Expressive Humanoid Face: a Preliminary Validation Study

Nicole Lazzeri, Daniele Mazzei, Alberto Greco,
Antonio Lanatà and Danilo De Rossi

Research Center "E. Piaggio"
University of Pisa
Pisa, Italy
Email: daniele.mazzei@centropiaggio.unipi.it

Annalisa Rotesi

Faculty of Psychology
University of Florence
Florence, Italy

***Abstract*—Non-verbal signals expressed through body language play a crucial role in our daily communications. Facial expressions, in particular, are the most universal signs to express innate emotional cues. Human faces convey important information in social interactions, which help us to better understand our interlocutor. Nowadays, humanoids and social robots are becoming increasingly similar to humans both aesthetically and expressively. However, their visual expressiveness is a crucial issue in making these robots more realistic and intuitively perceived as human-like. This paper presents a preliminary study aimed at evaluating the capability of a humanoid to perform facial expressions in terms of recognition rate and response time in comparison with humans' ability. Results showed that the recognition rate of human and robot expressions did not reveal differences while the physical robot can convey expressions better than its 2D photos and its 3D models. Moreover, the results showed that both human and robot positive expressions were better recognized than the negative ones.**

Keywords–Facial expressions; emotion perception; humanoid robot; expression recognition; social robots.

I. Introduction

Human beings communicate in a rich and sophisticated way through different channels, i.e., sound, vision, touch and smell. In particular, in human social relationships visual information plays a crucial role. Human faces convey important information both from static features such as identity, age and gender, and from dynamic changes such as expressions, eye blinking and muscular micro-movements. The ability to recognize and understand facial expressions of an interlocutor allows us to establish and manage empathic links, which drive our social relationships.

Charles Darwin was the first to observe that basic expressions such as anger, disgust, contempt, fear, surprise, sadness, happiness, are universal and innate [1]. Indeed, human beings are able to recognize faces and read facial expressions almost unconsciously and with little or no effort [2].

In the last years due to rapid advances in robotics and computer graphics, more and more interactive robots and agents have become common in our daily lives. The rapid growth of robotics has made possible the development of a new class of emphatic machines known as social robots. These innovative agents are used in various fields ranging from entertainment to human assistance and health care [3]. Hashimoto and his collegues [4] proposed an android robot called SAYA as a teacher in elementary and university classes. SAYA was remotely controlled by an opertor makeing the robot able to perform facial expressions, head and eye movements, and utterances. The experimental studies showed that SAYA was more accepted by elementary school children than by university students enhancing their interests for the class.

The ability to express emotions is clearly becoming fundamental for a social robot's believability [5] driving the research on the design of user-friendly social robots able to reproduce human-like facial expressions [6]. Costa and her team [7] presented a perceptual study with ZECA, a robotic child able to perform facial expressions and gestures. ZECA was used in human-robot interaction studies with children with autism demonstrating their capability to recognize the robot expressions.

Humanoids and social robots are usually high-cost products typically used in academia and research fields only. On the other hand virtual avatars are widely used as social characters for games, storytelling and tutoring [8]. However, humanoids and avatars differ in a fundamental aspect: the *embodiment*.

This work is based on the hypothesis that highly anthropomorphic robots with physical embodiment are able to convey expressions and socially interact easier and more intuitively than avatars and 3D models [9][10]. Indeed, the embodiment could help robots to express their emotions by means of a physical and real aspect, which is absent in a screen.

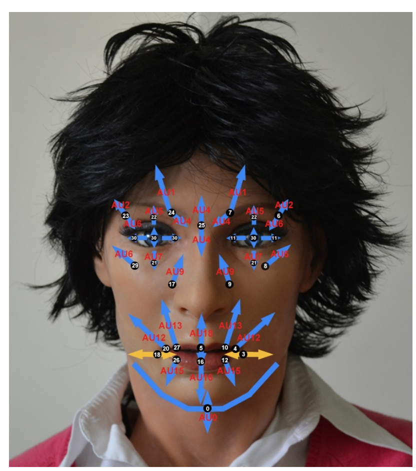

Figure 1. The FACE robot with references of the servo motor positions and of the corresponding FACS AUs.

