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RESEARCH PAPER

Brain signal evaluation of children with Autism Spectrum Disorder in the interaction with a social robot

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Abstract This work consists of a pilot study in which brain signals captured by electroencephalography (EEG) of children diagnosed with Autism Spectrum Disorder (ASD) are evaluated during the interaction with a social robot. Social skills and interaction of children with ASD with the robot are proposed and assessed, using quantitative scale and images recorded by video cameras. During interaction with the robot, results show high activation of alpha and beta rhythms in brain regions important to social skills. Quantitative scales indicate a positive children–robot interaction and point out the social robot as a potential tool to stimulate social skills and facilitate the interaction with other people.

Introduction

Autism Spectrum Disorder (ASD) is a neurodevelopmental disorder characterized by essential features as pervasive and sustained impairments in communication and social interaction, besides restricted and repetitive patterns of behavior, interests, or activities (American Psychiatric Association, 2013). Deficits in social–emotional reciprocity are noted specifically in young children with this disorder, manifesting little or no initiation of social interaction and no sharing of emotions, along with reduced or absent imitation of others' behavior as well as reduction of eye gaze and facial expressions (American Psychiatric Association, 2013; Bal et al., 2010; Kanner, 1943). Although yet there is no cure for people who fall on the autism spectrum (Perry et al., 2001; Barnes & McCabe, 2012), there are therapies based on social features applied to improve behavioral disorders exhibited by these individuals and, thereby, increase their life quality and independence (Dautenhahn & Werry, 2004; Kozima, Michalowski, & Nakagawa, 2009; Scassellati, Admoni, & Matarić, 2012).

Recently, robots have been developed for diagnostics, therapies and stimulation of social and communication skills in children with ASD (Cabibihan, Javed, & Aljunied, 2013;

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Dautenhahn & Werry, 2004; Kim et al., 2013; Kozima et al., 2009; Scassellati et al., 2012; Scassellati, 2007). As an aid to pedagogical treatments, robots can present many functions that allow an optimistic interaction with these children, calling their attention and stimulating them to get contact with the surrounding environment (Robins, Ferrari, et al., 2010; Scassellati et al., 2012). Examples of social robots are KASPAR, ROBOTA, PLEO and KEEPON (Duquette, Michaud, & Marcier, 2008; Kim et al., 2013; Kozima et al., 2009; Robins, Amirabollahian, Ji, & Dautenhahn, 2010). The interaction between children with ASD and robot has shown to be positive, since robots can be programmed to be more predictable, simpler and easier to understand than humans (Duquette et al., 2008; Robins, Amirabollahian, et al., 2010). Moreover, taking into account the social impairment in the ASD involving the interpersonal interaction (DeRosier, Swick, Davis, McMillen, & Matthews, 2011; White, Keonig, & Scahill, 2007), many studies have shown that the interaction between children with this disorder and robots increases the interaction with parents, caretakers and others (Cabibihan et al., 2013; Scassellati et al., 2012).

As robotics plays an important role in a positive interaction with children with ASD, including in therapies, it would be interesting, challenging and innovative to find out an approach to understand what happens in the ASD child's brain, and which cortex areas are more active in the moment of the interaction with the robot. Electroencephalography (EEG) is a powerful tool in the field of neurophysiology and has been used in works that assess mental states of children with ASD (Duffy & Als, 2012; Peters et al., 2013; Teplan, 2002; Wang et al., 2013). In addition, EEG becomes useful in this study, due to advantages as high-speed, non-invasiveness and painless to humans (Teplan, 2002).

The goals of this study are: (1) analyze brain signals of two children diagnosed with ASD, using EEG, in order to assess which brain areas are more active during the interaction with a ludic social robot; (2) evaluate the interaction between children with ASD, typically developing (TD) children (control group) and the social robot, using the quantitative scale Goal Attainment Scaling (GAS) (Krasny-Pacini, Hiebel, Pauly, Godon, & Chevignard, 2013) and images recorded by video cameras; (3) analyze additional reactions and behaviors observed in children with ASD during the interaction; (4) verify if the robot is able to stimulate social skills in children with ASD.

This study is depicted in the following sections: Material and Methods, reporting the experimental protocol; Results, addressing the main findings; and Discussion, pointing out the relevance of the results found, limitations and conclusions.

Material and methods

Participants

In order to recruit children with ASD and establish cooperation agreements, letters of intent containing information and intention of the study were previously sent to the Association of Friends of Autistics of Espirito Santo (AMAES/Brazil), a nonprofit institution that provides educational/pedagogical therapies, psychological care and speech therapy to individuals diagnosed with ASD.

