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Humanoid robots versus humans: How is emotional valence of facial expressions recognized by individuals with schizophrenia? An exploratory study

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ABSTRACT

Background: The use of humanoid robots to play a therapeutic role in helping individuals with social disorders such as autism is a newly emerging field, but remains unexplored in schizophrenia. As the ability for robots to convey emotion appear of fundamental importance for human-robot interactions, we aimed to evaluate how schizophrenia patients recognize positive and negative facial emotions displayed by a humanoid robot.

Methods: We included 21 schizophrenia outpatients and 17 healthy participants. In a reaction time task, they were shown photographs of human faces and of a humanoid robot (iCub) expressing either positive or negative emotions, as well as a non-social stimulus. Patients' symptomatology, mind perception, reaction time and number of correct answers were evaluated.

Results: Results indicated that patients and controls recognized better and faster the emotional valence of facial expressions expressed by humans than by the robot. Participants were faster when responding to positive compared to negative human faces and inversely were faster for negative compared to positive robot faces. Importantly, participants performed worse when they perceived iCub as being capable of experiencing things (experience subscale of the mind perception questionnaire). In schizophrenia patients, negative correlations emerged between negative symptoms and both robot's and human's negative face accuracy.

Conclusions: Individuals do not respond similarly to human facial emotion and to non-anthropomorphic emotional signals. Humanoid robots have the potential to convey emotions to patients with schizophrenia, but their appearance seems of major importance for human-robot interactions.

1. Introduction

Perception of emotions and recognition of facial expressions play a critical role in social interaction between humans (Frith, 2009; Little et al., 2011). Humans interpret personality attributes, appearance, and emotional states of others mainly on the basis of facial cues (Russell et al., 2003). Schizophrenia patients show facial emotion perception deficits, which are trait-like (Chan et al., 2010; Salva et al., 2012), present at the onset of psychosis (Barkl et al., 2014) in unaffected first-degree relatives of patients (Allott et al., 2015; Ruocco et al., 2014), and thus represent a robust finding in individuals with schizophrenia (Edwards et al., 2002). Such deficits are associated with impairments in social interaction and predict functional outcome (Barkl et al., 2014; Trémeau, 2007). To date, studies on emotion facial recognition in schizophrenia have exclusively focused on human facial emotions. However, socially assistive robots have recently been developed to manage specific health care for populations such as elderly people (Shibata and Wada, 2011), patients with chronic stroke (Liao et al., 2012), and individuals with autism (for a review, see Scassellati et al., 2012). In the last decade, studies on social assistive robotics (SAR) have emerged, dominantly in autism (Jordan et al., 2013). SAR aims to create robots able to interact and communicate with humans autonomously or semi-autonomously (Dautenhahn, 2007). Indeed, humans have a tendency to attribute

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human traits to robots (Breazeal, 2003: Wendt & Berg, 2009), especially when they display human-like physical and behavioral characteristics. Thus, the physical appearance of humanoid robots can support a more naturalistic communication during human-robot interaction, leading to a better acceptance of social robots (Wendt & Berg, 2009).

A new breed of robots called “socially interactive robots” has therefore been designed to simulate facial emotions (Lütkebohle et al., 2010) and other non-verbal cues such as co-verbal gestures to increase the quality of human-robot interactions (Li & Chignel, 2011). Consequently, a central question in SAR concerns the physical appearance of robots and how it relates to emotions perception (Scassellati et al., 2012).

On the one hand, humanoid robots may encourage social interaction and communication, as they possess all necessary features to convey social signals, particularly facial expressions (Breazeal, 2003; Dautenhahn, 2007). On the other hand, patients with deficits in recognizing and interpreting social cues, such as autistic spectrum disorders or schizophrenia patients, may have difficulties interpreting complex social cues from humans and by extension extreme human-like robots (Scassellati et al., 2012). Consequently, more simplistic human-like robots with a physical appearance that exaggerates social cues might be more easily recognizable, in particular by individuals with attentional and gaze control deficits during face exploration (Delerue et al., 2010). Thus the challenge in SAR is to find the good balance between realism and simplicity.

A humanoid face is suggested to trigger an automatic orientation of spatial attention, as a human face (Chaminade & Okka, 2013). Nevertheless, it remains poorly understood whether humans can decode and interpret with the same accuracy facial expressions of emotions displayed by humanoid robots or by humans. Recent work suggests that robotic faces expressing emotions are perceived differently from human faces, and that the difference depends on the human-like characteristics of the robot's face (Pais et al., 2013). Indeed, Dubal et al. (2011) showed that early processing of emotions using EEG techniques did not differ between human faces and non-humanoid robot face, whereas Chaminade et al. (2010) showed that perception of emotions expressed by humanoid robots or by humans led to different neural activation in higher brain structures.