Current research literature aims at evaluating facial expressions on robots and virtual avatars with different approaches

 ISBN: 978-1-61208-382-7

[11][12][13]. Our work aimed at studying the capability of a realistic humanoid robot to show facial expressions in comparison with 2D pictures and 3D models of itself and of a female human. Our robot was built with a female appearance in order to take advantage of the higher expressivity of female expressions as demonstrated by Adolph et. al. [14]. In our experiments, participants were asked to evaluate three set of facial expressions through questionnaires, as previously done by Becker-Asano and Ishiguro [15] and in other similar works [16][17] and their answers were evaluated in terms of recognition rate and response time.

This paper is structured as follows: Section II describes the material used to create the stimuli for the experiment; Section III presents the method and the protocol of the experiment and its setup; Section IV explains the statistical analysis and the related results about the facial expression recognition; in the end, Section V summarizes the results of the experiment drawing a general conclusion.

II. MATERIALS

The material used for the experiment included various stimuli: the FACE (Facial Automaton for Conveying Emotions) robot; the FACE robot avatar and a set of 2D and 3D pictures of a women performing facial expressions.

A. The robot FACE

FACE is an android female face used to study human-robot interactions with a focus on non-verbal communication, developed in collaboration with Hanson Robotics [18][19][20]. FACE consists of a passive body with a realistic facial system made of an artificial skull covered by a porous elastomer called Frubber™. FACE is animated by 32 servo motors positioned inside the skull and in the upper torso (Figure 1).

In this study the attention was focused on recognizing the six basic emotions considered as 'universally accepted' by Paul Ekman [21], i.e., happiness, sadness, anger, fear, disgust and surprise. The FACE's original facial expressions were manually created using the Hybrid Engine for Facial Expression Synthesis module (HEFES) [19] following anatomical facial expressions guidelines (Artanatomia) [22].

To standardize the methodology for creating the FACE's facial expressions, we adopted the Facial Action Coding System (FACS) developed by Ekman and Friesen [23]. Using FACS, a facial expression can be decomposed into Action Units (AUs), which are defined as observable independent facial movements. The FACE's servo motors are positioned similarly to the major facial muscles therefore it is possible to find a correspondence between them and the AUs (Figure 1).

B. Synthetic 2D and 3D stimuli

The stimuli chosen for the experiment were 2D images and 3D models of the robot FACE and of a female human.

An image of each of the 6 basic emotions plus the neutral face was used to create the set of 7 2D photos for FACE. The set of 7 3D models of FACE was created using the Autodesk 123D catch® program, which generates 3D models taking as inputs one hundred photos acquired moving around the robot from the left to the right side covering about 180°.

The set of human 2D photos and 3D models was taken by selecting a female subject (item bs103) from the Bosphorus Database [24], a 2D/3D collection of FACS-based facial

Figure 2. The stimuli used in the experiment: 2D photos (first row) and 3D models (second row) of (a) FACE expressions and (b) human expressions

expressions acquired using a structured-light 3D scanner [25]. Figure 2 shows 2D photos and 3D models of FACE and the human subject used in this experiment.

Due to technical problems of a servo motor corresponding to the buccinator muscle (motor n. 4), FACE was partially enable to raise the left part of the smile obtaining an ambiguous happiness expression. Motor n. 4 is used only in the happyness expression, consequently we excluded the data relative to the happyness from the analysis.

III. METHOD

A. Experimental setup

Participants were seated comfortably at a desk about $0.5m$ far either from a TV screen (Size: 32 inch, Frame rate: 100Hz, Resolution: 1920 x 1080) or the robot. The experiment setup included one laptop for controlling the robot FACE and one laptop for controlling the animation on the TV screen.