Table 1 Features of the selected children with ASD.

Children (Genre)	A.L. (Girl)	J.V. (Boy)
Age	7	8
Date of the diagnostic	March 2nd, 2011	June 20th, 2011
Drugs	Absence	Absence
Social interaction	Impaired	Impaired
Verbal language	Language delay	Language delay
Stereotyped movements	Absence	Absence
Unusual behaviors	Harsh actions when upset	Meaningless verbalization; speak loudly

This study involved the participation of four children (two with ASD and two with typical development). Both groups were involved in the interaction with a social robot. For all children, the inclusion criteria were as follows: age between 7 and 11 years old, right-handed children, not using drugs and lack of experience of traumatic episodes or phobias. Still, for children with ASD, medical diagnosis for ASD was required. Exclusion criteria were: children with simultaneous occurrence of neurological diseases, such as epilepsy, hydrocephalus, hemiparesis and other syndromes that affect the brain development; children with stereotyped/repetitive sharp movements; agitated children or prone to aggression.

The signing of the Informed Consent by all legal guardians of the selected children and the approval of the Ethics Committee of the Federal University of Espirito Santo (UFES) (under number 1.101.769) were prerequisites for data collection.

The selection of the children with ASD took into account the aid of the parents and AMAES, which provided the children's behavioral data and individual diagnosis confirmed by a medical professional. Table 1 shows the features of the two children with ASD who fulfilled the inclusion criteria.

Material used to capture brain signals

The device used to acquire EEG was the Emotiv EPOC headset, certified by the FCC (Federal Communications Commission-USA), according to security international standards. It is a wireless device, which records data in a sampling rate of 128 Hz, with a bandwidth from 0.2 to 45 Hz, and is composed of 14 channels arranged according to the 10—20 International System, covering the following brain regions: AF3, F7, F3, FC5, T7, P7, O1, O2, P8, T8, FC6, F4, F8, AF4. For all signal processing, the software Matlab 1.8 (R2013a) was used.

Mobile autonomous robot for interaction with autistics — MARIA

With the goal of investigating aspects of social interaction between children with ASD and robot, an anthropomorphic social robot, called MARIA (Mobile Autonomous Robot for Interaction with Autistics) (Fig. 1), was built at the Federal University of Espirito Santo (UFES), Brazil. It is 1.35

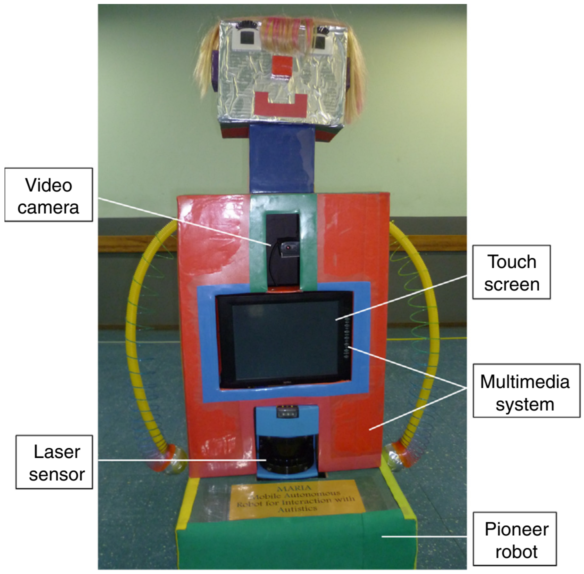


Figure 1 MARIA (Mobile Autonomous Robot for Interaction with Autistics) developed at Federal University of Espirito Santo (Brazil). MARIA is a social robot built to interact with children with ASD, in order to stimulate social skills. For this, it comprises a multimedia system to show infant videos, a mobile robot (Pioneer robot) and a sensor laser to detect the child's location. Besides, the robot has a video camera to capture child's facial images and an onboard computer to control the interaction (inside the structure).

meters tall, and its mobile activity is performed by a PIONEER 3 DX robot with three wheels (two driven wheels and a free wheel). Furthermore, MARIA is equipped with a monitor and two speakers (to emit images and sounds, in order to attract the child's attention), a laser sensor (to detect the child's location), an onboard computer (to perform rules for interaction with the child), and a video camera (to capture images of child's face). Two video cameras (global) are used to record the experiments.

Experimental session

Individually, four children (two TD girls, and one boy and one girl with ASD), aged 7.25 ($\pm$0.43), accompanied by their legal guardians, participated of a single session of interaction with MARIA. The child was invited to sit on a carpet put on the floor in a comfortable way, in a quiet room. EEG electrodes soaked in a saline solution were placed on the child's head. Simultaneously, the brain signal acquisition and robot control systems were connected (by two different operators). In this work, alpha and beta rhythms were evaluated through child's mental activity, by analysis of the power spectrum density.

