Human responses to an expressive robot

Nadel, J.*, Simon, M*., Canet, P*., Soussignan, R.* , Blancard, P.,Canamero, L., & Gaussier, P**
* UMR CNRS 7593, Paris; ** UMR 8051, Cergy-Pontoise
jnadel@ext.jussieu.fr ; mausimon@ext.jussieu.fr; gaussier@ensea.fr

Abstract

This paper reports the results of the first study comparing subjects' responses to robotic emotional facial displays and human emotional facial displays.

It describes step by step the building of believable emotional expressions in a robotic head, the problems raised by a comparative approach of robotic and human expressions, and the solutions found in order to ensure a valid comparison. Twenty adults and 15 children aged 3 were presented static (photos) and dynamic (2-D videoclips, or 3-D live) displays of emotional expressions presented by a robot or a person.

The study compares two dependent variables: emotional resonance (automatic facial feed-back during an emotional display) and emotion recognition (emotion labeling) according to partners (robot or person) and to the nature of the display (static or dynamic). Results for emotional resonance were similar with young children and with adults. Both groups resonated significantly more to dynamic displays than to static displays, be they robotic expressions or human expressions. In both groups, emotion recognition was easier for human expressions than for robotic ones.

Unlike children that recognized more easily emotional expressions dynamically displayed, adults scored higher with static displays thus reflecting a cognitive strategy independent from emotional resonance. Results are discussed in the perspective of the therapeutic use of this comparative approach with children with autism that are described as impaired in emotion sharing and communication.

1. Introduction

There is a growing interest for emotion in neurocognitive sciences and in cognitive sciences such as robotics, developmental psychology and developmental psychopathology.

Neuroimaging activations of Mirror Neurons in Broadman area when emotional stimuli are presented (Dapretto et al., 2006) supports the idea that the perception of an emotion resonate in the perceiver as if s/he felt the emotion expressed: that is why Trevarthen et al. (2005) call Mirror Neurons *the sympathy neurons*. Emotional resonance that couple the perception of one person to the action of another may be the underlying mechanism for emotional sharing (also called intersubjectivity). This phenomenon may well be expressed by the general tendency to mimic facial stimuli (Dimberg, Thunberg, & Elmehed, 2000).

Empathy is seen also as a case of emotional sharing (Decety & Jackson, 2004; Wicker et al., 2003), but here a frontier is designed between the owner of the emotion and the participant who knows that s/he is not experiencing directly the events at the origin of the emotion: the Who system activates agency and introduces a distance between experiencing and feeling (Decety & Jackson, 2004).

Moreover, understanding the meaning of emotional displays as such does not necessarily leads to emotional sharing. In the field of developmental sciences, the recent stress on the 'intentional stance' has led to shed light on the cognitive role of emotions in the understanding of intentions (Hobson, 2004).

This suggests that emotional resonance and emotion understanding and recognition are two separate though related components of the emotional system. How far they are related is not fully documented at the moment. It is however a main question for further knowledge in the field but also for the design of therapeutic tools in developmental psychopathology. Indeed, if we know more about the links between the cognitive aspects of emotion (reading emotion) and the phenomenological experience in play when we share, we will be able to propose to children with autism displays that altogether generate feelings and enhance reading emotion instead of our present designs that only deal with one of the two aspects. Within this framework, it is of high interest to know whether emotional resonance facilitates emotional recognition and understanding, whether emotional recognition enhances emotional resonance and whether these phenomenon can be observed also when facing an expressive robot compared to an expressive person. If we can resonate in front of a robot that displays believable facial expressions of emotion, then we can reasonably expect using expressive robots as therapeutic tools for emotional remediation in children with autism.

In the field of robotics, the design of architectures aimed at reproducing and understanding the internal dynamics of emotional processes is an important part of the spurt of 'affective devices' (Wherle, 2001). Besides this option, affective computing has invested a large variety of foci with the ultimate goal to give a computer the ability to detect and use the different functions of emotional signals: communication (Breazeal, 2002), problem solving and performance improvement (Canamero, 2001), information processing (Botelho & Coello, 2001; Frijda, 1995), interpersonal relationships (Aubé, 2001), and even empathy (Kozima, Nakagawa & Yano, 2003).