10 participants (7 males, 3 females) aged $19 - 31$ years (mean age 24.1 ± 3.4) were recruited for the experiment. All participants attended scientific disciplines at University of Pisa (IT), were native Italian speakers and had either normal or corrected to normal vision. All participants gave written informed consent for the experiment.

B. Experimental Protocol

The protocol of the experiment was organized in 3 phases:

- **First phase:** each participant had to recognize 14 2D photos of facial expressions: 7 photos of humans from the Bosphorus database and 7 photos of FACE, in random order (different for each participant);
- **Second phase:** each participant had to recognize 14 3D models of facial expressions: 7 3D models of humans from the Bosphorus database and 7 3D models of FACE, in random order (different for each participant);
- **Third phase:** each participant had to recognize 6 basic expressions performed by the robot FACE in random order (different for each participant).

TABLE I. CONFUSION MATRIX OF THE RECOGNITION RATES (IN PERCENTAGE) OF SEVEN (FOR HUMANS) AND SIX (FOR THE ROBOT) FACIAL EXPRESSIONS WITH PRESENTED MODELS (COLUMNS) AGAINST SELECTED LABELS (ROWS). THE HIGHEST VALUES ARE SET IN BOLD. THE COLUMN LABELS ARE A=ANGER, D=DISGUST, F=FEAR, N=NEUTRAL, SA=SADNESS AND SU=SURPRISE.

Confusion matrix (N=10)																	
	Human 2D photos						**Human 3D models**						**Physical robot**				
	A	**D**	**F**	**N**	**Sa**	**Su**	**A**	**D**	**F**	**N**	**Sa**	**Su**	**A**	**D**	**F**	**Sa**	**Su**
Anger	20	10	0	0	0	0	**40**	0	0	0	0	0	**50**	20	0	0	0
Disgust	0	**40**	0	0	10	0	0	**30**	0	0	0	0	10	**50**	10	0	10
Fear	0	0	30	0	0	0	10	**30**	30	0	0	0	10	0	**60**	0	10
Neutral	0	0	0	**80**	0	0	0	0	0	**90**	0	0	/	/	/	/	/
Sadness	0	20	0	10	**20**	0	0	0	0	10	**40**	0	0	0	0	**50**	0
Surprise	0	0	**60**	0	0	**100**	0	0	**60**	0	0	**90**	0	0	20	0	**80**
Pride	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Embarrassment	0	10	0	0	0	0	0	20	10	0	20	0	0	0	0	0	0
Pain	10	20	0	0	**20**	0	0	10	0	0	30	0	10	0	0	10	0
Pity	0	0	0	0	**20**	0	10	0	0	0	0	0	0	10	0	40	0
Contempt	**30**	0	0	10	10	0	10	0	0	0	0	0	20	20	0	0	0
Interest	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Shame	0	0	0	0	0	0	0	0	0	0	10	0	0	0	0	0	0
Excitement	0	0	0	0	0	0	0	0	0	0	0	10	0	0	0	0	0
I do not know	30	0	10	0	**20**	0	30	10	0	0	0	0	0	0	10	0	0
No answer	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

The Unity 3D® software was used as front end animation tool to show both 2D photos and 3D models. In each phase, the participant had at most 30 seconds to recognize the expression. A C# program was developed to orchestrate the expression times as follow: at most 10 seconds was given to observe the expression followed by at most 20 seconds to answer. In the first and second phase, after the first 10 seconds or whether the participant pressed "Enter" on the keyboard (before the end of the first 10 seconds), i.e., the participant was ready to give an answer, a black screen appeared on the TV. After pressing "Enter" the participant had to choose one of the possible answers of the questionnaire (listed in Table I). The response time was also recorded on the "Enter" key pressing.

In the third phase, after the first 10 seconds or whether the participant selected the answer on the screen (before the end of the first 10 seconds), i.e., the participant was ready to answer, the robot performed the neutral expression. In this case, the participant evaluated 6 instead of 7 different facial expressions since the neutral expression was used as "black screen". To answer, the participant had to select an option directly on the screen through a software tool running on a laptop. The response time was recorded on the mouse clicking.