No studies have so far used robot in schizophrenia rehabilitation. Although robot-assisted therapy could open a new perspective in this field, notably for the rehabilitation of social deficits (Bardy et al., 2014), it raises important issues concerning both clinical interest and social acceptability. As facial emotions appear central for the quality of human-robot interactions, this study aimed to evaluate the ability of patients with schizophrenia, in comparison with healthy controls, to recognize positive and negative facial emotions displayed by a humanoid robot. However, it is important to note that our current study is not designed to propose a robot based remediation program. But there is compelling evidence that robot assisted rehabilitation could be more interesting for patients instead of virtual reality programs for example (Pan & Steed, 2016). Several lines of research suggest that in comparison with virtual reality programs, the physical presence of a robot allows for a more engaging and enjoyable interaction than virtual agents (Lee et al., 2006; Wainer et al., 2006). The most obvious and unique attribute of a robot is its physical embodiment, and there are convincing arguments to suggest that during human-robot interaction, individual's impression of a robot's helpfulness, trustiness and enjoyability (Wainer et al., 2006, 2007) is significantly affected by embodiment. Indeed, contrary to existing avatars social remediation programs, robots can generate dynamic interactions that reflect faithfully nature of human-human interaction in real time. As recently shown, nonverbal communication during social interaction is impaired in schizophrenia (Lavelle et al., 2013). Patients generate fewer nonverbal behaviors during social interaction (Del-Monte et al., 2013), have difficulties to synchronize their movement with others (Varlet et al., 2012), inducing in their interactive partner poorer feeling of connectedness toward themselves (Raffard et al., 2015). Thus robot-assisted therapy could be particularly promising in comparison to non-embodied systems (e.g., virtual companion agents, personal digital assistants, intelligent environments, etc.) for the rehabilitation of social interaction deficits repeatedly found in individuals with schizophrenia.

2. Methods

2.1. Participants

We included 21 schizophrenia outpatients and 17 healthy participants matched for age, sex and years of education (Table 1). We recruited patients meeting DSM IV-TR criteria for schizophrenia in Montpellier University Hospital. None were in the acute phase of psychosis. Inclusion criteria were being between 18 and 55 years of age, having a diagnosis of schizophrenia and being able to understand, talk and read French. Exclusion criteria were substance dependency other than cannabis or tobacco, substance abuse other than cannabis or alcohol, and co-morbid neurological disorder.

Controls were recruited from the general population with no personal lifetime history of any psychosis or affective disorders diagnosis (MINI; Sheehan et al., 1998). Controls with a family member with bipolar or schizophrenia disorders were excluded.

All participants were native French speakers with a minimal reading level validated using the National Adult Reading Test (f-NART; Mackinnon & Mulligan, 2005). In addition, a good reason to use f-NART is that reading accuracy has been shown to be directly correlated with the IQ.

All participants provided written informed consent, prior to the experiment, approved by the local Ethics Committee conforming to the Declaration of Helsinki.

2.2. Humanoid robot: iCub

iCub (see Fig. 1), a humanoid robot with 53 degrees of freedom, was designed to offer a platform for cognition investigation (Metta et al., 2010). This robot provides a range of modulates for social interaction from bodily movements to verbal communication. For instance, the eyes of this robot can be used to simulated human-like gaze behavior (Khoramshahi et al., in press). Moreover, the robot is able to interact with physical world by movements such as reaching, grasping, manipulating, and handing over objects (Metta et al., 2010). More specific to this study, the robot is able to generate the primary emotions (Pais et al., 2013). (See Fig. 2.)

2.3. Stimulus

Full-face, frontal view, black and white photographs of human faces (gender-matched), extracted from the FACES Database (Ebner et al., 2010), and of a humanoid robot (iCub; Pais et al., 2013) expressing either a positive (happiness) or a negative emotion (anger) were employed in a reaction time task (see Fig. 1). These two emotions were chosen because they are easily recognized and distinguished by healthy participants (Pais et al., 2013). The two non-face stimuli consisted of a plus or a minus sign symbol. Thus, 6 different stimuli were presented to the participants. All stimuli had a gray background. An editing program (Photoshop) was used to match pictures for luminance. Stimulus size was 620 × 480 pixels. It is also important to note that this protocol is an experiment part of another protocol in which participants have to actually perform a motor task with the iCub robot. In order to control the online feedback given during this motor task, we've decided to measure it in a reaction time task, in comparison with social emotional stimuli. Therefore, pictures with non-social stimuli with emotional valences cannot be used as online feedback stimuli whereas plus or minus signs can.

Table 1
Social, demographic and clinical information of schizophrenia patients and healthy controls.

	Schizophrenia patients ($N = 21$)		Healthy controls ($N = 17$)		
	M	SD	M	SD	Statistics
Age	30.10	5.86	29.88	7.48	$t = 0.098$, $p = 0.92$
Education (years)	12.61	2.52	12.71	2.20	$t = -0.11$, $p = 0.912$
Fnart (Premorbid IQ)	106.25	10.63	106.74	5.44	$t = -0.172$, $p = 0.864$
PANSS Positive	10.57	3.60			
PANSS Negative	11.52	4.56			
PANSS General Psychopathology	23.10	4.73			
PANSS Total score	45.19	8.35			
Gender	N	%	N	%	
Man	16	76.2	10	68.4	$\chi 2 = 1.31$, $p = 0.252$

2.4. Measures

2.4.1. Positive and Negative Syndrome Scale (Kay et al., 1987)

The PANSS is a 30-item rating scale completed by clinically-trained research staff at the conclusion of a semi-structured clinical interview to evaluate clinical symptom severity.

2.4.2. Mind Perception Questionnaire (MPQ; Gray et al., 2007)

The MPQ was developed to evaluate how individuals perceive the mental capacities of various human and nonhuman characters. The MPQ evaluates how individuals perceive living and non-living things in terms of Experience (e.g. How much is the XX capable of experiencing physical or emotional pleasure?) and Agency (e.g. How much is the XX capable of remembering things?). Here, we applied the questionnaire to evaluate individuals' perceptions of a robot using a modified version proposed by Stafford et al.(Stafford et al., 2014). Participants responded to each question using a 7-point Likert-scale. Higher scores indicate that individuals perceive the robot as having a mind. The modified version is composed of two subscales: mind *agency* (six items; perceived capacity of the robot to recognize emotions, have thoughts, memory, self-control, be moral) and mind *experience* (five items; perceived capacity of the robot to feel pleasure, hunger, pain, and have personality and consciousness).