The session of interaction with MARIA consisted of two stages evaluated through recording of images obtained from two video cameras. In total, we analyzed about 270 min of images.

Stage 1: Catch the child's attention and robot's exposure in a ''self-presentation''. The robot moves slowly straight ahead toward the child (seated on the carpet), with movements that allow the child to see its entire body, displaying musical videos, and, finally, stopping at 60 cm of the child. The goals of this stage are to introduce the robot MARIA, becoming the child confident, safe and comfortable in relation to it, and to assess the eye gaze (impaired in ASD), by counting the number of times per minute the child moves the eyes away from the robot.

Stage 2: Invitation to interact with the robot and mediator. It starts when the mediator/researcher invites the child to get up to touch and play with the robot if he/she is interested. After, the mediator demonstrates a kind of game played with the robot named ''back and forth game'': when the child remains near the robot, it begins to move away, on the other hand, when the child is away from the robot, it approaches her/him again. Both the remote controller and the laser sensor enable this game. This stage finishes after about 30 min in mean. Here, the goals are to increase the child–robot interaction and count the number of times per minute the child touches the robot and if she/he attends the mediator's commands, imitates or interacts with the mediator of other ways.

Experiment evaluation

Goal Attainment Scaling (GAS) is the scale used to evaluate the success of the interaction between the child and the robot. On this scale, general goals of the interaction are defined and, then, subdivided into five tasks scored from -2 to $+2$ according to the child's performance in the interaction. The tasks can be performed less than expected outcome (with scores smaller than 0) or greater than expected outcome (with scores more than 0). *T* (average 50) is the final score of this scale, which is based on the values of the tasks and goals (Krasny-Pacini et al., 2013). For this work, three general goals were chosen taking into account actions of social behavior impaired in ASD: eye gaze, touches and social engagement (interaction with the mediator) (American Psychiatric Association, 2013; Costa, Lehmmann, Dautenhahn, Robins, & Soares, 2015). Table 2 describes the expected tasks (with score equal to 0) for the three general goals possibly performed by the child during the interaction.

Results

Analysis of the ASD children's brain activation during the interaction with the robot

Considering the several applications of EEG technique (Teplan, 2002), a procedure was conducted in order to identify and evaluate the brain activity of the children with ASD at the time of the interaction with the social robot MARIA. Although the procedure of interaction with the social robot was performed with TD children, the analysis of the brain activity was possible only for two children with ASD (7 and 8 years old), due to numerous bodily movements performed by the other children, which triggered many artifacts in the brain signals during all the experiment.

Fig. 2 shows a representative sequence of the acquired results for the two children with ASD. The analysis of their brain activity was based on their alpha and beta rhythms, through power spectrum density. Due to numerous bodily

Table 2 Goal Attainment Scaling (GAS) for three goals, showing the expected level of outcome.[a]

GAS		Goals		
Predict attainment	Score	Look at the robot	Touch the robot	Interact with the mediator
Expected level of outcome	0	Look at the robot in the stage 1 and maintain eye contact with the monitor	Touch the robot at least 2 times	Understand the commands and perform them, encouraged by the mediator

[a] The complete GAS table is available on request.

