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Emergent Emotional and Verbal Strategies in Autism are Based on Multimodal Interactions with Toy Robots in Free Spontaneous Game Play

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***Abstract*—Under the hypothesis that multimodal cognitive processes could be though as a building block from which language could emerge in autistic children, we used a toy robot with and without free game play. A range of cognitive nonverbal criteria including eye contact, touching, manipulation, and posture were analyzed; the frequency of the words and verbs was calculated. Only during game play the children interact quasi-continually and multimodally with the robot and express language. A positive correlation exists between expressive language and multimodal cognitive processes only when free game play with the robot is possible. The data suggest that a mobile toy robot could be used as a neural orthesis in order to improve autistic children's brain multimodal activity and incite them to express language.**

I. INTRODUCTION

Interactive robots are utilized in training, education and neurorehabilitation of autistic children. The aim of the present study is to analyze the relationship between multimodal cognitive nonverbal and verbal interactions in middle and moderate autistic children.

Autism spectrum disorder is a complex and heterogeneous neurological deficit which affects cognitive functioning but also emotional and social behavior as well as language development [1]. Language problems appear early and persist. Half the population of children with autism do not develop expressive language. However, when autistic children do acquire expressive language, it is often lacking any depth, it is echolalic and it is characterized by a lack imagination [2]. Genetic studies have highlighted the complexity of the genetic architecture underlying autism [3]. Post-modern analysis has demonstrated evidence of altered brain development which strongly affects the formation of a neural network. Functional neuroimaging studies have given evidence of reduced activity in amygdala neural development [4]; impaired integrity of white matter tracking development connections among temporal areas [5]; an increase in activation of primary motor and sensory processing [6]; atypical network activity and connectivity within temporal and orbitofrontal brain growth [7]. Multimodal in nature, these posterior and anterior cortical areas are involved in complex cognitive functions such as perception, emotion, social communication and language.

Autistic children show difficulty in their play activities, as play activities necessitate multimodal interactions [8]. Different approaches are being utilized to better understand the capacity of autistic children to interact and play with a robot. The Aurora's project aim is to create a tool based on an autonomous robot (Labo-1, Kaspar, Robota doll, for example) that convinces autistic children to engage in a process of interaction [9]. Tito [10], Roball [11], Keepon [12], were employed in social interaction; Roboto caused behavior imitation on the part of the autistic child [13]; Pleo reinforced social behavior [14]. These studies have shown that animate robots, humanoid or not, using different stimulations encourage interaction in autistic children. Even if quantitative metrics of social response for autism diagnosis including robots were developed [15]; only one study has used a quantitative technique for analyzing robot child interaction for therapy [16]. With the exception of Labo-1 in the Aurora project, Roball in Michaud's project and GIPY I in our studies so far, only fixed robots have been utilized which essentially reduce the child's spontaneity and self–expression in game play.

Using a multimodal cognitive nonverbal approach (visual, tactile, manipulation, posture) [17] which was also related to an emotional one [18], we have shown that a mobile toy robot "GIPY I" could be used as a neural mediator to bring neurocognitive improvements to autistic children. The multimodal cognitive interactions could be thought of as the building block from which expressive language could emerge. In order to test this hypothesis, we used a new mobile toy robot named "POL" which incites the child to engage in interaction and express language. On the hypothesis that autistic children will be in quasi-constant interaction with the robot which could give the child the possibility to express him/her self, the relationship between multimodal cognitive nonverbal criteria (visual, tactile, manipulation and posture) with expressive language behavior (positive or not) was analyzed in the free spontaneous game play.

Beginning with the design of the study, we will continue with the analysis of multimodal cognitive nonverbal and verbal data. We will describe the correlation between multimodal cognitive nonverbal

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interactions and expressive language before discussing the embodiment of multimodal information during free spontaneous game play between a mobile toy robot and autistic children.

II. METHOD

A. Participants

Eleven children (8 boys and 3 girls) participated in this study. Their chronological ages ranged from 7 to 8 years old (mean 7.3 years; sd 6 months); their developmental age from 5 to 6 years old (mean 6 years; sd 4 months). The mean age when first words appeared was 38 months (sd 5 months). The children were diagnosed according to the DSM IV-TR criteria of autism [19]. The Childhood Autism Rating Scale [20] had been administrated at the age of 6 years by an experienced psychiatrist. The present population is composed by middle and moderate autistic children. They are all verbal (table I). The study was approved by the local ethics committee and was in accordance with the Helsinki convention. Anonymity was guaranteed.