2.5. Procedure

Participants were tested individually in a quiet environment and completed all measures in one session. Schizophrenia and healthy participants were assessed by a trained psychologist (M.B). Participants sat at a distance of 60 cm to a 17-inch monitor. The experimental task was designed and presented using E-prime software. Participants were instructed to determine whether the stimulus displayed in the screen was positive or negative by pressing one of two buttons in a keyboard (N or C). A sticker was placed on each button showing a positive or a negative signal. The buttons were counterbalanced across participants. Each stimulus was presented during 1 s, followed by a fixation cross which lasted between 0.3 and 0.5 s. Participants performed 300 trials (i.e. 300 pictures) divided in 5 blocks. Thus, each picture appeared 50 times. Subsequently, both groups completed the MPQ and patients completed the PANSS.

2.6. Statistical analysis

We compared groups' characteristics using the Student t or χ^2 tests. A 3 (type of stimulus: human face, robot face, non-face stimulus) × 2 (emotion: positive and negative) × 2 (group: schizophrenia and healthy participants) repeated measures ANOVA was performed on reaction time (RT) and accuracy. Post-hoc analyses were performed using Bonferroni or paired *t*-test. Correlations between RT, number of correct answers and clinical symptoms were analyzed.

RT was calculated as the time interval between the onset of the RT signal and the time when the participant pressed the keyboard to answer it. RTs lower than 0.1 s were also discarded from further analysis. No upper threshold was established since participants had only 1 s to respond. RT data was normally distributed. SPSS (The Statistical Package for the Social Sciences version) 17.0 was use.

3. Results

3.1. Social, demographic and clinical data

No significant differences were found between groups on age, education, and gender. Mind Perception questionnaire's mean and standard deviation is presented in Fig. 3. No significant differences were found between groups (all *p*-values > 0.05).

3.2. Reaction time measures

First, the effect of stimuli type was significant, $F(2, 72) = 112.64$, $p < 0.0001$, $\eta^2 = 0.76$. Post-hoc analysis indicated that both groups were faster when responding to the non-facial stimuli than to the robot and human faces ($p < 0.0001$). Participants were faster when responding to the human's face than to the robot's face ($p < 0.0001$) (Fig. 4).

Second, the effect of group was significant, $F(1, 36) = 10.12$, $p = 0.003$, $\eta^2 = 0.22$. Healthy controls were faster than schizophrenia patients. Third, an interaction between stimuli type and emotion was found, $F(2, 72) = 21.57$, $p < 0.001$, $\eta^2 = 0.37$. Further post-hoc analysis indicated that participants were faster when responding to the positive compared to the negative human face ($p < 0.0001$). Conversely, participants were faster when responding to the negative compared to the positive robot face ($p = 0.001$). No differences were found between positive and negative non-facial stimuli ($p = 0.19$).

Finally, the interaction effect between group and stimulus type, group and emotion, as well as the three-way interaction (group, stimulus type and emotion) were not statistically significant (all *p*-values > 0.05) (Fig. 5).

3.3. Number of corrected answers

A main effect of stimuli type was found, $F(2, 72) = 60.58$, $p < 0.0001$, $\eta^2 = 0.63$. Post-hoc analysis indicated that both schizophrenia patients and healthy controls performed better when responding to neutral stimuli than to the robot face and human face ($p < 0.0001$). A trend toward significance indicated that participants also performed slightly better when responding to the human face compared to the robot's face ($p = 0.052$). Second, the interaction between group and stimuli type was statistically significant, $F(2, 72) = 7.64$, $p = 0.001$, $\eta^2 = 0.17$. Post-hoc analysis indicated that healthy controls statistically outperformed schizophrenia patients only when responding to the human face ($p = 0.032$). A trend toward significance was observed on

Fig. 1. Anthropomorphism in robotics: iCub (EU, © 2010 RobotCub Consortium) - Nexi (USA, © 2015 Personal Robots Group. MIT Media Lab) – HRP4 (Japan, © National Institute of Advanced Industrial Science and Technology) - Kansei (Japan, Graduate student Lei Igarashi smiles in front of a humanoid robot named Kansei, © Meiji University's Robot and Science Institute laboratory) – Dion (China, © Beijing Institute of Technology) – Geminoid HI-1 (Japan, © Hiroshi Ishiguro Laboratories).

the robot face variable ($p = 0.051$) indicating that the patients performed worse than healthy controls. No differences were found on the neutral stimuli ($p = 0.306$). Third, an interaction between stimuli type and emotion was found, $F(2, 72) = 14.14$, $p < 0.001$, $\eta^2 = 0.28$. Additional post-hoc analysis indicated that participants performed better when responding to the positive compared to the negative signal ($p < 0.0001$). Conversely, participants performed better when responding to the negative compared to the positive robot face ($p < 0.0001$). No differences were found between positive and negative human faces ($p = 0.278$). Moreover, differences between robot and human face on accuracy were specific to positive faces ($p = 0.01$).

Finally, the two-way interaction between group and emotion, as well as the three-way interaction (group, stimulus type and emotion) were not statistically significant (all p-values > 0.05).

3.4. Correlations analysis

We tested the correlations between clinical symptoms of patients and reaction time and accuracy. Two significant correlations emerged between negative symptoms and both robot's and human's negative face accuracy (Table 2).