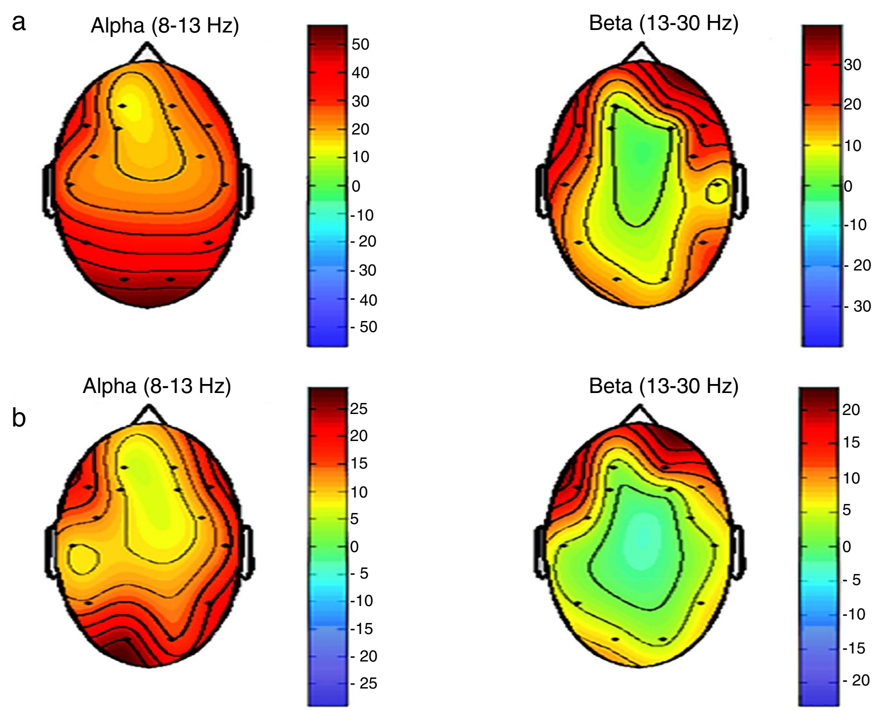


Figure 2 Brain activations characterized by the alpha and beta rhythms of the boy (a) and girl (b) with ASD during the stage 1. The analysis of the power spectrum density shows the most active brain areas (highlighted in dark color) during the child's initial visual contact with the robot. Representation of the human head with the nose pointing up.

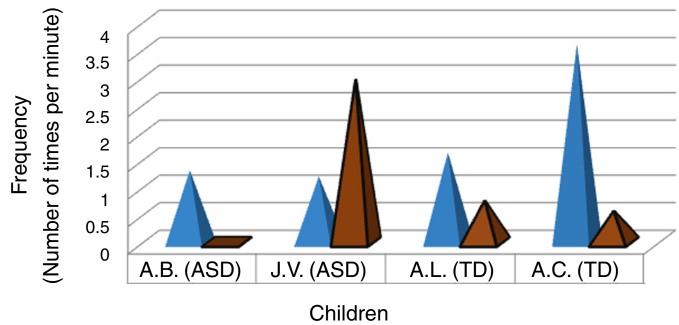
movements performed in the stage 2, generating many artifacts in the brain signals, the brain analysis was possible only in the stage 1.

Through the software Matlab 1.8 (R2013a), the analysis of the power spectrum density was characterized by obtaining the first 1024 samples from the brain signals. The samples correspond to the average activation observed in the stage 1, in which the children looked at the robot, while they were sitting on the carpet without much bodily movement, and the robot moved slowly toward them to start a possible interaction. The analysis of the power spectrum density shows the most active brain areas (highlighted in more intense color). Both brain activities (Fig. 2a and b) indicate alpha rhythms more pronounced in the occipital regions, and beta rhythms more pronounced in the frontal regions.

Analysis of the children–robot interaction

Examples of social skills likely impaired in ASD are eye gaze, touch (tactile interaction) and social engagement (imitation, communication, joint attention) (American Psychiatric Association, 2013; Costa et al., 2015; Duquette et al., 2008; Kanner, 1943). Therefore, such features are themes of our analysis. To evaluate the eye gaze, the frequency (number of times per minute) in which the child moved his/her eyes away from the robot in the stage 1 was analyzed. To assess the ability of touching, the frequency in which the child touched the robot in the stage 2 was examined. Fig. 3 shows a comparison of the frequencies achieved between ASD and TD children.

According to Fig. 3, in general, the frequency in which the children with ASD moved their eyes away from the robot was lower than the frequency performed by TD children, being possible to infer that the children with ASD had the attention more attracted by the robot MARIA. Thus, the eye gaze was more stimulated in children with ASD than in TD children. On the other hand, although one child with ASD did not touch the robot, the other one performed a greater frequency of touches than TD children, indicating the robot was able to stimulate the tactile interaction for this child.



Average frequency performed by each child

	A.B. (ASD)	J.V. (ASD)	A.L. (TD)	A.C. (TD)
Moving eyes away from the robot	1.31	1.2	1.63	3.6
Touching the robot	0	2.97	0.76	0.57

Figure 3 Frequencies (number of times per minute) relative to social skills (eye gaze and tactile interaction) performed by children with ASD and TD children, during the stages of the interaction session. Eye gaze was evaluated considering the frequency that the child moved the eyes away from the robot during the stage 1. On the other hand, the tactile interaction was assessed considering the frequency of touches that the child performed in the robot during the stage 2. The average values of the performance of such social skills by children can also be observed.

Table 3 Analysis of the social goals performed by children with ASD and TD children using GAS.