TABLE I. GENERAL CHARACTERISTIC OF POPULATION

subjects	***developmental age***	***sex***	***C.A.R.S*** a
A.B	5.7	M	34
D.H	6.2	M	35
J.E	5.6	F	32
R.K	6.5	M	36
B.M	5.9	M	36
G.B	6.7	M	34
A.R	5.8	F	32
R.V	6.7	M	36
T.L	5.7	F	34
K.B	5.7	M	33
A.M	5.5	M	35

a Childhood Autism Rating Scale

B. Robot

A mobile robot, called "POL", which is animal-shaped, was used: a mobile chicken. An operator manipulated the robot via a wireless control. The robot could move forward, backward and turn on itself at low speed.

C. Protocol

The study takes place in a room which is familiar to all the children. We have defined two conditions: one with and another without game play. The duration of each condition was 10 minutes (figure 1).

"*Without game play":* Children's observation behavior with the immobile robot placed on the ground beforehand, in the center of the room. There is no game play session.

"With game play": Children's observation with the mobile robot. The robot was placed on the ground beforehand, in the center of the room. The game play session began as follows: when the child and the adult entered the room, the teleoperated robot carried out three movements (move forward, move back, 360° swivel). As in real human interaction, the child and the robot altered their responses. All movements were constant and standardized (see also [17], [18]).

The two conditions were counterbalanced across the children. The inter-condition interval was about 2 minutes.

For the needs of the analysis, all the sequences were recorded.

D. Analysis

For both conditions, two dependent variables (DV) were utilized: a) the duration of child-robot interaction; b) the frequency of words and verbs the children expressed.

For the first DV, four criteria were defined: 1) eye contact (looking at the robot), 2) touch (touching the robot without manipulating it), 3) manipulation (operating the robot), 4) posture (changing corporal position toward the robot) (table II). We calculated the duration of all the characteristics of each criterion. This was defined as the duration between the onset time and the offset time of each child's behavior toward the robot.

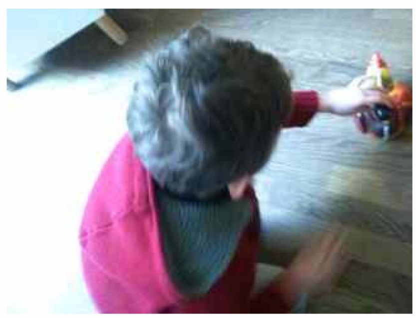

Figure 1.Child during game play with "POL" robot

In both conditions, the duration of each criterion, (onset time and the offset time of each child's behavior toward the robot) was calculated in seconds and was considered independently. Concerning, for example, the characteristic "s/he looks at the immobile robot" ("eye contact") the onset time corresponded to the time when the child looked at the robot and the offset time to the moment when the child looked away from the robot. We calculated the duration of all the characteristics of each criterion (table II). We summed up the duration corresponding to each criterion. Only the total duration is presented in the results section.

TABLE II. CHARACTERIZATION OF EACH COGNITIVE CRITERION

posture	*touching*	*eye contact*	*manipulation*
S/he sits downs in front of robot; S/he bends towards the robot; S/he bends over the robot; S/he squats and bends over the robot; S/he steps over the robot	S/he puts the left hands on the robot; S/he puts the right hand on the robot; S/he touches the robot with both hands	S/he looks at the immobile robot; S/he watches the robot turning; S/he watches the robot going away; S/he watches the robot approaching	S/he seizes and blocks the robot with the two hands; S/he lifts of the robot; S/he stops the robot with both hands; S/he catches the robot; S/he returns the robot; S/he tilts the robot around itself and looks of its wheel; S/he puts back the robot upright

For the second DV, we have calculated the total number of expressive language (words and verbs, e.g., nice, came her) and the number of words and verbs which express positive emotion (e.g. nice).

Two independent judges unfamiliar with the aim of the study completed the observations of the whole protocol (*"with"* and *"without"* game play) performing the analyses of video sequences with Elan software. Prior to assessing the protocol improvement, inter-judge reliability was assessed to ensure that both judges who analyzed videotapes were consistent in their analyses. The inter-judge reliability was assessed using intra-class coefficients to make the comparison between them. The inter-judge reliability was good (Cohen's kappa =0.67).

III. RESULTATS

The distribution of duration according to the criteria in the two conditions approximates a non parametric shape. With such distribution, the median has been chosen as a central index for the comparisons. The statistical comparisons have been conducted with the Chi-Square Test ($\chi 2$ Test); relation between cognitive nonverbal interactions and verbal expression was analyzed with the nonparametric Spearman rank correlation coefficient (Spearman's ρ correlation coefficient).