Our common interdisciplinary interest for the intersubjective aspect of emotion has led to design a robotic expressive head with the purpose to explore how far it generates human emotional responses that can be compared to human-human intersubjective exchanges via emotion. As a second aspect of the question, recognition of facial expressions will be compared when the robotic or human stimuli presented are static displays or dynamic ones. This is of particular value given that dissociable neural pathways has been shown to be involved in the recognition of emotion in static and dynamic facial expressions (Kilts, Egan, Gideon, Ely, & Hoffman, 2003). It will be interesting to see whether the non-canonical aspect of the robotic expressions render more difficult the mental strategies required to recognize static displays in robots than in human.

Before addressing this question in the realm of early normal and impaired development, an important pre-requisite was to fix the external features of the emotional expressions of the robotic head. As put forward by Canamero and Gaussier (2005), “building a ‘believable’ expressive robot …poses many challenges that need to be approached from a multidisciplinary perspective” (p. 251). This was exactly our process.

The first step in our approach was to design the emotional patterns of the robot according to the scientific standards of the universal prototypical facial expressions described by Ekman and Friesen in their Facial Action Coding System (1976). Two FACS certified members of our group devoted much effort to achieve this step in order to ensure a valid comparison between the responses of the same adults when facing the expressive robot and when facing an expressive human actor.

In a second step, the human actor was trained to mime consistently and reliably (according to the same scientific standards), the same prototypical expressions. His performance was validated by 20 adults who recognized his expressions as successfully as the prototypical expressions from Ekman and Friesen (1976).

The third step was devoted to evaluate whether the robotic expressions were recognizable by a group of 20 adults and to modify the static and dynamic displays accordingly.

We will first present the set up, detail the steps aimed at preparing the experiment and then report the results concerning emotional resonance and emotion recognition according to the partner (robot or actor) and the display (dynamic or static) with a population of adults an a population of young children. The experiment with high functioning children with autism is in process.

2. Setting and basic software

The set-up was created by Gaussier and Canamero, and designed by Canet. It is composed of a robotic head linked to a laptop. Nested in the eye of the robot, a micro-camera films the subject’s behavior during the session. The eyes, eyebrows, eyelids and mouth are moved by 12 servomechanisms connected to a 12 Channel Serial Servo Controller with independent variable speed. A home software is used to generate the 5 prototypical facial expressions (+ neutral face) and to command the different servo motors.

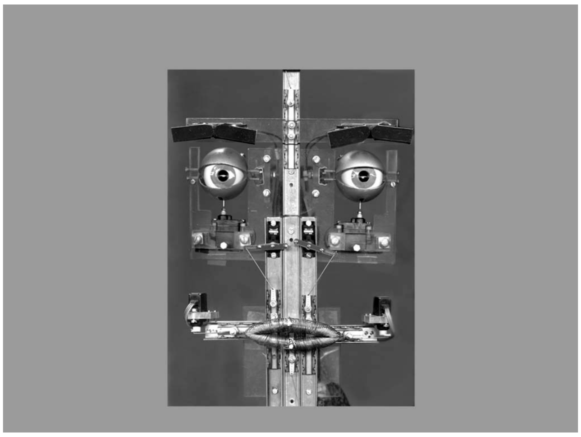

Figure 1- Neutral expression of the robotic head

The communication speed between the robot head and the PC is 9600 Bd allowing to control each actuator every 40ms (25 times / sec) which is sufficient in the case of the present experiment. For each expression, a handwritten file describes the profile of speed and intermediate positions each actuator must follow in order to mimic correctly the corresponding facial expression (according to the judgement of human experts). As a whole, the set-up gives a reasonably believable version of a face though it is not totally realistic as there are no chin, no cheeks and no nose.

We consider however that there are good reasons to privilege simplicity over nearly perfect realism (Canamero & Gaussier, 2005). Movement seem to have more weight than appearance and a caricaturized face with rudimentary movement can be more effective than a sophisticated head from which people would expect highly realistic movements (Reichard, 1978). Here the movements are coherent, well synchronized and we have adjusted the timing according to the converging judgement of 15 adults during pre-experiments.

