Three Study Cases of Social Robotics in Autism Spectrum Disorder Treatment: Personalization and Usability of CASTOR Robot

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***Abstract*— Social assistive robotics in autism has been implemented in studies and therapies to improve social skills and encourage children to comply with therapies. However, autism symptoms vary in their spectrum, which generates difficulties in implementing social robotics in a general way. In this study, the CASTOR social robot was implemented in three cases: one case of autism fulfilling the inclusion and exclusion criteria and two cases with comorbidities typically excluded in social robotic studies. A pre and post-test professional evaluations were made, and 12 variables about social skills were measured during the implementation. Four sessions of 30 minutes were performed for each study case, improving focal attention, following instructions, working and procedure memory, identifying emotions, and physical and verbal imitation. Regarding the qualification method used at the Howard Gardner Clinic for each speciality, the most remarkable improvements were P1 increased by 20% in physiotherapy, P2 increased by 23% in psychology and P3 increased by 10% in occupational therapy. The pre and post-test results indicate that the presence of the social robot in therapies improves children's progress independently of their qualities.**

I. INTRODUCTION

Autism spectrum disorder is the term used to describe a group of social communication deficits and repetitive sensory-motor behaviours, usually diagnosed in childhood. Improving the social communication skills of those with ASD is critical to their independent community inclusion in adulthood [1].

Although individuals with ASD are different, since there are no reliable biomarkers, the diagnosis must be made based on behaviour. The Diagnostic and Statistical Manual of Mental Disorders (DSM)-5 criteria is one of the methods of diagnosis and severity classification of ASD within the two domains (social communication and restricted, repetitive, or unusual sensorimotor behaviours) [2].

There are defined subtypes within ASD, such as Asperger's disorder and pervasive developmental disorder not otherwise specified. In addition, the DSM-5 recognizes that ASD can be accompanied by other disorders, such as fragile X syndrome and attention deficit hyperactivity disorder (ADHD) [3]. In addition, there are comorbidities of autism, such as the prevalence of visual and hearing impairments [4].

Social Assistive Robotics (SAR) implements of robots in environments of social or physical interaction with humans for welfare or clinical purpose [5]. The treatment of ASD with SAR has brought varied results [6], [7], so it has been questioned in which cases and for which children can be effective, including those with significant comorbidities [1]. Healthcare professionals can provide timely and individualized therapy to families according to the ASD symptoms, which is an issue in implementing SAR in general in children with ASD.

Within ASD and SAR implementations, inclusion and exclusion criteria are used to control the study group [8]. This does not allow those with other disorders to participate in the studies, influencing implementation in general in the ASD population.

II. RELATED WORK

Social robots have been implemented in different therapeutic environments. In the treatment of ASD it has been implemented in several studies, as previously reported [9].

Different variables and skills have been evaluated in several studies implementing Social Robots in ASD. The therapies applied in ASD include activities depending on the robot's capacities and the objective of the implementation. Some of these activities include physical contact motivation [12], use of songs [12], dancing activities [12], storytelling [12], colors identification [14], communication through a triadic interaction [17] and speech therapies [10].

In addition, the different implementations measure a variety of variables: Visual contact, through gaze detection [16] or through video-analysis [12], sensory information [17], performance in the activities [8], professional evaluations [15], imitation time [13], surveys for caregivers [10]. In the case of gaze detection *Esteban et al.* [16] applied the NAO robot (Aldebaran Robotics Softbank, France). They used different AI methods to obtain the gaze and the skeleton detection for a JA task. The use of cameras and kinects increases the robotic implementation cost. More detailed information can be seen in Table I.

The CASTOR (CompliAnt SofT Robotics) project has a long trajectory of studying the ASD in developing countries; initially, a study was conducted with the ONO social robot (Ghent University, Belgium) on children with special needs to analyze the interaction patterns with social robots [18].

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Robot	Duration and sample	Skills worked	Main findings
NAO [10]	One 20-minute weekly session for one school year with one participant	- Speech therapy - JA activities	Robotic treatment helps improve long-term results and social skills compared to conventional treatment
NAO [11]	Five modules worked with one participant	- Autistic behaviour therapies	The HRI methods implemented with the robot can suppress the erratic autistic behaviours of the children during the interaction
NAO [12]	Implementation for 21 days to 11 participants (7 children with ASD and four children with ASD and ADHD)	- Physical imitation - JA, - Turn-taking skills - Emotional response	Children engage better when activities depend on the preferences of the participant
NAO [15]	Therapies for a month with 3 weekly sessions to 6 children with ASD	- Imitation	They obtain positive results in imitation activities for participants with low and medium functionality. However, those with profound intellectual disability had no improvement
NAO [8]	Long-term study with 20 sessions to 73 participants with ASD	- Social communication	They conclude that the robot contributes to the effectiveness of the intervention using games combined with motivational components of the Pivotal Response Treatment
NAO [6]	11 sessions of 10 minutes each, to three ASD high-functional children and one ASD low-functional child	- Motor skills - JA - Colors identification - Learn essential music	Confirm the benefits of the implementation of the NAO robot in musical education with the xylophone and the drum during cognitive rehabilitation therapy for children with ASD
NAO [7]	Long-term application of 22 sessions of 10 minutes to 5 participants with ASD	- JA	They notice that the use of more cues for JA cueing increases the children's performance, considering each participant's results and individual analysis
NAO [17]	2 test sessions to 7 participants	- Communicate their needs	They validate the initial test of the NAO robotic tool to improve the communication of needs and thoughts in a triadic interaction
Jibo [13]	A month of duration with daily sessions of 30 minutes with 12 participants with ASD	- JA - Emotional response - Eye contact - Social and communication skills	The robot maintained engagement for one month, and the children showed improved joint attention skills with adults post-test
Cozmo [14]	Robotic application for ten weeks to 24 children with ASD	- Emotions - JA - Colours identification	Treatment with the robot improves long-term results in the activities compared to conventional treatment

