CHAPTER 10

Human-Robot Interaction: Exploring the ability to express emotions by a social robot

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Abstract. Robots should have characteristics that make the interaction effective and fluent for a successful Human-Robot Interaction (HRI). Since the emotions play a fundamental role in the human interaction process, many robots are introduced facial expressions, speech, body movements, among others to deepen the HRI. This chapter presents the exploration, design, and evaluation of the recognition of emotions displayed by a social robot. Initially, a pre-experiment was done to program the emotions in a virtual prototype. Afterwards, a pilot study and two experiments were conducted by manipulating the robot facial expressions and body movements to evaluate the recognition of the emotions. The results show that joy, surprise, and sadness have higher correct recognition and fear, disgust, and anger reported as lower recognition. Further study is needed regarding body movement and displacement of the robot for disgust, fear, and anger. Moreover, a robot should be introduced in a specific context to increase the recognition of emotions.

Keywords: Human-Robot Interaction, Emotional design, User Experience, Robot emotions, Basic emotions.

1. Introduction

It is expected to increasingly penetrate social robots to everyday life (e.g., Graaf & Allouch, 2013). Until a few years ago industrial robots were occupying a prominent place, currently, social robots play an increasingly important role in the lives of humans. On one hand, industrial robots were created with the aim of helping, or even replace, the human in routine and dangerous tasks (e.g., blasting bombs). On the other hand, social robots are designed to interact and accompany humans in their daily tasks (Siegel, Breazeal, & Norton, 2009). This type of robot operates autonomously while performing tasks and interacts with humans contributing to the human's well-being (Schraft & Schmierer, 2000; Siegel, Breazeal, & Norton, 2009).

When a human interacts with another human, this interaction is guided by a complex set of characteristics (i.e., verbal and nonverbal) which make it effective. One of the most important characteristics for the interaction between humans is the expression of emotions (e.g., Frith, 2009). Although there is not a single, universal definition of emotions, this can be defined as the tendency that humans have to start, maintain and finish an interaction with the environment and/or with another human (Frijda, 1986). Emotions are considered subjective experiences (because they vary from individual to individual in terms of intensity, arousal, and such) and are commonly accompanied by biological changes (i.e., changes in the nervous system) and behavioral reactions (e.g., start or stop one behavior), which allows the individual to adapt to a particular situation or event (Levenson, 1994). In this sense, emotions play an important role in human life. However, different theories ascribe different functions. Thus, the physiological theories (e.g., James, 1884) argue that when an individual experience an event, the nervous system generates a physical reaction in relation to this event (e.g., crying), which causes an emotional reaction (e.g., sadness). This means, according to these theories, that the emotion is the result of the interpretation that the individual makes about physical reactions caused by an event.

In addition, cognitive theories (e.g., Schachter & Singer, 1962) argue that there are two key factors for the emergence of emotion, arousal, and cognitive label. The arousal is the psycho-physiological condition caused by an event. This condition is derived from the activation of the endocrine and autonomic nervous system. After this, the individual seeks environmental clues to assign a label to that activation.

Finally, the most common theory about emotions is the evolutionary theory (e.g., Darwin, 1872; Ekman, Friesen, & Ellsworth, 1982). For authors who advocate this theory, some emotions are innate and universally recognized, which allows the individual to identify, in their interaction with others, potential dangers to their survival. According to Ekman, Friesen, and Ellsworth (1982), there are six basic emotions (i.e., joy, sadness, fear, disgust, surprise, and anger) that are expressed and recognized universally (through facial expressions), regardless of cultural and social factors. In this sense, it is easy to understand that emotions play a key role in human's life, allowing them to interact effectively with others.

Reeves and Nass (1998) argue that humans tend to apply social rules in their interaction with computers, similar to those that apply in their interaction with other humans, for example, assign gender, name or personality (e.g. Nass, Moon, & Green, 1997). The same can be true for Human-Robot Interaction (HRI). In the case of robots, their interaction with humans is influenced by several factors, such as robot appearance, facial expressions, body movement, among others (e.g., Hwang, Park, & Hwang, 2013; Kulic & Croft, 2007; Nehaniv *et al.*, 2005). In this sense, there are some authors who argue that HRI is effective only when an empathic relationship between human and robot is created, which is possible through the expression of emotions (e.g., Picard, 2000). This is the reason that an increase in the number of robots is seen, particularly social robots, able to express and recognize emotions (e.g., Blow, Dautenhahn, Appleby, Nehaniv, & Lee, 2006; Breazeal, 2003; Zecca *et al.*, 2009; Zecca *et al.*, 2010). Expressing and recognizing emotions are important features of social robots, as these features allow them to respond adequately to the needs of its user (Picard, 2000). Depending upon the sort of the robot, the tasks it performs, the context and its social life, the robot needs to express emotional state as well as the emotions of the people it interacts (Norman, 2004). However, it should be noted that when referring to the robots that present emotions, the expression is not the same as in humans since robots are not humans and they do not have human cognitive abilities (e.g., assigning a meaning to an interaction) (Blow, Dautenhahn, Appleby, Nehaniv, & Lee, 2006) and can also have diverse limitations (i.e., people's faces are rich in muscles).

Norman (2004) denotes that in order to increase people's satisfaction and appreciation emotional expressions of robots are needed to inform people about robots' motivations, desires, accomplishments, frustrations which increase people's satisfaction and appreciation. Therefore, the main objective of this study was to explore and evaluate the recognition of emotions displayed by a social robot. The ability of participants' recognition of emotions by a robot (i.e., a virtual replica of a social robot) was tested. Accordingly, a pre-experiment (in order to program the emotions in the virtual prototype), a pilot study, and two experiments were conducted.