GAS									
Session	Stage 1	Stage 2		*T*	Session	Stage 1	Stage 2		*T*
Children with ASD	Look at the robot	Touch the robot	Interact with the mediator		TD children	Look at the robot	Touch the robot	Interact with the mediator	
(A.B.)	0	−2	−1	36.3	(A.L.)	0	+2	+2	68.2
(J.V.)	+2	+2	+2	77.4	(A.C.)	+2	+2	+2	77.4

The evaluation of the interaction between the child and the social robot MARIA, through GAS scale, is shown in Table 3. Each goal received the correspondent score to the task performed by the child during the interaction with the robot. In GAS, three main social goals were assessed through five specific tasks, which can be performed much worse or much better than the expected outcome, with scores ranging from −2 to +2; or according to the expected level of outcome, with score equal to 0. The calculation based on the scores relative to the three goals corresponds to the general punctuation of the GAS (*T*), which has 50 as average.

For three out of the four children, the GAS was greater than 50. On the other hand, for one child with ASD, the GAS was less than 50. In general, these results allow inferring that there was a positive interaction between children and the mobile robot MARIA (Fig. 4), indicating, at the same time, the need of some improvements in the robotic system.

Discussion

Analysis of the ASD children's brain activation during the interaction with the robot

Analysis of the power spectrum density shown with more intense color, by topographic images, regions of the children with ASD's brain cortex that were more stimulated by the social robot during the stage 1 of the session. A pronounced difficulty in recording brain signals during the stage 2 was verified due to the existence of various bodily movements performed by the children and the limited range of operation of the EEG device (until 1 m). Therewith, for this stage, numerous artifacts were generated, decreasing the quality of the brain signals acquired and not allowing analysis. Nevertheless, the ASD children's brain activity was recorded in the stage 1, since these children performed few movements in the first minutes, during the robot visualization, obtaining a better signal quality.

According to Fig. 2, the regions with more intense color represent the most active ones. In fact, alpha rhythms, present in mental relaxation state, are found more clearly in the occipital region of the brain, reflecting mainly the visual processing (Nicolas-Alonso & Gomez-Gil, 2012). This explains a greater activation evidenced in this brain area during the stage 1, when the children looked at the robot while it was moving. On the other hand, the beta rhythms are strongly registered in the central and frontal regions (Nicolas-Alonso & Gomez-Gil, 2012). The presence of beta rhythms, evidenced by Fig. 2, reveals the activation of the frontal region, which plays a vital role in functions that are impaired in ASD, such as language, cognition,

Figure 4 Interaction of children with ASD with the robot MARIA. The figure records the moment of evolution of the child–robot interaction (stage 2), in which the child is invited to play with the robot (back and forth game).

social behaviors and processing of emotions (Davidson, 2004; Courchesne & Pierce, 2005). In the early years of life, children with ASD demonstrate some signs of frontal lobe dysfunction, realized as abnormalities related to the social attention and development of verbal and nonverbal communication (Courchesne & Pierce, 2005).

In this case, it is motivating to note that the social robot stimulated the frontal cortex of these children, as well as social abilities, which will be depicted below. However, further studies are necessary to prove the therapeutic function of the robot, assessing it as a tool capable of stimulating brain regions responsible for specific activities generally disturbed in the autistic disorder.

Analysis of the children–robot interaction

In general, there was no negative reaction or expression of the children in relation to the social robot MARIA. Moreover, the attractive image of the robot MARIA and the presence of videos, the ability of locomotion of the robot enables to increase the ASD children's attention impact, since this feature becomes the robot more dynamic and inviting to an interaction, agreeing with studies of Cabibihan et al. (2013). Another important feature of robot MARIA, highlighted by those authors, is the height close to the child, as similar child–robot height enables an easier eye contact and interaction, increasing the interaction between children with ASD and robot and making this interaction more enjoyable.

For eye gaze and touches analysis (Fig. 3), comparing both children groups, the frequency of the eye gaze with the robot performed by children with ASD was larger than the TD children's frequency, since the former moved their eyes away from the robot less times. In relation to frequency of touches, one child with ASD performed a larger frequency than TD children's frequency. The interest to touch the robot's face and arms was larger, since they are the two more attractive parts of the robot's body. Thus, the colors, shape, height, musical videos and locomotion capacity of the robot MARIA can have contributed to attract the attention of the children with ASD. Thus, it is reasonable to infer that the social robot MARIA is able to catch children's attention and stimulate social abilities in children with ASD.

During the session, in general, the children showed several reactions, as caution in interacting at the beginning, curiosity, interest, demonstrating an effective interaction with speeches, touching and playing with the robot in different ways. Although the children–robot interactions had been positive in overall, both children with ASD presented some distinct behaviors during the session, according the following analysis.