IV. DATA ANALYSIS

The set of expressions considered in the analysis included anger, disgust, fear, sadness and surprise. As mentioned in Sec. II-B, the happiness expression of the robot was ambiguous due to technical problems with a servo motor therefore it was excluded from all datasets in the data analysis.

The facial expression recognition rates were analyzed using the Cohen's kappa [26], a statistical measure of inter-rater reliability used to examine the agreement between observers on the assignment of categories of a categorical variable. The Cohen's kappa ranges from -1.0 to 1.0, where large numbers mean better reliability, values near zero suggest that agreement is attributable to chance, and values less than zero signify that agreement is even less than that which could be attributed to chance. According to Landis and Koch [27], with a significance level of 0.05, kappa can be classified according to the following: $k <= 0.00$ less than chance agreement, $0.01 < k < 0.20$ slight agreement, $0.21 < k < 0.40$ fair agreement, $0.41 < k < 0.60$ moderate agreement, $0.61 < k < 0.80$ substantial agreement, and $0.81 < k <= 1$ almost perfect agreement.

The Kolmogorov-Smirnov test [28] and the analysis of variance were applied to the datasets of the response times. The Anova-1way parametric test with a post-hoc Bonferroni test [29] was used to examine the category differences. The statistical inference was carried out using the OriginLab software [30].

A. *Are facial expressions of the robot perceived as well as the expressions of humans (expressed as 2D photos or 3D models)? Yes*

Table I shows the confusion matrix of the participants' answers for 2D human photos, 3D human models and robot FACE's expressions. The Cohen's kappa of the three categories showed a homogeneous expression evaluation with the best level of agreement for the expressions performed by the physical robot: $K_{Hum2D} = 0.570$ ($p < 0.001$) 95% CI (0.350, 0.789), $K_{Hum3D} = 0.606$ ($p < 0.001$) 95% CI (0.401, 0.809) and $K_{Robot} = 0.701$ ($p < 0.001$) 95% CI (0.530, 0.871). For all three categories, the best recognition rate was achieved for the surprise expression. Human anger, fear and sadness were not so well understood when shown both as 2D photos and 3D models.

Figure 3 shows a trend of increasing recognition rate for stimuli that gradually become more realistic, i.e., from human 2D photos to human 3D models up to the physical robot. This supports our hypothesis about the importance of the embodiment in conveying expressions.

All participants were instructed to choose a label for each expression as soon as they recognized it and their response time was recorded. Table II shows the means and the standard deviations of the response time for each expression in the three categories: human 2D photos and 3D models and FACE robot.

The Anova-1way parametric test did not find significant differences between the three categories (F(2,68) = 0.55309,

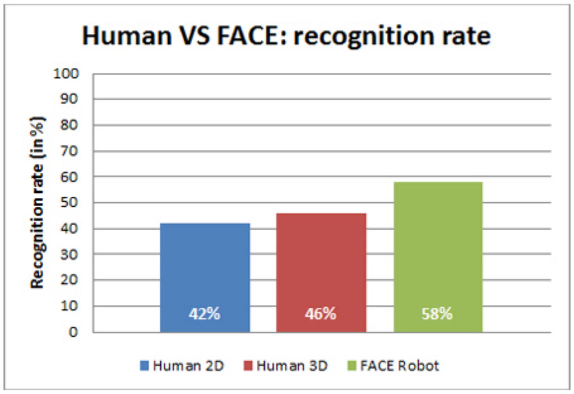

Figure 3. Recognition rate (%) of the human 2D photos, human 3D models and robot FACE.

TABLE II. MEANS AND STANDARD DEVIATIONS OF THE PARTICIPANTS' RESPONSE TIME (S) IN RECOGNIZING FACIAL EXPRESSIONS OF THE HUMAN AND THE ROBOT FACE.