2. Pre-experiment

This part was mainly to define the characteristics that the virtual robot which presented the facial expression, movement, and displacement, to represent eight basic emotions: joy, trust, fear, surprise, sadness, disgust, anger, and anticipation (Plutchik, 1980). Pre-experiment was divided into two phases: Definition; and Design (Giambattista, Teixeira, Ayanoglu, Saraiva, & Duarte, 2016).

2.1 Definition Phase

The objective of this phase was to define a combination of characteristics, i.e., facial expressions, body movements, and displacement) to represent 8 emotions (i.e., joy, trust, fear, surprise, sadness, disgust, anger, and anticipation). The study was conducted with 10 students who tried to simulate a robot's behavior, namely Monarch (Ferreira & Sequeira, 2017) to express emotions, by using two cardboard arms (Figure 1). The students were informed about the limitations of the robot's movements: they could move their arms only up and down, walk forward backward and move sideways, rotate their head and body to the left and right, but they could not bend their body.

Figure 1. A student is imitating the robot with cardboard arms

The participants were voluntaries and that they consented the video recording of their participation in the experiment. The procedure took place in a photography studio/lab and the performance of the participants was video recorded. In the lab, the participants could perform each emotion in a limited area which was marked on the floor as 2 by 2 meters. Before performing each emotion, they were asked to perform training in which they were shown an emotion besides the 8 emotions. If they accomplished this session as requested, then they were asked to start performing the 8 emotions in which each was written on a sheet of paper. The order of the emotions was randomized and after each performed emotion, the participants were asked to clarify some facial expressions and movements that are not clear to the researchers.

The videos were analyzed by two researchers to identify the characteristics of each emotion, based on the criteria defined and given to the participants, with a focus on the characteristics (e.g., eyes, mouth, arms and body movements) that the virtual robot would be able to reproduce. A table was filled in which each emotion was identified by various features (Figure 2).

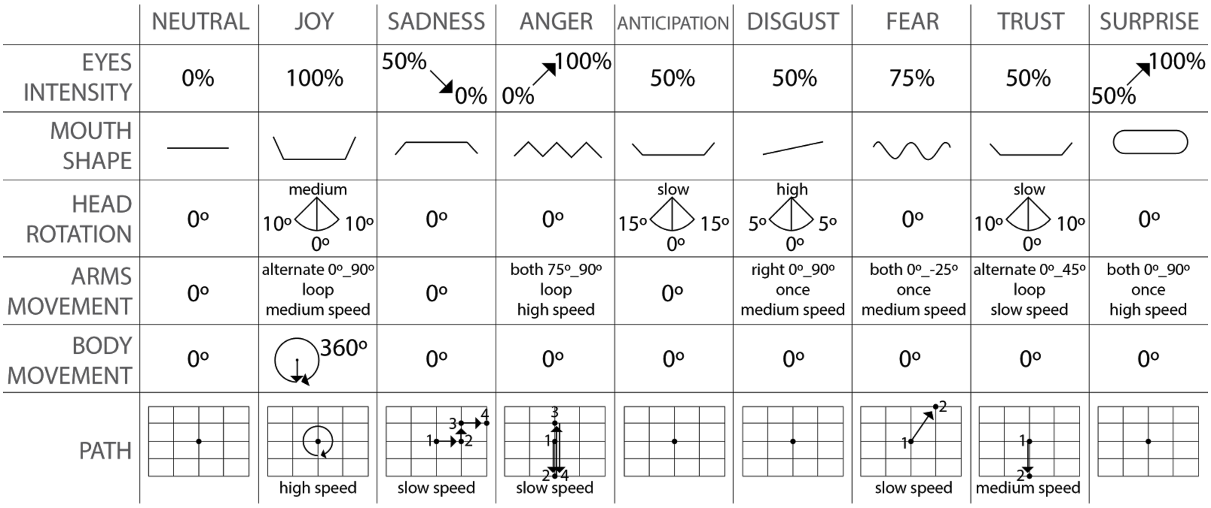


Figure 2. Each emotion's variables which were implemented to the virtual robot

2.2 Design Phase

In the Design phase, a Virtual Environment (VE) was created. The VE was a 5m long hospital corridor, and the virtual robot was placed at the end of the corridor. The context was chosen due to the Monarch's case study's aim (Messias, *et al.*, 2014) which is improving the quality of life of inpatient children. Both VE and virtual robot were created using Rhinoceros, then exported to Unity 3D to program and represent the emotions that robot would express. The VE was simple and neutral since the aim of the study was that the participant focuses on the robot performance and not on the environment (see Figure 3). Participants were seated during the procedure. The virtual robot was presented to participants in 3D, and for this, a 3D projection-based virtual reality system with a 1280x720 pixel resolution at 120 Hz was used.