3. Experiments

Stimuli

A. Robotic emotional expressions

We have followed a discrete categories approach to produce five primary expressions: joy, sadness, surprise, fear and anger, completed by a neutral expression. The emotional expressions were created following the Facial Action Coding System standards elaborated by (Ekman & Friesen, 1976). Once created, each emotional expression was analysed according to the action units that it involves and compared to the prototypic emotional expressions of human faces described by (Ekman, Friesen, & Hager, 2002) as shown in figure 2 for surprise.

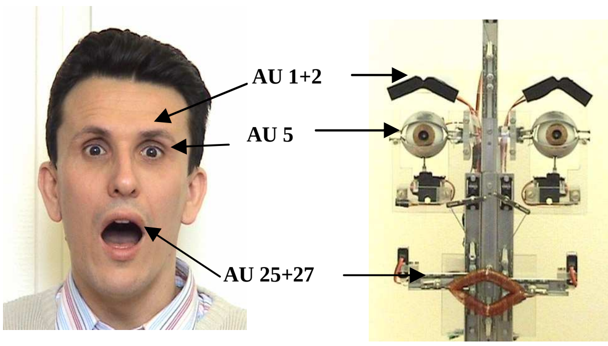

Figure 2. Surprise activates muscular action units that can be patterned by the robotic head

Given that the set up has no nose, no chin and no cheeks, it is worth noticing that some action units cannot be created in the robot head (i.e. AU6, orbicularis oculi action, present in Duchenne Smile, see (Soussignan, (2002).

The comparison between human and robotic expressions was lead by Simon and Soussignan (FACS certified) and asserted by Oster (as part of collaborative exchanges with Nadel's group).

Three series of robotic stimuli of emotion were derived from the expressions selected: static stimuli (photos), 2-D dynamic stimuli (3-sec. films); 3-D dynamic stimuli (robot facing the subject *on line*).

B. Human emotional expressions

An experimenter was trained by the two FACS certified judges to display a neutral expression as well as the five primary emotional expressions (joy, sadness, surprise, fear and anger), until he met criterions of FACS emotional expressions. The expressions were analyzed in terms of the action units standardized by Ekman and Friesen (Ekman & Friesen, 1976) and compared to the prototypical expressions of Ekman, Hager and Friesen's repertoire (2002).

Two presentations of the human stimuli were prepared: a static presentation (photos matched in quality of light, size and contrast with the photos of the robotic expressions) and a 2-D dynamic presentation (films matched on duration with the films of robotic expression). We did not use a 3-D presentation for the person, because of the embarrassment or fun triggered by the sight of somebody miming disembedded emotions, but we will use it later with children and persons with autism.

The recognition of the experimenter's static expressions were compared to the recognition of pictures of facial affect developed by Ekman and Friesen (1976) in 20 young adults. A ANOVA with repeated measures showed no differences between the recognition of Ekman's emotional expressions (m=4.85, SD=.366), and of our emotional expressions (m=4.85, SD=.489) [F(19,1)=0,000…, p=1]. Our population was shown to recognize the facial expressions similarly to Ekman and Friesen's population

	Ekman's population	Our population
Anger	100	100
Happy	100	100
Fear	92	95
Sadness	96	95
Surprise	96	95

Table 1- Percent recognition of Ekman' s facial expressions in Ekman & Friesen population and in our own population

These convergent elements allow us to consider that the facial expressions of our actor were similar to the prototypical ones provided by Ekman and Friesen's (1976) classical set of facial expressions.

Hypotheses

We hypothesized a positive effect of dynamic display on both resonance and recognition of emotional expressions. Our second hypothesis was that our subjects will respond more readily to human expressions than to robotic expressions, as a function of intersubjective resonance. This should be more obvious for young children that are not at ceiling concerning emotion recognition and labeling.

Procedure

The subjects (adults or children) were presented the 3 series of robotic emotional stimuli first, and the two series of human emotional stimuli in a counterbalanced order. The series were proposed in the following order: dynamic 3-D, photos and dynamic 2-D for the robot head, photos and dynamic 2-D for the human face. There was a counterbalanced order for presentation of the different emotions in the different series. As we were willing to record spontaneous feed-back to an emotional display, we mentioned only to the subjects that they will have to label the emotion displayed.