	Response time in seconds (N = 10)					
	Human 2D		Human 3D		Robot	
	Mean	SD	Mean	SD	Mean	SD
Anger	4.09	0.60	9.53	5.94	8.53	4.43
Disgust	8.52	4.04	10.79	3.30	12.32	6.78
Fear	9.71	6.90	10.25	1.34	9.02	3.66
Sadness	19.31	7.84	10.90	6.53	16.02	0.96
Surprise	8.13	5.99	9.13	3.39	9.65	4.93

p = 0.57774, $\alpha = 0.05$) (Figure 4). This data confirm that the facial expressions performed by FACE were perceived similar to human expressions.

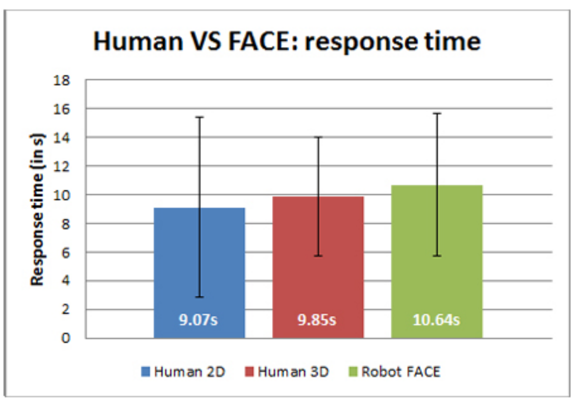

Figure 4. Response time (s) of the human 2D photos, human 3D models and robot FACE expression recognition.

B. *Is there a valid and useful reason to create and develop a realistic humanoid robot instead of using its 2D photos or its 3D models? Yes*

Previous results demonstrated that FACE can convey expressions that are recognized with a similar rate of human 2D photos and 3D models. Moreover, our study tried to investigate if the embodiment of the FACE robot is an added value, which could help people to better understand and interpret the expressed emotional status.

Table III shows the confusion matrix of the participants' answers for the robot expressions shown as 2D photos, 3D models and physical robot. As in the previous case, for all three categories, the best recognition rate was achieved for the surprise expression. The expressions performed by the robot were less confused than those shown in 2D photos or 3D models. The level of agreement between the participants was comparable for the three categories of the facial expressions performed by the FACE robot with the best level of agreement for stimuli performed by the physical robot as in the previous case: $K_{FACE2D} = 0.519$ ($p < 0.001$) 95% CI (0.284, 0.752), $K_{FACE3D} = 0.604$ ($p < 0.001$) 95% CI (0.375, 0.832) and $K_{Robot} = 0.701$ ($p < 0.001$) 95% CI (0.530, 0.871).

A comparison between the robot stimuli that gradually become more realistic, i.e., from 2D photos to 3D models up to the physical robot, shows a trend of increasing recognition rate for stimuli performed by the physical robot (Figure 5). This suggests that the embodiment of the robot conveys the expressions better than 2D photos and 3D models.

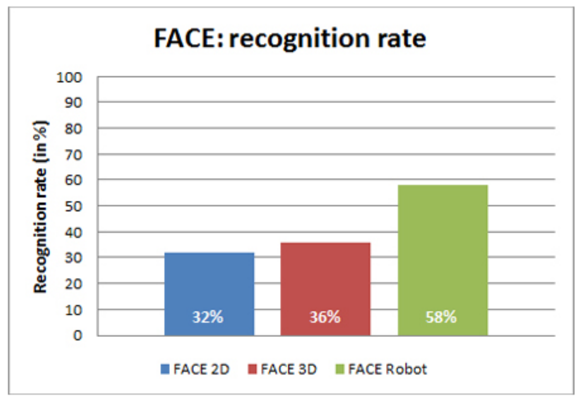

Figure 5. Recognition rate (%) of the robot 2D photos, robot 3D models and robot FACE expressions.

Table IV shows the response time means and standard deviations for each expression in the different categories of FACE: 2D photos, 3D models and the physical robot.