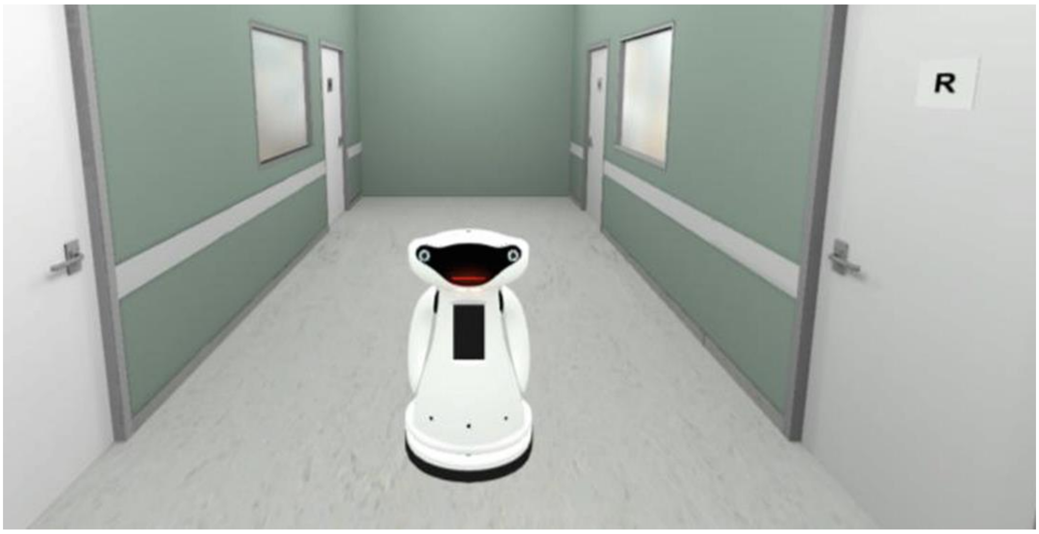


Figure 3. Robot's neutral emotion in the VE

Eight target emotions; i.e., joy, trust, fear, surprise, sadness, disgust, anger, and anticipation were selected, gathered from Plutchik's theory (1980). An animation was created for each emotion that was based on the results of the Definition phase. The static images of the emotions are shown in Figure 4. In the animation, before each emotion, the robot showed the neutral emotion first and then the target emotion.

Figure 4. Static images of the eight target emotions with facial expressions and body movements for the pilot study

3. Pilot Study

This study's main objective was to understand whether the 8 emotions programmed into the virtual robot model was correctly recognized by the participants. To this end, all materials developed in the Design phase were tested.

3.1 Participants

Thirteen participants volunteered in this experiment. Seven were female (53.8%) and six males (46.2%) aged between 19 and 37 (M = 24.6; SD = 5.02) years old.

3.2 Stimuli and Materials

8 emotions (i.e., surprise, sadness, trust, fear, anticipation, disgust, anger, and joy) were used proposed by Plutchik.

Initially, the participants answered to some demographic's questions (e.g., age, education) and were asked about the previous experience/contact with social robots. If participants had already had contact with a robot of this type, they should indicate the context and the frequency of interaction. Then it was presented a questionnaire to the participants. The questionnaire was divided into four sub-questionnaires: a) Technological Attitude Scale - before the interaction with the robot; b) Perception Scale about Robots - before the interaction with the robot; c) Emotion Recognition Task - during the interaction with the robot; and d) Perception Scale of the Virtual Model - after the interaction with the robot. The stages are described below:

a. Technological Attitude Scale (based on Lakatos *et al.*, 2014) – this scale aims to understand the relationship that the participants have with technology, in general. It consists of 7 affirmations (e.g., *my technological knowledge is excellent*), and the participant must, in a 5-point Likert scale (1 - *I Strongly Disagree*, 2 - *I Disagree*, 3 - *Undecided*; 4 - *I Agree*; 5 - *I Strongly Agree*) choose the answer that best applies.

b. Perception Scale about Robots (based on Nomura, Suzuki, Kanda, & Kato (2006) – it is a scale that aims to evaluate the participants' perception about robots (e.g., *I worry that the robots can be a bad influence on children*). It consists of 10 affirmations and it was used the same 5-point Likert scale used previously.

c. Emotion Recognition task – it is composed of a list of 16 emotions (8 main emotions and 8 distracting emotions): joy, trust, fear, surprise, sadness, disgust, anger, anticipation, anxiety, irritation, shame, contempt, guilt, pleasure, despair, proud, and the option "*none of the above emotions is correct*". This task aims to understand if participants would correctly identify the emotions expressed by the virtual robot. To this end, after the robot expressed each emotion, the participants selected in this list, the emotion that thought to have been expressed by the robot.

d. Perception Scale of the Virtual Model – this scale aims to analyze the perception that participants have about the virtual robot. To this end, participants must, a 5-point Likert scale, report their opinion for three affirmations: 1- *I would feel comfortable if I had to interact with this robot*; 2 - *I would not like to have this robot in my house*; 3 - *I would feel sorry if I had to destroy this robot*. In the end, the participants were asked about the robot's gender (i.e., female, male, without defined gender) and one question about the functions that the robot could perform (e.g., tourist guide).

3.3 Procedure

The procedure took place in a dark room (user experience laboratory), with ideal conditions (e.g., controllable light, temperature conditions) for the use of virtual reality and had a maximum duration of 15 minutes. When participants arrived, they were informed about the general objectives of the study and they signed informed consent. Also, they were warned for the possibility of slight negative effects due to the use of 3D glasses (e.g., possibility of nausea due to simulator sickness). Then, participants answered the demographic's questions, the Technological Attitude Scale, and the Perception Scale about Robots.

Thereafter, participants were told that the virtual robot would start its performance, i.e., to express emotions. Participants sat at a distance of 1 meter from the wall screen and put the 3D shutter glasses. After that, the robot appears in the virtual environment, with a neutral expression. In the neutral expression, the mouth of the robot was represented by a simple line, arms rested, and the eyes were lit but without any level of glow. Then, the robot moves in a straight line towards the participant. This phase was designed to accustom the participant to the virtual environment, the robot, and the 3D shutter glasses.

The researcher tells the participant that the robot would start its performance, expressing one emotion at a time. Each emotion was displayed for 10 seconds, after which, the participant had to recognize the emotion expressed by the robot in the list of 16 emotions presented. After expressing an emotion, the robot returned to the starting position (i.e., in front of the participant, where it started the performance). The robot remained still as it was turned off (i.e., mouth and eyes off, and arms down) until the following emotion expression that began with a key press by the researcher.