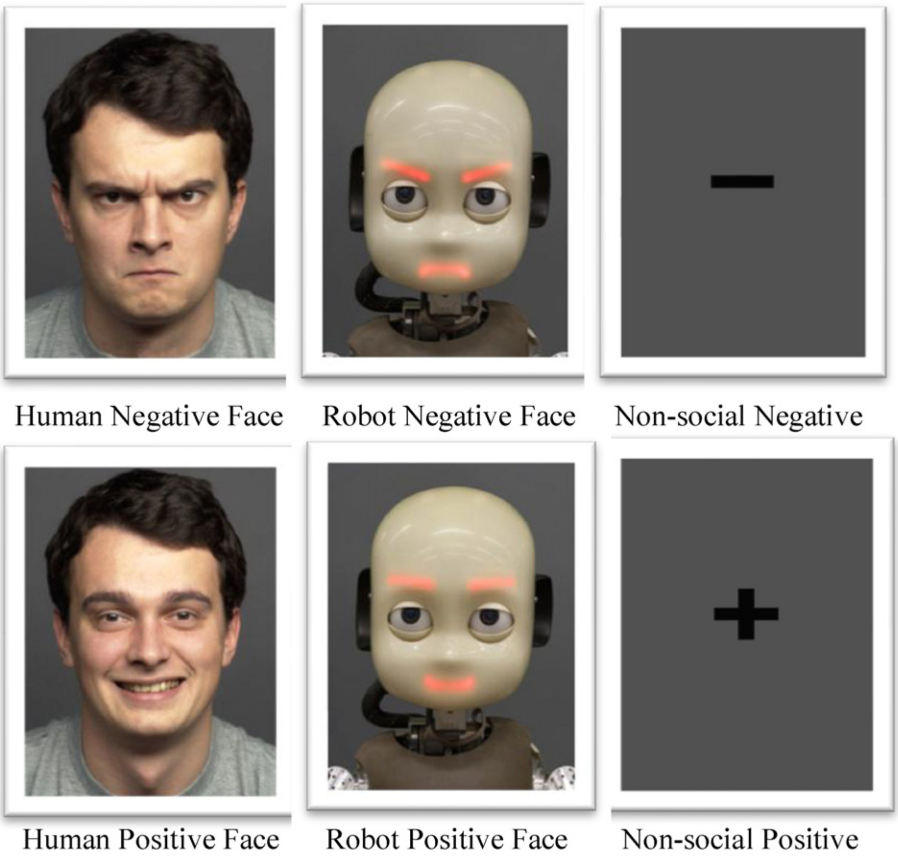

Fig. 2. Examples of stimuli used in the reaction time task.

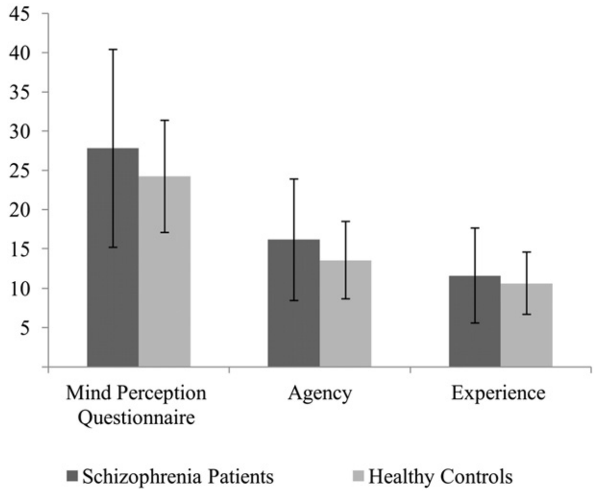

Fig. 3. Mean scores and standard deviation for both healthy controls and schizophrenia patients on the Mind Perception Questionnaire.

Subsequently, we tested the correlations between reaction time and accuracy for the robot face and the MPQ. A significant negative correlation was found between accuracy for the positive robot face and Experience subscale of the MPQ for both schizophrenia patients ($r_s = -0.503$, $p = 0.02$) and healthy controls ($r_s = -0.495$, $p = 0.04$). The more participants perceived the robot as being capable of experiencing things, the worse they performed in the task.

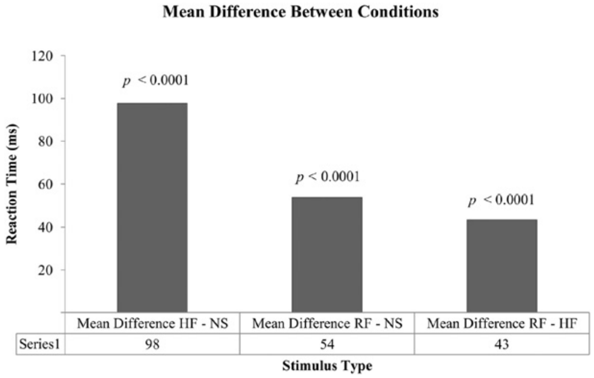

Fig. 5. Mean reaction time and mean difference between the different types of stimuli. HF = Human face. RF = Robot face. NS = Non-face stimulus.

4. Discussion

In human-robot interaction, the question of physical anthropomorphism — how much robots should resemble humans, is still heavily debated (Bardy et al., 2014). In this study, we extended this debate to individuals with schizophrenia, a mental disorder with highly frequent social deficits (Burns & Patrick, 2007). To our knowledge, this study is the first to investigate the ability to recognize the emotional valence of facial expressions displayed by a humanoid robot in comparison to the same human facial expressions in schizophrenia patients.