TABLE IV. MEANS AND STANDARD DEVIATIONS OF PARTICIPANTS' RESPONSE TIME (S) IN RECOGNIZING FACIAL EXPRESSIONS OF ROBOT 2D PHOTOS, ROBOT 3D MODELS AND THE PHYSICAL ROBOT. (* Only one response.)

	Response time in seconds (N = 10)					
	FACE 2D		FACE 3D		Robot	
	Mean	SD	Mean	SD	Mean	SD
Anger	16.49	11.20	6.17	*	8.53	4.43
Disgust	12.31	13.89	7.15	3.35	10.55	5.78
Fear	9.64	7.27	13.36	9.11	9.68	3.87
Sadness	13.87	3.29	11.73	6.82	16.02	0.96
Surprise	13.63	3.17	9.93	4.08	9.31	4.20

The Anova-1way parametric test could not distinguish between the three distributions (F(2,57) = 1.66754, p = 0.19778, $\alpha = 0.05$). The time for recognizing an expression performed by the robot was comparable to the one required to recognize the same expression as 2D photo or 3D model (Figure 6).

Figure 7 shows that the surprise expression achieved the best recognition rate in comparison with each negative expression with a difference of at least of 25%.

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TABLE III. CONFUSION MATRIX OF THE RECOGNITION RATES (IN PERCENTAGE) OF ROBOT FACIAL EXPRESSIONS WITH PRESENTED MODELS (COLUMNS) AGAINST SELECTED LABELS (ROWS). THE HIGHEST VALUES ARE SET IN BOLD. THE COLUMN LABELS ARE A=ANGER, D=DISGUST, F=FEAR, N=NEUTRAL, SA=SADNESS AND SU=SURPRISE.

Confusion matrix (N=10)																	
	FACE 2D photos						FACE 3D models						Physical robot				
	A	D	F	N	Sa	Su	A	D	F	N	Sa	Su	A	D	F	Sa	Su
Anger	20	10	10	0	0	0	10	20	0	0	0	0	**50**	20	0	0	0
Disgust	**30**	30	**20**	0	0	20	30	**40**	0	0	0	0	10	**50**	10	0	10
Fear	10	0	**20**	0	0	0	0	0	30	0	0	0	10	0	**60**	0	10
Neutral	0	0	0	**40**	0	0	0	0	0	**40**	0	0	/	/	/	/	/
Sadness	0	0	0	0	30	0	0	0	0	0	**30**	0	0	0	0	**50**	0
Surprise	0	0	0	10	0	**60**	10	0	20	0	0	**70**	0	0	20	0	**80**
Pride	0	0	0	30	0	0	0	0	0	20	0	0	0	0	0	0	0
Embarrassment	0	0	10	0	10	0	0	0	10	0	0	0	0	0	0	0	0
Pain	0	0	0	0	0	0	0	0	0	0	10	0	10	0	0	10	0
Pity	0	0	10	0	**40**	10	0	0	**40**	0	10	0	0	10	0	40	0
Contempt	20	**50**	10	10	10	10	**40**	**40**	0	10	0	0	20	20	0	0	0
Interest	0	0	0	10	10	0	10	0	0	20	10	10	0	0	0	0	0
Shame	0	0	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Excitement	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
I don't know	10	10	10	0	0	0	0	0	0	10	**30**	20	0	0	10	0	0
No answer	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

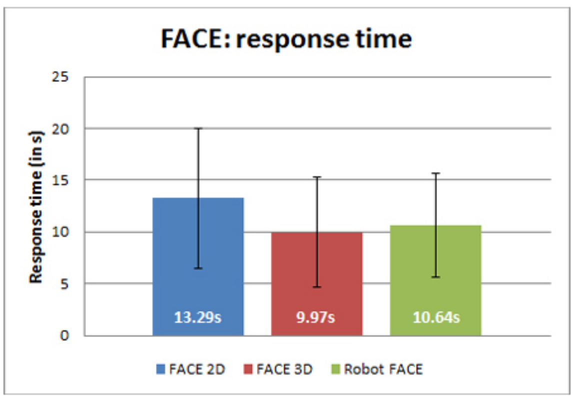

Figure 6. Response time (s) in recognizing the facial expressions of FACE 2D photos, 3D models and physical robot.