Emotions were presented to the participants in one of two sequences: Sequence 1 - surprise, sadness, trust, fear, anticipation, disgust, anger, joy; Sequence 2 - sadness, fear, trust, joy, surprise, anger, anticipation, disgust. All the emotions were placed in a website to generate several ordered lists and two were chosen.

After the performance of the robot, that is, at the end of the six emotions expression, participants answered the Perception Scale of the Virtual Model questionnaire and a question about the gender of the robot and its function. In the end, the researcher asked the participants some possible changes in the robot in order to improve the expression and recognition of emotions. After that, the participants were thanked, debriefed and dismissed.

3.4 Results

The main objective of the pilot study was to understand if participants were able to recognize 8 emotions correctly which were expressed by the robot. Therefore, only the results for Emotion Recognition Task are presented. In this sense, results revealed that participants had some difficulty in recognizing correctly the emotions expressed by the robot (33% correct answers). Figure 5 represents the percentage of correct answers for each presented emotion. The results revealed that joy (69%) and surprise (54%) were the ones with a higher percentage of correct answers, followed by sadness (46%) and anticipation (46%). The other emotions presented a percentage of accuracy below 25%: fear (23%), trust (15%), disgust (8%) and anger (0%).

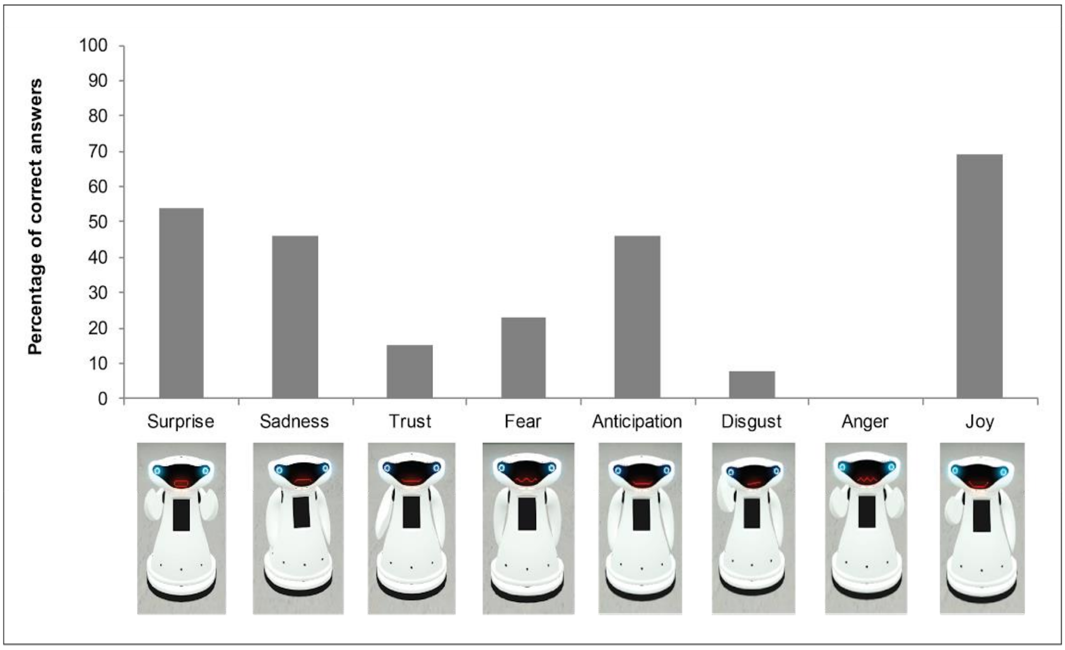


Figure 5. Percentage of correct responses for each emotion for Pilot Study

These results showed that some of the emotions are confused with others (e.g., trust was confused with joy in 46% of cases), which shows the need to implement some changes in the expressions of emotions by the virtual robot, making them easier to recognize. For more information about the results of this pilot study please see Giambattista and colleagues (2016).

4. Experiment 1

In the pilot study, the correct recognition of the emotions expressed by the virtual robot was quite low. This result revealed the need to make significant changes in the programming of emotions in order to increase its correct recognition. In this sense, also the theoretical approach to emotions was altered. Thus, in the following experiments, the 6 basic emotions (i.e., joy, sadness, fear, disgust, surprise, and anger**)** based on evolutionary perspective, proposed by Ekman, Friesen and Ellsworth (1982) were used. There are several studies (e.g., Bartneck, 2002; Kanoh, Iwata, Kato, & Itoh, 2005; Hashimoto, Hitramatsu, Tsuji, Kobayashi, 2006; Saldien, Goris, Vanderborght, Vanderfaeillie, & Lefeber, 2010) identifying the characteristics of the emotions for robots in terms of facial expression which can be combined with the features that was classified in Definition Phase.

4.1 Participants

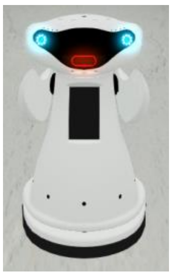
The sample consists of 20 volunteered students, 17 (85%) were females and 3 (15%) were male. The ages vary between 18 and 22 years (*M* = 19.75, *SD* = 1.04). The participation was voluntary. The participants did not receive course credits or any monetary compensation for participating in this study.

4.2 Stimuli and Materials

As mentioned before, this experiment used the 6 basic emotions proposed by Ekman (1999) instead of the 8 emotions proposed by Plutchik (1980), this means that the emotions trust and anticipation are not part of this experiment. In this experiment the same VE, virtual robot and questionnaires were used. However, since two emotions (i.e., trust and anticipation) were eliminated, the Emotion Recognition task has been slightly modified. In this sense, Emotion Recognition task is composed of a list of 12 emotions: 6 basic emotions and 6 distracting emotions: despair, anxiety, shame, anticipation, contempt, and trust; and the option "*none of the above emotions is correct*".

