
	The robot was committed to the collaboration.	Q10
Human Feeling about Collaboration	The robot and I are working towards mutually agreed-upon goals.	Q11
	I am satisfied with the outcome of our collaboration.	Q12
Satisfaction of Collaborative Partner	The robot was satisfied with my collaborative behavior.	Q13
	I was satisfied with the robot.	Q14

Figure 5: A sample black and white graphic that has been resized with the `includegraphics` command.

17 experiments.

5.5 Evaluation Results

Subjective – In our first hypothesis we predicted that the participants would prefer to collaborate with the robot controlled by AMC framework than the robot controlled by Disco. This prediction was supported by our analysis. There was a significant difference across two conditions in participants' preferrance to collaborate with the robot. In general ??? out of 33 participants preferred to collaborate with the robot controlled by AMC framework; ??? out of 33 participants found at least one behvaior generated by AMC framework useful for more complex tasks; ??? out of 33 participants found the robot controlled by AMC framework being able to exhibit behaviors that can prevent human errors; ??? out of 33 participants believe the robot controlled by AMC framework can exhibit behaviors that could improve efficiency of collaboration; and, ??? out of 33 participants mentioned at least one of the collaborative behaviors of the robot controlled by AMC framework as an interesting behavior during collaboration.

Objective –

6. ANALYSIS AND DISCUSSION

6.1 Generalization and Limitations

7. CONCLUSIONS

8. ACKNOWLEDGMENTS

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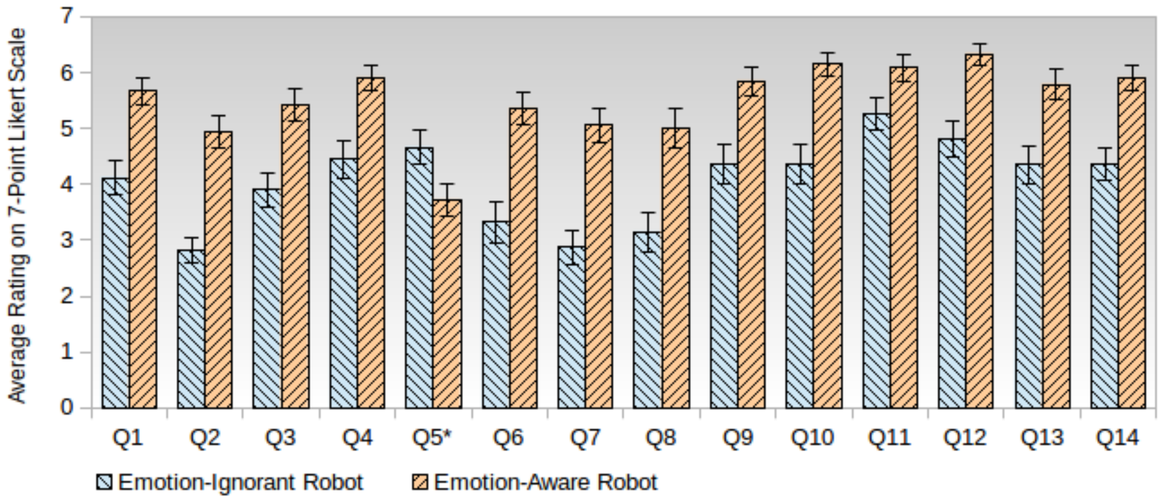

Figure 6: A sample black and white graphic that has been resized with the `includegraphics` command.

Question	Percentage of Participants Favoring Emotion-Aware Robot	*p*-value
Which of the two runs with the robot did you prefer?	100%	0
In which of the two runs did the robot exhibit behavior that could be useful in a more complex task?	93.75%	≪ 0.001
In which of two runs did the robot exhibit behavior that could prevent human error?	60%	> 0.1
In which of the two runs did the robot exhibit behavior that could improve the efficiency of collaboration?	83.9%	≪ 0.001
What was the most interesting behavior of the robot and in which run did it happen?	82.8%	≪ 0.001

Figure 7: A sample black and white graphic that has been resized with the `includegraphics` command.