In *"without game play"* condition, the children interact less with the robot (1 minute and 57 sec) than in *"with game play"* (8 minutes and 40 seconds) ($\chi 2=6.89$, $p<0.01$). The results show that the median duration of "eye contact" is longer in the *"with game play"* condition (4.27 sec) than in the *"without game play"* (1.48 sec) ($\chi 2=7.12$, $p<0.01$). Similarly, the median duration of "touching", "manipulating" and "posture" is higher in *"with game play"* condition than in *"without game play"* condition i.e., 2.36 sec vs. 1.24 sec; 1.16 sec vs. 0.66 sec; 1.51 sec vs. 0.97 sec respectively; ($\chi 2=6.07$, $p<0.025$; $\chi 2=4.7$, $p<0.05$; $\chi 2=4.01$, $p<0.05$ respectively) (figure 2).

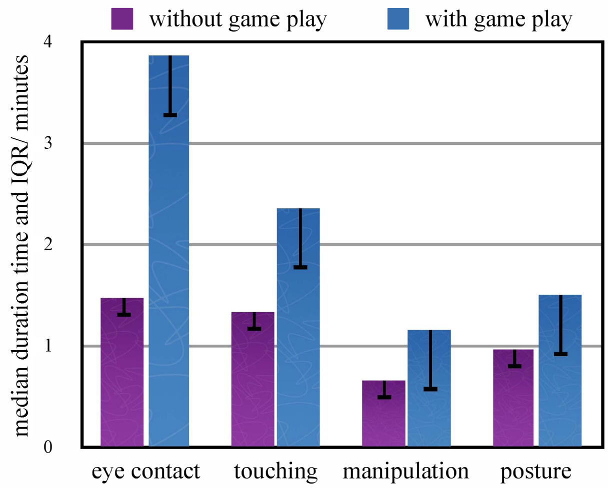

Figure 2. Duration of multimodal cognitive nonverbal interactions

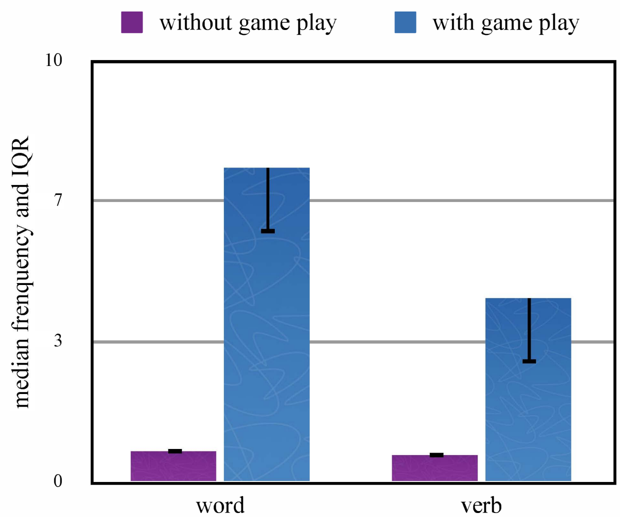

Figure 3. Median frequency of words and verbs

As the figure 3 shows expressive language was more frequent in *"with game play"* condition (7.45 median frequency for words; 4.36 for verbs) than in *"without game play"* condition (0.73 median frequency for words; 0.64 for verbs) ($\chi 2=7.16$, $p<0.01$ for the words; $\chi 2=6.99$, $p<0.01$ for the verbs) (figure 3). Only in *"with game play"* condition, the children express three words (nice, beautiful, good) and one verb (like) which involve positive emotion ($\chi 2$=3.99, p<0.05 for the words; $\chi 2$=3.88, p<0.05 for the verbs).

A positive correlation exists between expressive language (words and verbs) and multimodal cognitive information in the *"with game play"* condition (Spearman's ρ correlation coefficient=0.747, p=0.01 one-tailed Test) (figure 4).

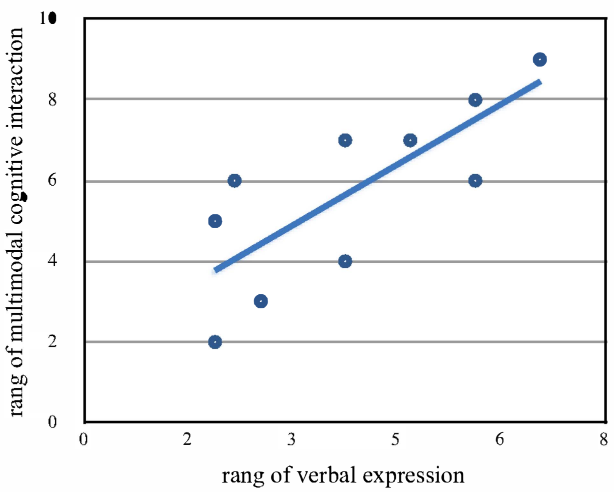

Figure 4. Relation between multimodal cognitive nonverbal and verbal (positive and neutral) information

In contrast, there is no positive correlation between the two variables in *"without game play"* condition (Spearman's ρ correlation coefficient=0.23, p >0.05 one-tailed Test).