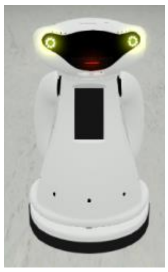
Considering the results of the pilot study, some changes were made in the programming of the emotions that had a low hit rate. The emotions joy and surprise were not changed, while the remaining four emotions suffered small adjustments in motion (i.e., anger and fear), shape of the mouth (i.e., anger, disgust, and fear), and eyes color (i.e., anger - red; fear - yellow; disgust - green; sadness - purple).

These changes were suggested and defined by a multidisciplinary team of researchers (e.g., designers, psychologists, engineers) taking into account the analysis and study of the expression of emotions in humans and robots, as well the opinions and suggestions of some participants who were subject to some tests of emotion recognition with the virtual robot. Figure 6 shows the expression of the six basic emotions by the virtual robot in a static manner.



Surprise

Sadness



Fear

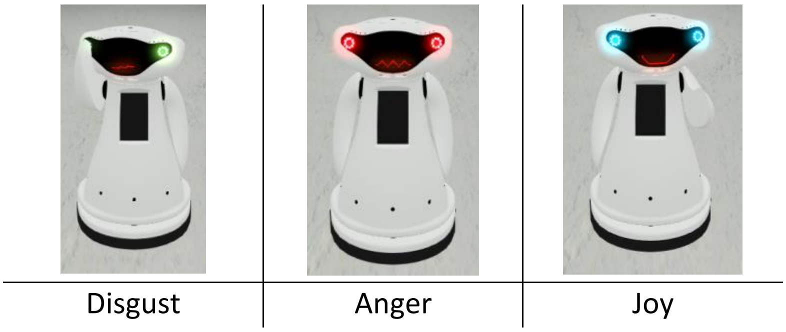


Figure 6. Static images of the six target emotions with facial expressions and body movements for Experiment 1

4.3 Procedure

The same procedure as in the Pilot Study was followed.

4.4 Results and Discussion

A qualitative analysis of the results is shown that was obtained for the different scales used and for the recognition of emotions expressed by the robot. The mode was calculated for each answer for all scales since they are ordinal scales. 18 out of the 20 participants mentioned they had never been in contact with a social robot before participating in this experiment.

a. Technological Attitude Scale

On this scale, most participants declared they liked to explore new technological devices (Q1) while assuming that their technological knowledge is not excellent (Q2). On the other hand, participants revealed that they could imagine having a social robot in your home (Q3) and agreed that they liked to have a social robot to help them (Q4). Also, in this sense, participants said they would like to try new robots (Q6) and they completely agreed that social robots were useful (Q7). In relation to question 5 (Q5 - *I am afraid that robots are used for bad purposes in the future),* the responses mode of participants was 3, or undecided.

b. Perception Scale about Robots

In this questionnaire, the participants revealed that they felt comfortable if robots would express emotions (Q1) and if they had to talk with them (Q3). Furthermore, the participants agreed that if the robots had artificial intelligence, something may go wrong (Q2). Regarding the questions related to the interaction that participants would be able to establish with robots, participants declared that they would not be able to establish a friendship with a robot that expresses emotions (Q5), they would feel nervous if they had to obey an order given by a robot (Q6), or if they depended on a robot to perform tasks (Q8). For the question "I would feel uncomfortable if I was given a job where I have to interact with robots" (Q4), participants were undecided about their response. This questionnaire also revealed that participants are undecided about the influence of robots could have on children (Q9) and about the domain of the robots in the future (Q10). Finally, participants agreed that they would not like if the robots were able to make judgments about different subjects (Q7).

c. Emotion Recognition task

Regarding the ability of the participants' correct recognition of the emotions expressed by the virtual robot, the results revealed that the success rate was 46%. This result was significantly higher than the results obtained in the pilot study (33%). However, these results were not comparable since two emotions (i.e., trust and anticipation) from the pilot study were removed, and the virtual robot has been reprogrammed. Figure 7 represents the percentage of correct answers for each of the six presented emotions.