The whole session lasted 3 minutes, each stimulus presented during 3 seconds.

The subjects were filmed at their eye level by the micro-camera nested in the robot's eye when the 3-D robotic display was concerned, or by a digital camera hidden in a box facing the subject for the presentation of all other displays.

Dependent variables and coding

Two dependent variables were used: subject's facial expressions during the presentation of the emotional stimuli, and naming the emotion expressed after the presentation.

In order to test the presence of a resonance effect, we analyzed the recordings of the subject's facial movements during the 5 displays (3 displays for the robot, 2 displays for the person) of the 5 expressions (joy, surprise, fear, anger, sadness) in the 20 subjects, thus reaching an amount of 500 analyses of facial expressions. The analysis of the Action Units was performed using the Ekman, Hager and Friesen (2002)'s FACS standards by the two FACS experts. The two experts coded independently 40% of the subjects' facial expressions with a mean Kappa agreement of .89. They were blind to the display observed by the subjects.

In order to evaluate emotion recognition according to the display and the partner (robot or person), we asked the subjects to name the emotion after each emotional display has been presented.

4. Results

A. EXPERIMENT WITH ADULTS

Population

The population was composed of 20 healthy young adults.

Results

A series of ANOVAs with repeated measures was conducted.

a. Resonance

Concerning the resonance scores, an overall analysis showed no effect of partner (M-robot=1.95; M-person=2.35), but a significant effect of the display ([F (1, 19) = 22,7, p = .0013]: Whatever the partner, robot or person, the subjects resonated more for dynamic displays than for static displays.

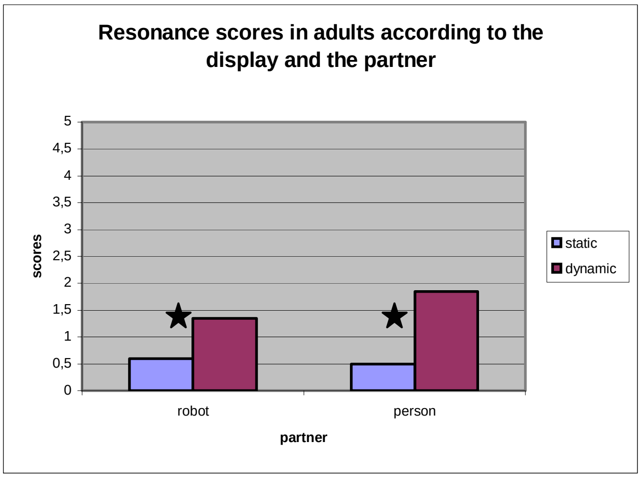

Figure 3- Adults resonate more to dynamic displays , whatever the partner

significant statistical difference at p<.05 ★

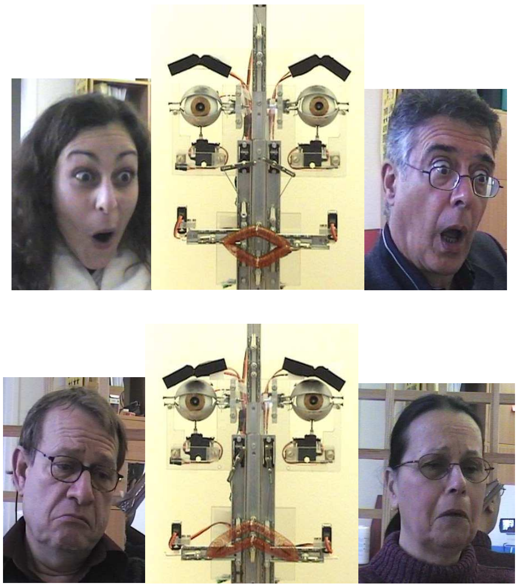

Figure 4- Spontaneous resonance to the expressive robot

However, when analyzing the resonance scores for each emotion, a difference appeared concerning fear. Post-hoc Cochran test showed that the dynamic expression of fear induces more facial movements of fear when displayed by the person than by the robot (q=11.3,p=.01). In this case, facing a biological movement may lead to more direct investment in the emotional expression due to the evolutionary selection of fear as a significant signal of danger and its short circuit (LeDoux, 2000).