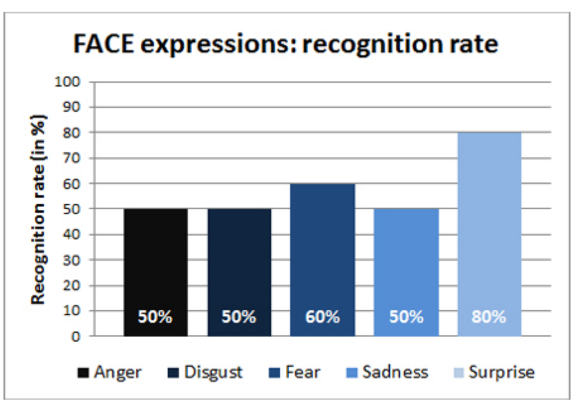

Figure 7. Recognition rate (%) of the FACE expressions.

V. CONCLUSION

Our study aimed at investigating (1) if the recognition rate of facial expressions performed by FACE were similar to the ones achieved with humans stimuli and (2) if there were differences in recognizing facial expressions performed by FACE using its 2D photos, 3D models or the robot itself.

The final dataset used in the analysis did not include the happiness expression because it was considered ambiguous due to an abnormal functioning of a servo motor.

In regard to the first question, our preliminary results demonstrate that the recognition rate of human expressions is similar to the one of the robot expressions. This supports our hypothesis that the robot is able to convey emotion through facial expressions as well as human 2D photos and 3D models.

Concerning the second question, we found that the physical robot can convey expressions better than its photos and its 3D models. We could hypothesize that this study support the direction of the contention that the dynamic and the embodiment of social humanoids improve the recognition and discrimination of emotions in comparison with 2D pictures and 3D displays [31][32][33].

Usually positive expressions may not require the analysis of the entire face to be recognized since they can be characterized by a single feature, such as a smiling mouth for the happiness [34]. This phenomenon makes the recognition of the expression simpler and then faster [35]. Our results confirmed this phenomenon. A comparison between the recognition rates of 2D and 3D human expressions showed that the surprise expression was generally recognized better than the negative expressions. Indeed, anger was often confused with contempt or not recognized at all, disgust was confused with fear or pain while fear with surprise and sadness with pity or pain. Even in the case of 2D and 3D robot expressions, the best recognition rate was achieved for surprise while anger and disgust were often confused with disgust or contempt, fear with disgust or pity and sadness with pity or not recognized at all.

In conclusion, we based our experiment on the hypothesis that the embodiment of highly anthropomorphic robots could help them to express their emotions by means of a physical aspect, which is absent in a virtual character on a screen. Our results found that there is a general tendency to better

 ISBN: 978-1-61208-382-7

recognize expressions performed by the physical robot than the ones shown as 2D photos and 3D models. The embodiment of the robot and its dynamics could be an added value to help people to better understand and interpret the emotional status of a robot.

This work represents a preliminary study of the emotion conveying capability of our robot and its results are encouraging for future experiments. These results highlighted that generating facial expressions is a challenging task that requires high-fidelity reproduction therefore future developments will concern improving the performance of the robot in expressing emotions. In addition to the exclusion of the expression of happiness, two factors may have influenced the statistical analysis: the small size of the sample and the extended forced-choice paradigm. Thus, new effective experimental tests will be designed to be more effective. Moreover, this study give us the foundations for the setup of a therapeutic scenario in which the FACE robot will be used as emotional display in the autism treatment.

ACKNOWLEDGEMENTS

We would like to thank Andrea Guidi, and Niccolò Albertini, for thei help during the preparation of the experiments. This work was partially founded by the European Commission within the Project EASEL (Expressive Agents for Symbiotic Education and Learning) (FP7-ICT-611971).

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 ISBN: 978-1-61208-382-7