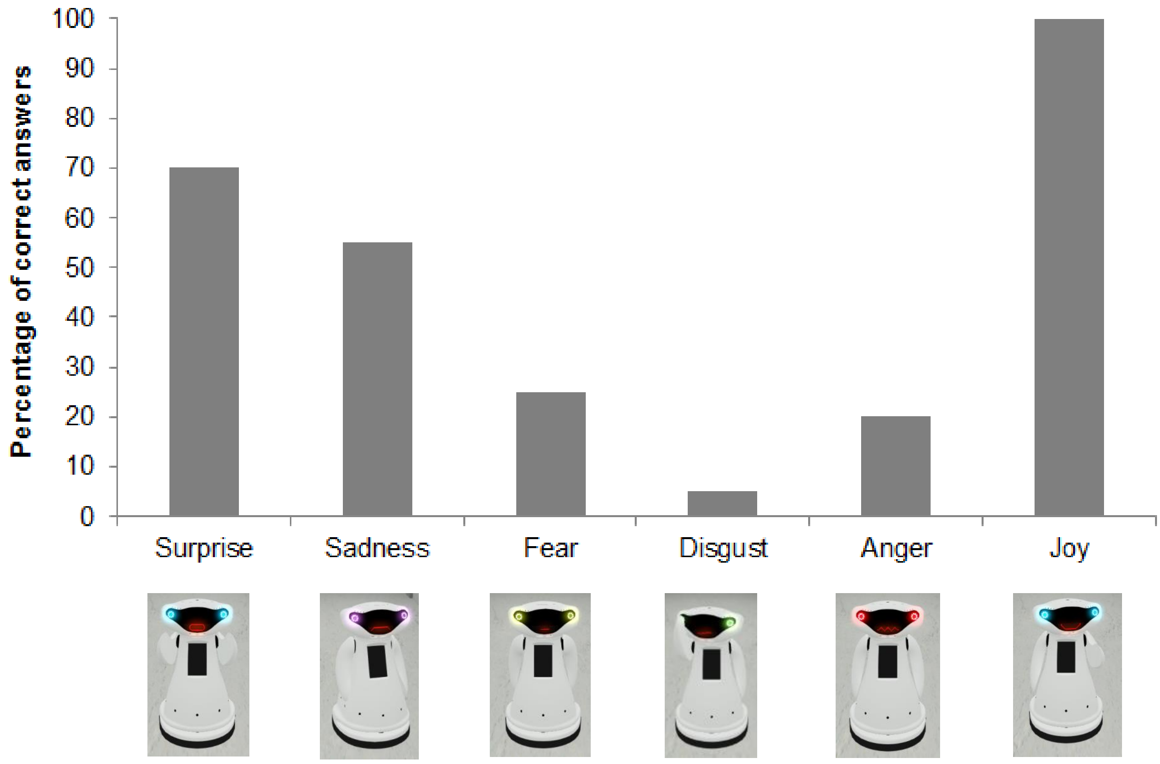


Figure 7. Percentage of correct responses for each emotion for Experiment 1

The emotion joy had a 100% success rate, i.e., all 20 participants recognized correctly this emotion. The other two emotions that also had a higher success rate were surprise (70%) and sadness (55%). Fear was correctly recognized in 25% of the cases and anger in 20% (which represents an improvement in relation to the pilot study result). Additionally, the emotion disgust had a low success rate (5%).

As mentioned before, participants could choose an emotion from 16 possible (6 target emotions and 6 distracting emotions) and also had the option "none". Regarding the association between the displayed emotions and the emotions listed, we found that participants identified some emotions from these distracting ones. In this sense, the emotion surprise was wrongly recognized in 20% of the cases as despair, anxiety, anticipation or trust, and 2 participants selected the option “none”. Despite this false recognition, surprise was the second most easily recognized emotion.

Besides, sadness was confused in 30% of cases with fear, which can be explained by the fact that the robot performed a backward movement which might have represented fear. This emotion was still confused in 5% of the cases with shame and 10% with disgust.

Fear was confused in 35% of cases with shame, which may be explained with the backward movement made by the robot and with a fast and rhythmic head shaking (i.e. disagree). In 30% of cases, the participants selected the option "none" or despair, and anxiety or surprise in 10% of cases. This distribution of participants' responses by different options reveals the difficulty experienced in recognizing emotion.

Disgust was confused with shame in 70% and fear in 15% of cases. This result may be due to the fact that the robot raised an arm to hide the face. This arm movement was intended to simulate repulsed by something but could be confused with shame or fear, because it might look like the robot was hiding from something or someone. In 10% of cases, the participants chose the option "none" or contempt.

Anger was confused in 50% of cases with despair and in 25% of cases with fear. This result may be due to the fact that the robot moved quickly from one side to the other which may mean despair like the robot did not know what to do. On the other hand, this rapid movement could be interpreted as being to flee from something (i.e., fear). In the remaining 5% of cases, the participants chose the option anxiety.

d. Perception Scale of the Virtual Model

In this questionnaire, the participants revealed that they would have felt comfortable to interact with the displayed robot (Q1) and they would have liked to have the robot at home (Q2). Participants also revealed that they felt sorry if they had to destroy the robot (Q3) which suggested that an empathic relationship with the robot was established. About the gender of the robot, 75% of participants said that the robot did not have a defined gender, and 20% reported that it was male. Finally, most of the participants suggested that the function of the robot was to help humans in housework.

It was possible to understand, compared to the pilot study, that some emotions, particularly anger, had a higher success rate of recognition. However, success rates remained low, especially for fear, anger, and disgust. This result reinforced the need to continue to make changes to the virtual robot in order to improve the correct recognition.

5. Experiment 2

Some of the emotions expressed by the virtual robot in experiment 1 were not correctly recognized. The low success rate for the emotions anger, disgust and fear can be an example of this. In this sense, in experiment 2, our objective was to make some changes in the programming of these emotions in the virtual robot and to test if these changed increased the success rates.

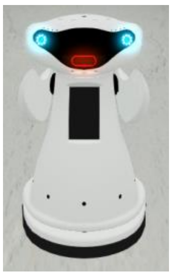
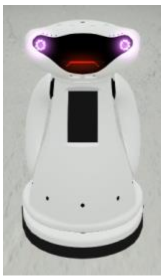
5.1 Participants

The sample consisted of 20 students, 11 (55%) were females and 9 (45%) were male. The ages of participants varied between 18 and 27 years (*M* = 20.95, *SD* = 2.16). As in the previous experiment, the participants were volunteers and did not receive course credits or any monetary compensation for participating in this study.

5.2 Stimuli and Materials

The same VE, virtual robot, questionnaire and emotions from Experiment 1 were used.

In terms of emotions, some changes were done in the virtual robot. In this sense, the emotion fear has changed the shape of the mouth and the robot moves backward and slightly to the left side. Regarding the emotion disgust, the arm movement was removed (in the previous version the right arm of the robot was raised parallel to its head) and the shape of the mouth was changed. In the emotion sadness the movement of the robot was removed, that is, the robot had only facial expressions (the same as in Experiment 1). Finally, in the emotion anger, the shape of the mouth was changed to simulate the existence of teeth. The robot raised both arms simultaneously at the level of the head and the robot moved from one side to the other. Figure 8 shows the expression of the six basic emotions by the virtual robot in a static manner.