The main result was that both patients and controls recognized better and faster the emotional valence of human facial expressions

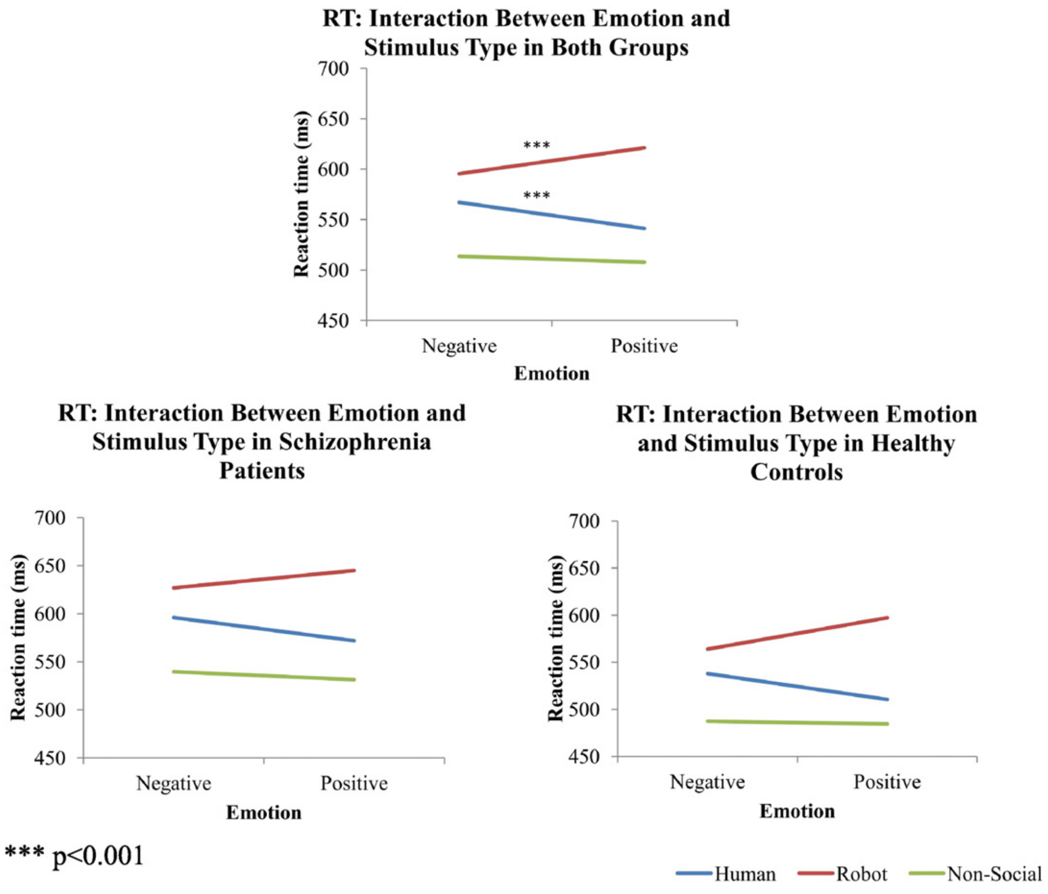

Fig. 4. Mean reaction time for both patients with schizophrenia and healthy controls according to the type of stimulus and emotion.

Table 2
Correlations between clinical symptoms of schizophrenia and emotion recognition measures (RT and Accuracy) for human face, robot face and non-facial stimulus.

Stimulus	Measure	Emotion	Positive symptoms	Negative symptoms δ	General psychopathology
Non-facial	Accuracy	Negative δ	0.078	−0.249	−0.327
		Positive	−0.556**	−0.404	−0.328
	RT	Negative	−0.291	−0.074	0.196
		Positive	−0.242	−0.026	0.055
Human	Accuracy	Negative	−0.416	**−0.446***	−0.353
		Positive	0.225	−0.119	−0.014
	RT	Negative	−0.331	−0.220	−0.070
		Positive	−0.405	−0.173	0.097
Robot	Accuracy	Negative	−0.010	**−0.566****	−0.339
		Positive δ	−0.317	−0.166	−0.271
	RT	Negative	−0.075	0.019	0.053
		Positive	−0.069	−0.307	0.119

Notes: $^{*}p < 0.05$; $^{**}p < 0.01$.
δ: Spearman Correlations.

compared to humanoid facial expressions (iCub). The facial expressions of iCub were rated as conveying less clear affect, as indexed by slower reaction times and less accurate responses. This result seems in contradiction with the results of Dubal et al. (2011). In this electrophysiological study, participants were asked to discriminate if pictures of humans or robots represented a neutral or an emotional expression. At the behavioural level, emotion shortened reaction times similarly for robotic and human stimuli. Furthermore, event-related potentials evoked by human expressions of emotion and by emotion-like patterns of the robot did not differ, suggesting that brain responded similarly to human facial emotion and to non-anthropomorphic emotional signals (Dubal et al., 2011). Nonetheless, in our study we used a behavioural task (i.e. recognition task) characterized by reactions times and accuracy measures, in which participants did not have to discriminate between an emotional vs. a non-emotional stimulus but had to discriminate the positive or negative valence related to stimuli. Furthermore we used a humanoid robot whereas Dubal et al. (2011) used a non-humanoid robot. We propose that the humanoid character of iCub is the main contributor to the discrepancy between these two studies. This is indirectly supported by the work of Chaminade et al. (2010) using a humanoid robot. Even if they did not use a recognition task, which prevents a direct comparison with our study, the authors showed that facial emotion gestures were perceived by healthy participants as being more emotional when expressed by a human than by a humanoid robot. In addition, using fMRI, they found a reduced brain activity (i.e. left anterior insula and the orbital cortex) for robot facial emotion in comparison to facial emotion displayed by a human.

Interestingly, we found different patterns of response to the robot's face and to the human's face when the emotional valence was considered. More specifically, we found that for human emotions, positive stimuli (happiness) elicited quicker reaction times than negative stimuli (anger) in both controls and schizophrenia patients. Such facilitation is in line with the literature of behavioural studies using human emotional faces as stimuli (Brosch et al., 2008; Nummenmaa & Calvo, 2015). Conversely, we found the opposite pattern for robot stimuli. Participants were faster when responding to the negative face of iCub compared to its positive face, confirming the findings of Pais et al. (2013). Such results are consistent with a recent meta-analysis conducted by Nummenmaa and Calvo (2015) who showed that photographic face stimuli resulted in a happy face advantage whereas schematic face stimuli (i.e. 'smiley' faces or simple schematic line drawings of faces) yielded an opposite, non-happy or angry face advantage.