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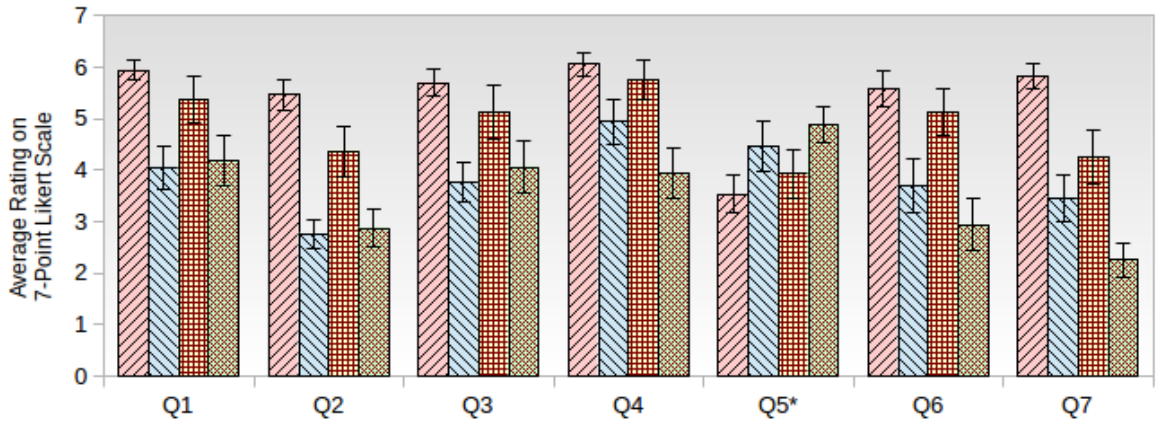

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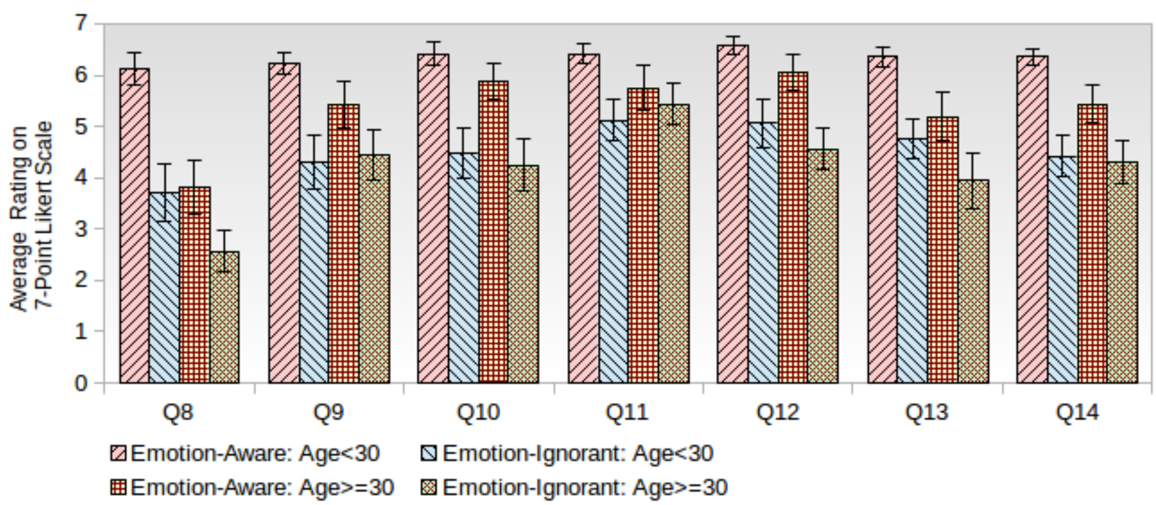

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