		
Surprise	Sadness	Fear

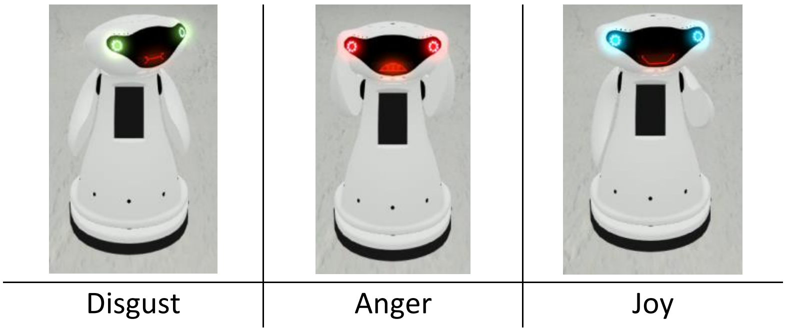


Figure 8. Static images of the six target emotions with facial expressions and body movements for Experiment 2

5.3 Procedure

Similar to Experiment 1.

5.4 Results and Discussion

Same data analysis was applied as previously in Experiment 1. Fifteen out of the 20 participants mentioned they had never been in contact with a social robot before participating in this experiment.

a. Technological Attitude Scale

On this scale, most participants declared that they liked to explore new technological devices (Q1), while they revealed to be undecided about their technological knowledge (Q2). As in Experiment 1, participants revealed that they could have imagined having a social robot at home (Q3) however they were undecided in relation to the question "I would like to have a social robot to help me" (Q4). Most participants agreed that they were afraid that robots could be used for bad purposes (Q5), but they would have liked to test new robots (Q6), and they agreed that social robots were useful (Q7).

b. Perception Scale about Robots

In this questionnaire, participants revealed that would have felt comfortable if robots expressed emotions (Q1) or if they had to interact with a robot during work (Q4). However, participants proved to be undecided in the response to questions "Something wrong could happen if the robots have artificial intelligence" (Q2), "I would feel comfortable speaking with a robot " (Q3), and "I would feel nervous if I had to obey an order given by a robot in front of other people" (Q6). The results of this questionnaire revealed that participants would be able to establish a friendly relationship with the robots if they had emotions (Q5), they liked the robots that were able to make judgments (Q7), and they did not feel nervous if they were dependent on a robot to perform tasks (Q8). Finally, participants said they worried about the robots could influence children badly (Q9), and they were convinced that society would be dominated by robots in the future (Q10).

c. Emotion Recognition task

The success rate for the recognition of emotions expressed by the virtual robot was 51% on average. Figure 9 shows the percentage of correct answers for each of the six presented emotions.

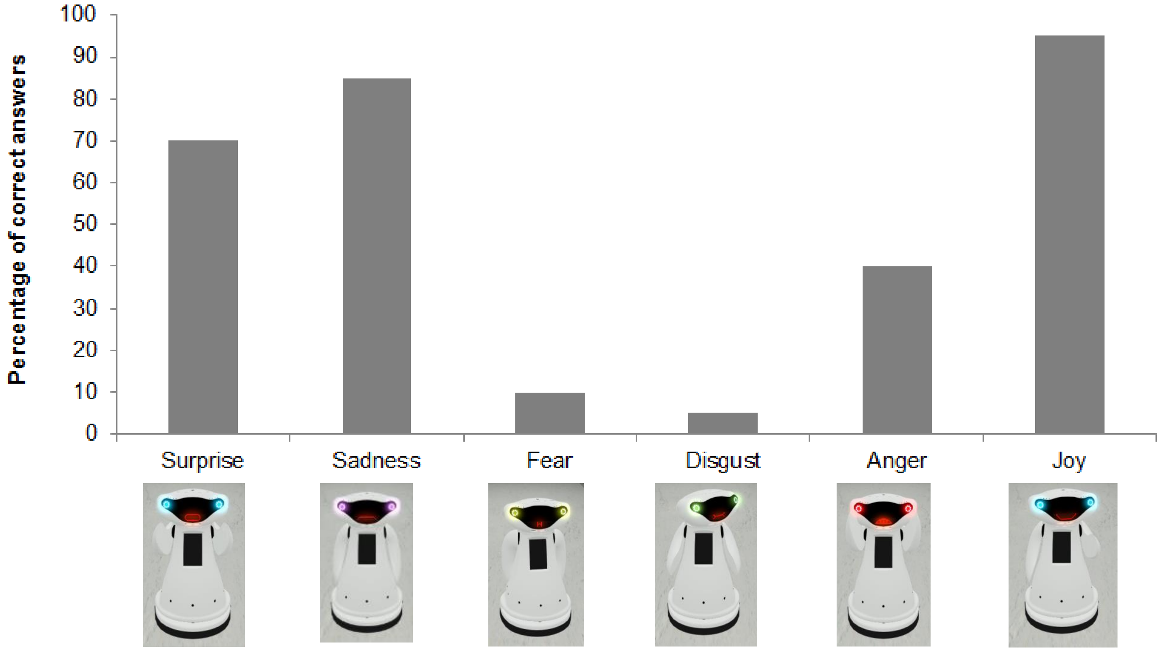


Figure 9. Percentage of correct responses for each emotion for Experiment 2

As for the emotions joy and surprise, no changes were made since a similar success rate was expected as Experiment 1. This hypothesis was confirmed with the joy getting a success rate of 95% and surprise getting 70% of success. Regarding sadness, it was possible to observe an increase in the success rate (85%) when compared with the result of Experiment 1 (46%).

Anger also increased in success rate (40%) when compared with Experiment 1 (20%). However, participants confused anger with despair in 40% of cases, which can be due to the robot's movement from one side of the wall to the other. This may indicate some level of despair. In the remaining 20% of cases, participants confused anger with fear (10%), anxiety (5%) or contempt (5%).