The girl with ASD (A.B.) demonstrated interest in the musical videos exhibited by the robot, keeping visual contact with the monitor during almost all stage 1. Although she understood the mediator's commands, she was not confidant to interact with the robot MARIA directly during the stage 2. Then, she said she would not like to touch it. Her facial expressions were neutral during all the session. On the other hand, during the stage 1, the boy with ASD (J.V.) demonstrated interest and happiness in watching the musical videos, presenting cheerful facial expressions, babbling words relative to the videos and demonstrating interest in keeping watching videos. In the stage 2, when encouraged by the mediator, he promptly got up and touched the robot, seeing its colors and shape, and sometimes, he looked at the mediator (joint attention). He imitated the game demonstrated by the mediator and played together to the robot and the mediator at the same time. Instantaneously, new interactions arose when the child took the one robot's hand, mimicking a walk with it. Then, the mediator took the other robot's hand, and all together walked in the session room. In another moment, he used one robot's hand as a microphone to talk things without much sense. When asked the names of the parts of the robot's body, he promptly answered and pointed them correctly. Contemplating the social engagement, he demonstrated to understand the mediator's commands, performing them. In addition, he presented eye gaze with the mediator, when called; played with the robot and the mediator at the same time; communicated and performed other manners of interacting with the robot. The video (available on https://youtu.be/m7gtyfaUM7A) demonstrates part of the interaction of the boy with ASD with the robot MARIA, in the stage 2. It is possible to note him performing actions of social interaction, such as tactile interaction with the robot and social engagement with the mediator. In the background, the child's mother observes the son-robot interaction, and the other person is the mediator/researcher, who analyzes and establishes shared interaction with both child and robot.

It is interesting to emphasize that the TD children performed similar actions performed by the boy with ASD. Besides, it is possible to infer the robot played the role of intermediator during the interaction between the child with ASD and researcher, complying with the goal of stimulating social skills.

Three general goals evaluated in GAS (Table 3), commonly disturbed in ASD, were: look at the robot (eye gaze), touch the robot (tactile interaction) and interact with the mediator (social engagement). According to the American Psychiatric Association (2013), a highlighted feature in ASD is the reduced or atypical use of visual contact, which implicates in deficit in the social contact. Likewise, an important ability to develop cognitive and social aspects in humans is the tactile sensitivity, characterized as one of the first mechanisms used by humans to connect with the world around (Costa et al., 2015). Considering the social engagement, in addition to aspects as communication by the usage of (non) verbal language and physical/visual contact, another social skill observed in the experiment comprises the imitation capacity, essential for the cognitive and social development and behavioral and language learning (American Psychiatric Association, 2013; Duquette et al., 2008; Ingersoll, 2012; Kanner, 1943; Warren et al., 2015).

GAS indicated that one child with ASD (A.B.) presented a poor performance (T lower than 50), which means a poor interaction with the robot in relation to other children. This child presented apprehension in interacting with the robot, and this can be considered normal during the first contact, characterized as a new experience. A common feature in ASD is the insistence on sameness, which characterizes such children as vulnerable to unpredictable changes or new situations, which can trigger possible anxiety reactions (American Psychiatric Association, 2013; Won & Zhong, 2016). Thus, further, it would be interesting to establish subsequent contacts between child and robot, allowing the child to get used to the robot, in order to improve the interaction. In addition, promoting a customized interaction could also be interesting for further sessions. Analyzing the third goal of the GAS scale, related to social engagement, the same child with ASD performed it in a less than expected way, according to Table 3. In spite of understanding the mediator's commands, the child did not fulfill them, even being encouraged. On the other hand, all the other children carried out satisfactorily the commands given by the mediator (touch the robot and play with it), interacting with the robot MARIA and the mediator.

Taking into account the reduced or absent imitation of others' behavior in ASD (American Psychiatric Association, 2013; Kanner, 1943; Warren et al., 2015), it was observed that the child with ASD (J.V.) imitated the game performed prior by the mediator. Therefore, it is possible to deduce that the robot favored continued social engagement, stimulating eye gaze, tactile interaction, joint attention, imitation and communication, and may be a key tool to attract the attention of children with ASD and improve their social interaction. Thereby, it can be viable in promoting their cognitive and social development (Costa, Santos, Soares, Ferreira, & Moreira, 2010). The social robot used in this research is still a prototype and more tests with the children and the robot must be performed.