Figure 5- Resonating to a 2-D human display of fear

b. Recognition

Concerning recognition scores, an overall analysis showed a significant effect of partner: human expressions lead to higher scores of recognition than robotic expressions [F(1,19) = 12,7; p=.0021. A significant interaction between partner and display was found, showing that static displays of human expressions are more recognizable than the dynamic displays (although the static displays originate from the dynamic displays). To sum up, static displays of human expressions (photos) were recognized at best.

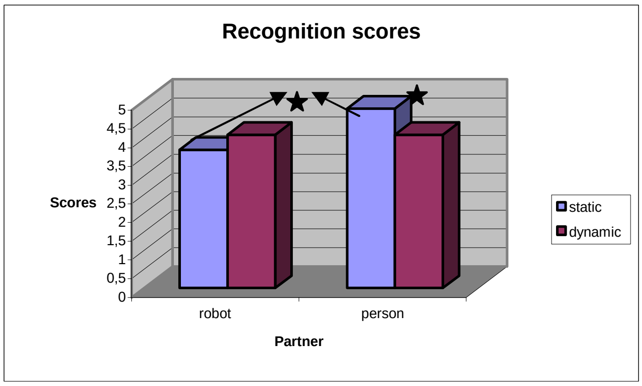

Figure 6- Static displays of human expressions are recognized best compared to dynamic human displays to robotic displays
p<.05. ★

Results found with adults allowed us to consider the robotic design believable and suitable for developmental research.

B. EXPERIMENT WITH CHILDREN

Population

The population was composed of 15 children aged 2 years 10 months to 3 years 4 months (mean age: 3 years). The parents have given their informed consent and the children enrolled where those willing to participate.

Results

A series of ANOVAs with repeated measures was conducted.

a. resonance

An ANOVA comparing the overall synchronous (automatic) responses to facial expressions showed no effect of partner but a significant effect of display [F (2,28)= 5.76, p<.008], whatever the partner (see figure 6).

b. recognition

Computing together the responses for the 3 displays (photos, videoclips and live), we found that 3-year-olds recognize above chance the emotions of joy (42%) and sadness (38%) when expressed by the robot and the emotions of joy (64%), sadness (71%) and anger (60%) when expressed by a person. Fear and surprise wee not recognized above chance. The ANOVA showed an overall effect of partner [F (1, 14) = 31,4 ; p = 0.000065]: the expressions of the person were recognized more frequently than the robotic expressions. This was true whatever the type of display as shown by significant post-hoc Tukey tests (p =.001 for all displays). There was an overall effect of display [F (2, 28) = 4,8 ; p = 0,016]. Post-hoc Tukey test indicated that the dynamic 2D display (videoclip) generated significantly higher emotion recognition (p= 0,013). Dynamic displays were especially helpful for recognition of robotic expressions.

5. Discussion

The main results of our research can be summarized as follows: dynamic displays enhance emotional resonance to robotic expressions as well as to human expressions. By contrast, static displays facilitate emotional recognition, especially when human expressions are concerned. These results however are not corroborated when the displays are presented to young children. We will now discuss these findings in relation to robotic, psychological and neuropsychological state of the art.

When roboticists are involved in the process of building an expressive robot, they are mainly concerned with the imperative that the facial emotional displays should be believable for humans. Otherwise, they are interested in establishing automated systems that can human facial muscle actions and learn to associate them to emotion (Panti2006). Not only did we ensure that our robotic expressions were believable in a series of pre-experimental presentations, but we built up the emotional displays according to the universals of facial expressions described by Ekman and Friesen (1976) and Ekman, Friesen and Hager (2002). Thus the emotional facial displays are not only believable but they also represent universals of expressions. This is true as far as our 12 servomechanisms can simulate complex and multiple facial muscle actions. More sophisticated robots with a silicon envelop may display a more fully successful simulation of muscle actions. But minimalist as it is our robotic head has lead to results that more accomplished designs will necessarily replicate if they were set-up according to the universal action units described by the FACS (Ekman, Friesen and Hager (2002): adults resonate to dynamic robotic expressions as readily as to dynamic human expressions. These results are highly encouraging for further development of human-machine interface. They are also critical for research in the realm of psychopathology of emotion. Indeed, if social aversion in autism inhibits emotional resonance, an expressive robot that does not generate such aversion might play an important role in emotion and interaction therapy (see Dautenhahn, 2003).