On the other hand, the results for the recognition of fear decreased in success rate in Experiment 2 (10%) compared with Experiment 1 (25%). In 80% of cases, participants confused fear with shame. This result may be due to the movement that the robot makes to one side of the wall. Participants interpreted the robot's movement as hiding from something or someone as if the robot did something wrong. This result revealed the clear need to implement new changes in the virtual robot to make the recognition of this emotion easier. Some participants suggested that the eye color should be changed from yellow to white, and the motion should be changed. In this sense, it has been suggested by participants that the robot should move backward instead of moving to the side. However, this was the movement that the robot was in Experiment 1, and as verified then, the success rate was also low (25%). this shows that the difficulty in recognizing fear was not only related to the movement, but more changes and tests are required.

Finally, despite the changes made in the expression of disgust, the success rate remained very low (5%) as in Experiment 1. Participants confused disgust with all other emotions, except joy, anger and trust: sadness (5%), despair (5%), surprise (5%), anticipation (5%), fear (5%), anxiety (10%), shame (15%), and contempt (25%). In the remaining 20% of the cases, the participants chose the option “none”. The fact that the participants indiscriminately chose other emotions, without any pattern, was indicative of the difficulty in recognizing the emotion disgust.

d. Perception Scale of the Virtual Model

In this questionnaire, the results of Experiment 1 were replicated, i.e., the participants showed that they would have felt comfortable to interact with the displayed robot (Q1) and they would have liked to have the robot at home (Q2). Participants also revealed that they would have felt sorry if they had to destroy the robot (Q3). Regarding the gender of the robot 80% of participants said that the robot does not have gender, and 20% reported that it is male. Once again, the participants suggested that the function of the robot was to help humans in housework.

6. Conclusion

The expression of emotions allows humans to communicate their internal states to others that through empathic responses understand and react adequately to their needs. Canãmero (2005) discussed that modeling emotions in robots can offer several valuable contributions to emotion research regarding human perception of emotions although the field is still in its infancy. Thereby, the main objective of this study was to design the emotions expressed by a social robot and test the correct recognition of participants when they interact with the virtual robot. For this purpose, a pre-experiment was done in order to design and program the emotions for the virtual robot. Then, a pilot study was performed to understand whether the 8 emotions programmed into the virtual robot model were correctly recognized by the participants. The results showed that some emotions were easily recognized (e.g., joy) while others had a very low recognition rate (e.g., disgust, anger). In this sense, taking into account the feedback from participants in the pilot study and the experience of the research team, some changes were done in the robot’s expressions. One of the changes was theoretical in which the next two experiments would use Ekman’s theory of emotions because the facial expressions for the six basic emotions in humans are well documented in the literature and this could be an important help to design the emotion representation of the robot.

These two experiments were conducted to make changes in the expressions of low recognized emotions in the virtual robot, and to test if these changes increased the success rates of recognition. The results showed that the emotions that have higher correct recognitions were joy, surprise, and sadness. Moreover, fear, disgust, and anger were emotions with lower success rates. For these three emotions, several changes were done, though, participants always revealed that they were hard to recognize correctly. However, it is important to note that the success rate for anger increased significantly between Experiment 1 (20%) and Experiment 2 (40%). This means that changes made to the virtual robot worked as expected. It should also be noted that participants confused anger with despair, which may be due to the robot's movement which had signs from other emotions as well.

Furthermore, relative to disgust, some studies with humans have shown some problems in its correct recognition (e.g., Bullock & Russel, 1984; Widen & Russel, 2008; Panksepp, 2007). Between humans, the recognition of that emotion is difficult, therefore, between human and robot, it should be expected to be even harder since a robot has more limitations in terms of facial expressions and body movements than a human while expressing an emotion. Especially in this case of study, the virtual robot has several limitations: it was only possible to change the intensity of light and the color of the eyes; light on/off LEDs panel to draw the mouth; move arms up/down; move forward/backward, left/right. Also, usually, in humans, the expression of disgust involves the act of spitting (e.g., Widen & Russell, 2008), and this expression is impossible to program in the robot, because of the limitations, mentioned above.

Regarding fear, the success rate in Experiment 1 was higher than in Experiment 2. The difference between the two experiments was the robot’s body movement. While in Experiment 1 the robot walked back simulating moving away for something, in Experiment 2 it moved to the left side in the direction of the wall. However, in Experiment 1 the success rate was higher than in Experiment 2, but it was still low (25%). Therefore, the movement of the virtual robot was also more problematic than the facial expression in this emotion as well.

Also, it is worth to mention that in many projects with robots, the recognition of fear in facial expressions tends to be the most difficult (Fairchild, Van Goozen, Calder, Stollery, & Goodyer, 2009; Saldien, Goris, Vanderborght, Vanderfaeillie, & Lefeber, 2010). Since the robot had the most limitations related to face, it was expected to have a lower rate in correct recognition.

During the study, the robot was presented in a neutral context and it expressed all the emotions in sequence. However, in a real context, emotions arise in response to a stimulus, person or event in a given context, in a specific moment (e.g., Ekman, 1999; Frijda, 1987; Lazarus, 1999). All these circumstances are clues to the correct recognition of emotions. Due to the limitations, the robot could not express all the emotions successfully by using its facial expressions and body movements. However, a given context, and/or a scenario could help the success rate go higher for lower rated emotions. In this sense, it is important that in future studies, the virtual robot is presented in a context, accompanied by a narrative that allows participants to contextualize each emotion. Besides, further study is needed for body movements and displacement for the robot in particular emotions (i.e., disgust, fear, and anger).

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