At group level we found that healthy controls outperformed schizophrenia patients when responding to human and robot faces, regardless of the emotional valence. That is, controls performed significantly better than schizophrenia patients when seeing a negative robot face, a positive human face, and a non-face signal.

Another important result was the correlation found in both groups between accuracy for the positive robot face and the "experience" dimension of the mind perception questionnaire. The more participants perceived the robot as being capable of experiencing things and having a mind, the worse they performed in the task. The uncanny valley theory (UVT) proposed by Mori (1970) suggests a non-linear relationship between robotic anthropomorphism and affinity. UVT refers to that point along the chart of robot–human likeness where a robot looks and acts nearly—but not exactly—like a human. This subtle imperfection causes people's feelings toward robots to veer from fondness to revulsion. This concept captures the idea that an almost human-looking robot will seem overly strange and unnerving to some human beings, and will thus fail to evoke an empathic response toward the humanoid agent. This result fits well with the results of Gray and Wegner (2012). Using the Mind Perception Questionnaire, they showed in three experiments that robots become unnerving when people ascribe to them experience rather than agency, suggesting that feelings of uncanniness are tied to perceptions of the robot's capacity to feel and sense. In addition, as uncanniness negatively impacts response speed (Takahashi et al., 2015), we can hypothesize that the anthropomorphic aspect of iCub and more specifically its ability to express emotions and sensations could have induced a feeling of uncaninness resulting in increased RT during the recognition of iCub facial positive emotions. This finding also suggests that positive but not negative facial emotions induce an unnerving feeling. This hypothesis needs to be directly tested with uncaninness self-report indices in future studies (Cheetham et al., 2015). Another interesting result was the negative association between negative symptoms and both robot's and human's negative face accuracy in schizophrenia patients. This result is in line with previous studies showing that negative symptoms are the symptoms most associated with deficits in face processing (Bortolon et al., 2015). From a clinical perspective, clinical symptoms are important variables to take into account in future studies using socially interactive robots in populations with facial processing deficits such as autism or schizophrenia. As social cues and particularly facial emotions may facilitate the believability of a robot's social capability (Breazeal, 2002), one can assume that the presence of high level of negative symptoms in patients could negatively impact the acceptance and use of humanoid robots in this mental disorder.

However, our results must be considered as exploratory since no study exists on this subject in schizophrenia. Lazzeri et al. (2015) recently showed a trend in healthy participants to better recognize expressions performed by a robot than 2D photos or even 3D models. Future studies should explore whether schizophrenia patients and healthy participants interpret differently facial expressions shown as 2D photo or performed by a physical robot. In addition we only explored the recognition of two emotions (e.g. anger and happiness). It will be interesting in future studies to explore the ability for schizophrenia patients to recognize other universal facial emotions (e.g. sadness, disgust, fear) performed by humanoids robot in real world setting. Similarly, facial communicative signals comprise not only facial expressions, but also head gestures, and gaze. Future studies are needed to explore these social cues in individuals with schizophrenia. Another limit is our small sample size. Therefore, the results should only be generalized with caution. Finally, our results are specific to iCub and cannot be generalized to other humanoid robots.

5. Perspectives

We acknowledge that further development is needed to develop socially intelligent robot able to increase social functioning in mental disorders with social impairments. In this study we have studied an isolated cognitive element underlying social interaction. As highlighted by some researchers (Barsalou et al., 2007), human-robot interactions and social interactions in general relate to a complex set of processes (e.g. perception, inference, action, emotion, reward) that work together in a coordinated manner rather than in isolation. Thus, studying the coordination of different social processes is probably central to understanding human-robot interaction (Barsalou et al., 2007). As written above, this protocol is an experiment part of another protocol of the AlterEgo project in which participants have to actually perform a motor task with the iCub robot. The AlterEgo European project aims at producing a new robotic and avatar-based clinical method able to enhance social interaction of patients suffering from social disorders. Based on recent work in social robotics and neurosciences, the main hypothesis guiding AlterEgo states that if a patient faces an artificial agent similar to her/him, s/he will increase his/her engagement in a social interaction. This similarity entails for the artificial agent resemblance of patterns of bodily actions, both in space and time, to the one displayed by the patient. The avatar, or robot, will have to move to match the way the patient moves, and this convergence will encourage the patient to close the "social" gap with the artificial agent required for the exchange. We hope that this project should lead to developments in fundamental research in social interactions of normal individuals and psychiatric patients and new engineering designs leading to several mental health and industrial robotic applications.

Contributors

Stéphane Raffard, Robin Salesse and Mahdi Khoramshahi contributed to the study design. Catherine Bortolon, and Marianna Burca recruited and assessed the patients. Catherine Bortolon and Mahdi Khoramshahi performed the statistical analysis. Stéphane Raffard wrote the first draft. Stephane Raffard, Catherine Bortolon, Mahdi Khoramshahi, Robin Salesse and Valérie Macioce prepared the final manuscript, with feedback from the other authors.

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Conflict of interest

We wish to confirm that there are no known conflicts of interest associated with this publication and there has been no significant financial support for this work that could have influenced its outcome.

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References

Allott, K.A., Rice, S., Bartholomeusz, C.F., Klier, C., Schlögelhofer, M., Schäfer, M.R., Amminger, G.P., 2015. Emotion recognition in unaffected first-degree relatives of individuals with first-episode schizophrenia. Schizophr. Res. 161, 322–328.