Another finding with our population of adults is that emotion recognition is higher with photos than with dynamic displays. This tends to indicate independence between the process of recognition and the resonance to emotional patterns. The fact that dissociable neural pathways were found to be involved in the recognition of anger and happiness in static and dynamic facial expressions (Kilts et al., 2003) may explain this independence. As Kilts et al. concluded, the emotional content of static displays may be processed by mental strategies and neural activations that are distinct from more ecologically valid stimuli such as dynamic displays. The familiarity with photos and the stability of static stimuli may also be of help. These results however were found with a population of adults that were nearly all at ceiling for emotion recognition.

If we look now at what children teaches us about the development of the two aspects of emotion, resonance and recognition, and how they are related, we face another story.

Our developmental approach focused on children's responses to robotic vs. human expressions with a primary interest for the investigation of the role of emotional resonance as a basic condition for understanding others' emotions (Nadel & Muir, 2005). This hypothesis relies on infancy research. A series of studies have shown that infants as young as 2 months react negatively to a delay introduced in the interactive loop between their own emotional behavior and their mother's response (Murray & Trevarthen, 1985; Nadel et al., 1999; Nadel et al, 2005; Soussignan et al., 2006; Stormack & Braarud 2004), Their negative reaction is viewed as resulting from the early capacity to detect a violation of emotional resonance. As soon as mother responds contingently again, they re-establish positive signals of good emotional attunement. How can we interpret relatively poor emotional resonance in young children facing an expressive person or an expressive robot? What happened with 50% of our population of 3-year-olds suggest an explanation. Indeed we had to test 30 children aged 3 years to get 15 complete protocols. Fifty percent of the children refused to be presented the expressions of the human actor in vivo, while all of them accepted to be presented the robot in vivo. We understood that a context giving purpose and meaning to the facial emotions was required for the person while it was not for the robot. Around 3 years, children start relating facial emotional displays to mental states. This suggest that while an emotional display in itself is evocative for adults, or for 5-year-old children, the adequate context is needed for younger children (i.e. if the person displays sadness, there should be something wrong in the environment). The capacity to evocate is not strong enough to resonate without a meaningful context.

Recognition of emotion, as measured by labelling the facial display is limited to joy, sadness and anger. This is a classical finding with static displays of human expressions (Tremblay, Brun & Nadel, 2005). Unlike for adults, recognition is best in young children for static displays. What is striking is that young children resonate to facial expressions like fear that they cannot label. Reversely, they can label anger but do not resonate to, as if social display rules were controlling resonance (children should not show anger when their parents are angry toward them). Like for adults, these results support the idea of a relative independence between resonance and recognition, One could argue that measuring recognition by labelling may not correctly correspond to young children's capacity to distinguish different prototypic emotions. However, our results a re similar to previous results by Brun who used a non-verbal procedure where children had to match a facial expression with a vocal expression of emotion (see Tremblay et al., 2005 for details). As pointed by Kilts et al. (2003), maybe cognitive strategies in play in recognition of facial displays are not those activated in ecological and meaningful environments. The early sensitivity to resonance and its role in primary non verbal communication lead us to consider that it is the main basis for further understanding of emotions in others. What for children with autism and emotion therapy?

Behavioral studies (Hobson, 1986; Sigman et al., 1992), and more recently neuro-imaging studies (Dapretto et al., 2006; Oberman et al., 2005) have investigated the possible impairment of emotion understanding as a key factor of an impaired understanding of the social world in autism. Instead of pointing on emotion recognition, we propose rather to focus on the capacity to resonate in contexts that are meaningful. We will get another picture concerning possible emotional impairment. For instance, low-functioning children with autism initiate highly positive emotional exchanges with an unacquainted adult in a context of imitative interaction (Escalona et al., 2000; Field et al; 2001; Nadel et al, 2000).

Finally, our paper gives a honest description of the problems and the solutions that can be found when we compare emotions expressed by a robotic head and a human face, and the interdisciplinary benefits of such a comparison for fundamental knowledge about emotion, for the development of therapy based on new technologies, and for advanced human-machine interactions.

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