It would be interesting that other health professionals, such as therapists and educators involved with children with ASD, test robots as a mean of improving the pedagogical or social therapy with these children (Zubrycki & Granosik, 2016). To achieve this objective, our robot could facilitate the execution of games and activities that allow interaction with other children and with the environment around them, besides arousing attention, working with colors and shapes of objects, numbers, alphabet, verbal communication and tasks of day-by-day, i.e., stimulating cognitive development and social skills of these children. Therefore, researching new quantitative evaluation methods of pedagogical tasks is important in order to compare such therapy with and without the robot and, then, quantify its importance as an effective tool in the development of social and cognitive skills of children with ASD.

This work presented some limitations mentioned as follows. As a prototype, improvements in the robotic system should be deployed. Among these improvements, it is interesting for the child–robot interaction to become the social robot more autonomous, as suggested by Cabibihan et al. (2013), adding mechanisms to increase the social interaction and integrate systems of acquisition of EEG signals and robot control. Moreover, the lack of total integration of the computational tasks or synchronism should be repaired, as the systems of EEG signal recording and control of the robot and its accessories were performed on different computers, which may reduce the accuracy of some data processing. Besides, in spite of having a low cost and being painless, noninvasiveness and wireless, the EEG device used in this study (Emotiv EPOC) did not present high quality to acquire brain signals. Added to that, the presence of muscle movements performed by children triggered numerous artifacts in the process of signal acquisition, especially in the stage 2 of the session. Other limitations are relative to a small number of children with ASD who met the inclusion criteria and did not oppose the placement of the electrodes on their scalps, since individuals with ASD can present tactile sensitivity (Minshew & Hobson, 2008). As aforementioned, the difficulty of finding works in the literature that address the study of mental states in a dynamic interaction, using EEG in children with ASD, can be then explained.

All the observations from this pilot study corroborate the development of future works related to application of other devices and sensors (non-invasive and unobtrusive) for the recognition of emotional and mental states, considering the sensitivity to touch, common in ASD. Moreover, the building of a new shape and functions for the robot MARIA, such as, dynamic facial expressions to express emotions, speeches to stimulate the communication, body composed of materials with different textures and sensors to stimulate the tactile function are also desired in order to allow studies about the use of robots by therapists of the ASD area.

It is expected that this study might contribute to the basis of advancement of other researches that investigate brain activity as well as mental and emotional states in ASD and use a robot to stimulate cognitive and social skills in children affected by this disorder, aiding therapists, parents, caregivers, teachers and researchers.

Conflicts of interest

The authors declare no conflicts of interest.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.biori.2018.11.003.

References

American Psychiatric Association. (2013). *DSM-V diagnostic and statistical manual of mental disorders* (5th ed.). Washington, DC: American Psychiatric Association.

Bal, E., Harden, E., Lamb, D., Hecke, A. V. V., Denver, J. W., & Porges, S. W. (2010). Emotional recognition in children with autism spectrum disorders: Relations to eye gaze and autonomic state. *Journal of Autism and Developmental Disorders*, *40*, 358–370.

Barnes, R. E., & McCabe, H. (2012). Should we welcome a cure for autism? A survey of the arguments. *Medicine, Health Care and Philosophy*, *15*, 255–269.

Cabibihan, J. J., Javed, H. J., & Aljunied, M. A. S. M. (2013). Why robots? A survey on the roles and benefits of social robots in the therapy of children with autism. *International Journal of Social Robotics*, *5*, 593–618.

Costa, S., Lehmmann, H., Dautenhahn, K., Robins, B., & Soares, F. (2015). Using a humanoid robot to elicit body awareness and appropriate physical interaction in children with autism. *International Journal of Social Robotics*, *7*, 265–278.

Costa, S., Santos, C., Soares, F., Ferreira, M., & Moreira, F. (2010). Promoting interaction amongst autistic adolescents using robots. *Proceedings of International Conference of the Engineering in Medicine and Biology Society*, http://dx.doi.org/10.1109/IEMBS.2010.5627905

Courchesne, E., & Pierce, K. (2005). Why the frontal cortex in autism might be talking only to itself: Local over-connectivity but long-distance disconnection. *Current Opinion in Neurobiology*, *15*, 225–230.

Dautenhahn, K., & Werry, I. (2004). Towards interactive robots in autism therapy: Background, motivation and challenges. *Pragmatics & Cognition*, *12*(1), 1–35.

Davidson, R. J. (2004). What does the prefrontal cortex ''do'' in affect: Perspectives on frontal EEG asymmetry research. *Biological Psychology*, *67*(1–2), 219–234.

DeRosier, M. E., Swick, D. C., Davis, N. O., McMillen, J. S., & Matthews, R. (2011). The efficacy of a social skills group intervention for improving social behaviors in children with high functioning Autism Spectrum Disorders. *Journal of Autism and Developmental Disorders*, *41*, 1033–1043.