IV. Discussion

The present paper analyzes the multimodal cognitive nonverbal and verbal interactions between a mobile toy robot and middle and moderate autistic children with and without free game play. Our data show that the child-robot interaction is quantitatively and qualitatively continual only in free spontaneous game play. Precisely, we found that the duration of multimodal cognitive nonverbal interactions (visual contact, manipulation, touching, posture) is longer when free spontaneous game play with the robot is possible (with game play condition) than when game play is impossible (without game play condition). Consistent with previous studies ([17], [18]), these new results show, once again, that a mobile toy robot engages autistic children in multimodal nonverbal interactions (visual, tactile, manipulation, posture). Taken together, these studies clearly demonstrate that autistic children's behavioral interaction with a mobile robot changes over a period of time. Our suggestion is (as it has been developed in our previous studies) that a mobile toy robot could help autistic children to reduce repetitive and stereotypical behavior. Free game play which is very close to a everyday life situation encourages autistic children to interact with the robot in a spontaneous manner [21].

Consistent with the above is the fact that language is expressed only during game play. Even if the children of our study suffer from middle or moderate autism and are verbal, these results show that the expression of language is possible when the children interact with the robot (in free game play) using a multimodal mode. In the same vein, children produced three words and one verb which connote positive emotion only during game play. Moreover, positive correlation between multimodal cognitive nonverbal information and verbal expression is significant when the children spontaneous interact with the mobile robot. As such, these new data, are coherent with our hypothesis suggesting that multimodal cognitive nonverbal interactions could be considered as the basis of expressive language. The data also tell us that a mobile robot could not only be used as a mediator for social nonverbal [17] and emotional interaction ([18], [21]) but also for verbal expression which is the distinguishing characteristic of the inter-human communication. This is a comforting issue with regard to the potential of human-robot interaction. As such, the data suggest, that more mobile that immobile robots could be efficient for training, education and rehabilitation of autistic children. In other words, an artificial environment such as a mobile toy robot could provide the source of emergence of multimodal cognitive nonverbal information, which in turn, could be combined with emotional [18] and verbal information in a coordinated manner. The mobile robot, i.e., neural mediator, could pave the way for the development of synergistic dialogues between autistic children and human environment.

The data we report converge to say that autistic behavior can be improved via artificial environments, like mobile robots. This is coherent with the assumption that cognitive nonverbal/verbal and emotional development is the result of a complex process with three foci at least, one in the central nervous system, one in the mind and one in the child's dynamic interactions with the environment [21]. The human brain undoubtedly has its own dynamics that allows neurons to interact, which in turn, affects the development and function of the brain areas [8]. In the case of autism, the brain activity is characterized by an hypofunctioning. An artificial environment like a mobile robot, i.e., neural mediator (also named orthesis) seems improve the neural activity (and consequently) the behavior of autistic children: autistic children interact with the robot multimodally.

Our hypothesis is that this emerging brain multimodality is crucially shaped by the children's interactions with the environment. Nonverbal cognition, language and emotion develop at the interface between neural processes. They arise from the dynamic interaction between the developing brain and the artificial environment, i.e., the robot [21].

Our approach, actually in development, attempts to understand "how" artificial environments could be considered as the root of neuronal organization and reorganization ([8], [21]). Based on the brain's intrinsic properties, neuroplasticity and the fact that the brain is neurodynamic, our studies try to demonstrate that a mobile robot could be used as a neural orthesis, i.e., neural mediator in order to support the embodiment of cognitive nonverbal, emotional and verbal information processing.

To our knowledge, this data represents some of the first to analyze the relationship between multimodal cognitive nonverbal information with language expression during spontaneous free game play in middle and moderate autistic children using a mobile toy robot.

V. Conclusion

The present study is a part of our project actually in development which concerns multimodal representations in typically and atypically developing children using natural and artificial environments rented possible via robots. We need to better understand the base and the nature of the verbal expression we observed. Future studies should extend this work through systematic analyses within a larger sample of autistic children.

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