Bardy, B.G., Salesse, R.N., Gueugnon, M., Zhao, Z., Lagarde, J., Marin, L., 2014. Movement similarities and differences during social interaction: the scientific foundation of the ALTEREGO European Project. Proceedings of the 2014 IEEE International Conference on Systems, Man and Cybernetics 2014, pp. 786–791.

Barkl, S.J., Lah, S., Harris, A.W., Williams, L.M., 2014. Facial emotion identification in early-onset and first-episode psychosis: a systematic review with meta-analysis. Schizophr. Res. 59, 62–69.

Barsalou, L., Breazeal, C., Smith, L., 2007. Cognition as coordinated non-cognition. Cogn. Process. 8, 79–91.

Bortolon, C., Capdevielle, D., Raffard, S., 2015. Face recognition in schizophrenia disorder: a comprehensive review of behavioral, neuroimaging and neurophysiological studies. Neurosci. Biobehav. Rev. 53, 79–107.

Breazeal, C.L., 2002. Designing Sociable Robots. MIT Press, Cambridge, MA.

Breazeal, C., 2003. Emotion and sociable humanoid robots. Int. J. Hum. Comput. Stud. 59, 119–155.

Brosch, T., Sander, D., Pourtois, G., Scherer, K.R., 2008. Beyond fear: rapid spatial orienting toward positive emotional stimuli. Psychol. Sci. 19, 362–370.

Burns, T., Patrick, D., 2007. Social functioning as an outcome measure in schizophrenia studies. Acta Psychiatr. Scand. 116, 403–418.

Chaminade, T., Okka, M.M., 2013. Comparing the effect of humanoid and human face for the spatial orientation of attention. Front. Neurorobot. 3 (7), 12.

Chaminade, T., Zecca, M., Blakemore, S.J., Takanishi, A., Frith, C.D., Micera, S., Dario, P., Rizzolatti, G., Gallese, V., Umiltà, M.A., 2010. Brain response to a humanoid robot in areas implicated in the perception of human emotional gestures. PLoS One 5 (7), e11577.

Chan, R.C.K., Li, H., Cheung, E.F.C., Gon, Q., 2010. Impaired facial emotion perception in schizophrenia: a meta-analysis. Psychiatry Res. 178, 381–390.

Cheetham, M., Wu, L., Pauli, P., Jancke, L., 2015. Arousal, valence, and the uncanny valley: psychophysiological and self-report findings. Front. Psychol. 15 (6), 981.

Dautenhahn, K., 2007. Socially intelligent robots: dimensions of human-robot interaction. Philos. Trans. R. Soc. Lond. Ser. B Biol. Sci. 362, 679–704.

Delerue, C., Laprévote, V., Verfaillie, K., Boucart, M., 2010. Gaze control during face exploration in schizophrenia. Neurosci. Lett. 482, 245–249.

Del-Monte, J., Raffard, S., Salesse, R.N., Marin, L., Schmidt, R.C., Varlet, M., Bardy, B.G., Boulenger, J.P., Gély-Nargeot, M.C., Capdevielle, D., 2013. Nonverbal expressive behaviour in schizophrenia and social phobia. Psychiatry Res. 210, 29–35.

Dubal, S., Foucher, A., Jouvent, R., Nadel, J., 2011. Human brain spots emotion in non humanoid robots. Soc. Cogn. Affect. Neurosci. 6, 90–97.

Ebner, N.C., Riediger, M., Lindenberger, U., 2010. FACES—a database of facial expressions in young, middle-aged, and older women and men: development and validation. Behav. Res. Methods 42, 351–362.

Edwards, J., Jackson, H.J., Pattison, P.E., 2002. Emotion recognition via facial expression and affective prosody in schizophrenia: a methodological review. Clin. Psychol. Rev. 22, 789–832.

Frith, C., 2009. Role of facial expressions in social interactions. Philos. Trans. R. Soc. Lond. Ser. B Biol. Sci. 364, 3453–3458.

Gray, K., Wegner, D.M., 2012. Feeling robots and human zombies: mind perception and the uncanny valley. Cognition 125, 125–130.

Gray, H.M., Gray, K., Wegner, D.M., 2007. Dimensions of mind perception. Science 315 (5812), 619.

Jordan, K., King, M., Hellersteth, S., Wirén, A., Mulligan, H., 2013. Feasibility of using a humanoid robot for enhancing attention and social skills in adolescents with autism spectrum disorder. Int. J. Rehabil. Res. 36, 221–227.

Kay, S.R., Fiszbein, A., Opler, L.A., 1987. The positive and negative syndrome scale (PANSS) for schizophrenia. Schizophr. Bull. 13, 261–276.

Khoramshahi, M., Shukla, A., Raffard, S., Bardy, B.G., Billard, A., 2016. Role of gaze cues in interpersonal motor coordination: towards higher affiliation in human-robot interaction. Plos One (in press).

Lavelle, M., Healey, P.G., McCabe, R., 2013. Is nonverbal communication disrupted in interactions involving patients with schizophrenia? Schizophr. Bull. 39, 1150–1158.

Lazzeri, N., Mazzei, D., Greco, A., Rotesi, A., Lanatà, A., De Rossi, D.E., 2015. Can a humanoid face be expressive? A psychophysiological investigation. Front. Bioeng. Biotechnol. 26 (3), 64.

Lee, K.M., Jung, Y., Kim, S.R., 2006. Are physically embodied social agents better than disembodied social agents?: the effects of physical embodiment, tactile interaction, and people's loneliness in human-robot interaction. Int. J. Hum. Comput. Stud. 64, 962–973.