Duffy, F. H., & Als, H. (2012). A stable pattern of EEG spectral coherence distinguishes children with autism from neurotypical controls – A large case control study. *BMC Medicine*, *10*(64), 1–18.

Duquette, A., Michaud, F., & Marcier, H. (2008). Exploring the use of a mobile robot as an imitation agent with children with low-functioning autism. *Autonomous Robot*, *24*, 147–157.

Ingersoll, B. (2012). Brief report: Effect of a focused imitation intervention on social functioning in children with autism. *Journal of Autism and Developmental Disorders*, *42*, 1768–1773.

Kanner, L. (1943). Autistic disturbances of affective contact. *Nervous Child*, *2*, 217–250.

Kim, E. S., Berkovits, L. D., Bernier, E. P., Leyzberg, D., Shic, F., Paul, R., et al. (2013). Social robots as embedded reinforcers of social behavior in children with autism. *Journal of Autism and Developmental Disorders*, *43*, 1038–1049.

Kozima, H., Michalowski, M. P., & Nakagawa, C. (2009). Keepon: A playful robot for research therapy, and entertainment. *International Journal of Social Robotics*, *1*, 3–18.

Krasny-Pacini, A., Hiebel, J., Pauly, F., Godon, S., & Chevignard, M. (2013). Goal Attainment Scaling in rehabilitation: A literature-based update. *Annals of Physical and Rehabilitation Medicine*, *56*(3), 212–230.

Minshew, N. J., & Hobson, J. A. (2008). Sensory sensitivities and performance on sensory perceptual tasks in high-functioning individuals with autism. *Journal of Autism and Developmental Disorders*, *38*, 1485–1498.

Nicolas-Alonso, L. F., & Gomez-Gil, J. (2012). Brain computer interfaces, a review. *Sensors*, *12*(2), 1211–1279.

Perry, E. K., Lee, M. L. W., Martin-Ruiz, C. M., Court, J. A., Volsen, S. G., Merrit, J., et al. (2001). Cholinergic activity in autism: Abnormalities in the cerebral cortex and basal forebrain. *American Journal of Psychiatry*, *158*, 1058–1066.

Peters, J. M., Taquet, M., Vega, C., Jeste, S. S., Fernández, I. S., Tan, J., et al. (2013). Brain functional networks in syndromic and non-syndromic autism: A graph theoretical study of EEG connectivity. *BMC Medicine*, *11*(54), 1–16.

Robins, B., Ferrari, E., Dautenhahn, K., Kronreif, G., Prazak-Aram, B., Gilderblom, G., et al. (2010). Human-centred design methods: Development scenarios for robot assisted play informed by user panels and field trials. *International Journal of Human-Computer Studies*, *68*, 873–898.

Robins, B., Amirabollahian, F., Ji, Z., & Dautenhahn, K. (2010). Tactile interaction with a humanoid robot for children with autism: A case study analysis involving user requirements and results of an initial implementation. In *19th IEEE international symposium on robot and human interactive communication* http://dx.doi.org/10.1109/ROMAN.2010.5598641

Scassellati, B. (2007). How social robots will help us to diagnose, treat, and understand autism. *Robotics Research*, *28*, 552–563.

Scassellati, B., Admoni, H., & Matarić, M. (2012). *Annual Review of Biomedical Engineering*, *14*, 275–294.

Teplan, M. (2002). Fundamentals of EEG measurement. *Measurement Science Review*, *2*(2), 1–11.

Wang, J., Barstein, J., Ethridge, L. E., Mosconi, M. W., Takarae, Y., & Sweeney, J. A. (2013). Resting state EEG abnormalities in autism spectrum disorders. *Journal of Neurodevelopmental Disorders*, *5*(24), 1–14.

Warren, Z., Zheng, Z., Das, S., Young, E. M., Swanson, A., Weitlauf, A., et al. (2015). Brief Report: Development of a robotic intervention platform for young children with ASD. *Journal of Neurodevelopmental Disorders*, *45*, 3870–3876.

White, S. W., Keonig, K., & Scahill, L. (2007). Social skills deveelopment in children with Autism Spectrum Disorders: A review of the intervention research. *Journal of Autism and Developmental Disorders*, *37*, 1858–1868.

Won, H. Y., & Zhong, A. Z. W. (2016). Assessment of robot training for social cognitive learning. In *16th international conference on control, automation and systems (ICCAS)* (pp. 893–898).

Zubrycki, I., & Granosik, G. (2016). Understanding therapists' needs and attitudes towards robotic support the roboterapia project. *International Journal of Social Robotics*, *8*, 553–563.