Li, J., Chignel, M., 2011. Communication of emotion in social robots through simple head and arm movements. Int. J. Soc. Robot. 3, 125–142.

Liao, W.W., Wu, C.Y., Hsieh, Y.W., Lin, K.C., Chang, W.Y., 2012. Effects of robot-assisted upper limb rehabilitation on daily function and real-world arm activity in patients with chronic stroke: a randomized controlled trial. Clin. Rehabil. 26, 111–120.

Little, A.C., Jones, B.C., DeBruine, L.M., 2011. The many faces of research on face perception. Philos. Trans. R. Soc. Lond. Ser. B Biol. Sci. 366, 1634–1647.

Lütkebohle, I., Hegel, F., Schulz, S., Hackel, M., Wrede, B., Wachsmuth, S., Sagerer, G., 2010. The Bielefeld anthropomorphic robot head "Flobi". Proceedings of the IEEE International Conference on Robotics and Automation (ICRA), pp. 3384–3391.

Mackinnon, A., Mulligan, R., 2005. The estimation of premorbid intelligence levels in French speakers. Encéphale 31, 31–43.

Metta, G., Natale, L., Nori, F., Sandini, G., Vernon, D., Fadiga, L., von Hofsten, C., Rosander, K., Lopes, M., Santos-Victor, J., Bernardino, A., Montesano, L., 2010. The iCub humanoid robot: an open-systems platform for research in cognitive development. Neural Netw. 23, 1125–1134.

Mori, M., 1970. The uncanny valley. Energy 7, 33–35.

Nummenmaa, L., Calvo, M.G., 2015. Dissociation between recognition and detection advantage for facial expressions: a meta-analysis. Emotion 15, 243–256.

Pais, A.L., Argall, B.D., Billard, A.G., 2013. Assessing interaction dynamics in the context of robot programming by demonstration. Int. J. Robot. Res. 5, 477–490.

Pan, Y., Steed, A., 2016. A comparison of avatar, video, and robot-mediated interaction on users' trust in expertise. Front. Robot. AI. 3, 12.

Raffard, S., Salesse, R.N., Marin, L., Del-Monte, J., Schmidt, R.C., Varlet, M., Bardy, B.G., Boulenger, J.P., Capdevielle, D., 2015. Social priming enhances interpersonal synchronization and feeling of connectedness towards schizophrenia patients. Sci. Rep. 5, 8156.

Ruocco, A.C., Reilly, J.L., Rubin, L.H., Daros, A.R., Gershon, E.S., Tamminga, C.A., Pearlson, G.D., Hill, S.K., Keshavan, M.S., Gur, R.C., Sweeney, J.A., 2014. Emotion recognition deficits in schizophrenia-spectrum disorders and psychotic bipolar disorder: findings from the bipolar-schizophrenia network on intermediate phenotypes (B-SNIP) study. Schizophr. Res. 158, 105–112.

Russell, J.A., Bachorowski, J.A., Fernandez-Dols, J.M., 2003. Facial and vocal expressions of emotion. Annu. Rev. Psychol. 54, 329–349.

Salva, G.N., Vella, L., Armstrong, C.C., Penn, D.C., Twamley, E.W., 2012. Deficits in domains of social cognition in schizophrenia: a meta-analysis of the empirical evidence. Schizophr. Bull. 39, 979–992.

Scassellati, B., Admoni, H., Matarić, M., 2012. Robots for use in autism research. Annu. Rev. Biomed. Eng. 14, 275–294.

Sheehan, D.V., Lecrubier, Y., Sheehan, K.H., Amorim, P., Janavs, J., Weiller, E., Hergueta, T., Baker, R., Dunbar, G.C., 1998. The mini-international neuropsychiatric interview (M.I.N.I.): the development and validation of a structured diagnostic psychiatric interview for DSM-IV and ICD-10. J. Clin. Psychiatry 59, 22–33.

Shibata, T., Wada, K., 2011. Robot therapy: a new approach for mental healthcare of the elderly — a mini-review. Gerontology 57, 378–386.

Stafford, R.Q., MacDonald, B.A., Jayawardena, C., Wegner, D.M., Broadbent, E., 2014. Does the robot have a mind? Mind perception and attitudes towards robots predict use of an eldercare robot. Int. J. Soc. Robot. 6, 17–32.

Takahashi, K., Fukuda, H., Samejima, K., Watanabe, K., Ueda, K., 2015. Impact of stimulus uncanniness on speeded response. Front. Psychol. 21 (6), 662.

Trémeau, F., 2007. A review of emotion deficits in schizophrenia. Dialogues Clin. Neurosci. 8, 59–70.

Varlet, M., Marin, L., Raffard, S., Schmidt, R.C., Capdevielle, D., Boulenger, J.P., Del-Monte, J., Bardy, B.G., 2012. Impairments of social motor coordination in schizophrenia. PLoS ONE 7, e29772.

Wainer, J., Feil-Seifer, D., Shell, D., Matarić, M.J., 2006. The role of physical embodiment in human-robot interaction. IEEE Proceedings of the International Workshop on Robot and Human Interactive Communication. Hatfield, United Kingdom, pp. 117–122.

Wainer, J., Feil-Seifer, D., Shell, D., Matarić, M.J., 2007. Embodiment and human-robot interaction: a task-based perspective. 16th IEEE International Conference on Robot & Human Interactive Communication, pp. 872–877.

Wendt, C., Berg, G., 2009. Nonverbal humor as a new dimension of HRI. Proceedings of The 18th IEEE International Symposium on Robot and Human Interactive Communication (RO-MAN), pp. 183–188.