TABLE I

ROBOTS IMPLEMENTED IN ASD THERAPIES. SOCIAL ROBOT, AUTHOR AND YEAR, STUDY DURATION AND SAMPLE, SOCIAL SKILL, AND MAIN FINDINGS.

Subsequently, a participatory design was conducted with the ASD community in Colombia, where different social aspects that influenced the creation of a social robot specifically for ASD therapies were analyzed [19]. *Casas et al.* [20] designed the Open-Source Social Robot CASTOR. A low-cost robot designed employing Soft Robotics. It has been previously implemented in physical interaction studies [21], [22].

This study presents the implementation of the CASTOR social robot in three study cases in four sessions. Two participants have comorbidities of ASD that could affect the performance of social robotics due to their special needs. Some adaptations were made to identify the usability of the CASTOR robot in different scenarios of ASD therapies by evaluating the same variables in the same activities.

III. METHOD

The study was carried out at the Howard Gardner Rehabilitation Clinic in Bogota, Colombia, where there are professionals from four therapy areas: occupational therapy, physiotherapy, psychology and phonoaudiology. For the pre and post-test, the professionals evaluated the functionality of three participants with ASD based on the qualification method used at the Howard Gardner Clinic for each speciality.

Four sessions were conducted using the CASTOR social robot with three participants with ASD; 1) A participant who fulfilled the inclusion and exclusion criteria for using the social robot (P1); 2) A participant with hearing sensitivity (P2), and 3) A participant without verbal expression (P3). The sessions have approximately 30 minutes in which social skills are worked on: focused attention, following instructions, working and procedural memory, physical and verbal imitation, and recognition of basic emotions.

At the end of the session, the therapist fills out an evaluation form with seven variables, focused attention (FA), following instructions (FI), working and procedure memory (WMP), physical and verbal imitation (PI-VI), emotion identification (EI), emotional response (ER) and performance (P). In addition, five variables were obtained from the recordings, two-time variables, robot attention time (RT) and therapist attention time (TT), and three physical interaction variables, robot-provoked interactions (RI), therapist-provoked interactions (TI) and spontaneous interactions (SI).

Parents were informed of the study and its objective; the consent was read and signed before starting the study. The ethics committee of the Colombian School of Engineering Julio Garavito approved the protocol. For the initial plan, inclusion and exclusion criteria were defined.

Inclusion criteria: Children diagnosed with ASD, between 2 and 15 years of age, obtained the informed consent signed by their parents.

Exclusion criteria: Children with hearing, speech and vision deficits, with abnormal eye movements and comorbidities such as Fragile X Syndrome or Down's Syndrome. Additionally, children who do not obtain informed consent from their parents.

A. Participant 1

Participant 1 (P1) is a 10-year-old child with ASD in the functionality level 2 who fulfils the inclusion and exclusion criteria previously mentioned.

B. Participant 2

The participant is a 7-year-old child with functionality level 1 and has hearing sensitivity to sounds. Due to P2's hearing sensitivity, he maintains anti-noise hearing aids that do not allow the participant to hear the instructions of the CASTOR robot. He did not fulfil the study's for the hearing deficit.

The method for giving instructions in the sessions had to be adapted for this implementation. An additional tablet was added with which the therapist provided the indication with pictograms to the child. In addition, therapists often communicate with him through sign language with simple instructions.

C. Participant 3

The participant is a 14-year-old child with level 1 and has no verbal ability and difficulty identifying objects and instructions. Due to P3's lack of verbal communication, some activities cannot be performed, and he did not fulfil the exclusion criteria.

Because of this, the activities were adapted to be performed by the participant. In the case of imitation, only physical imitation was evaluated. In addition, the instructions were simplified to instructions that the participant could follow, i.e., the instruction "Where is the car?" was changed to "Bring the car".

D. Procedure

The study was carried out in the physiotherapy room of the Howard Gardner clinic. Objects known to the participants were distributed, a video camera was placed, and the robot was placed on the table facing the participant and the therapist. Outside the room, the robot operator manipulates the actions of the CASTOR robot through the video camera with the Wizard of Oz method, as shown in figure 1.

Before the study, a professional evaluation was performed by the four specialities managed in the clinic as a pre-test. The participants were classified in a level of functionality by speciality and at a general level by evaluating their social and behavioural skills. In addition, a percentage of evolution in each speciality was provided to demonstrate the progress in the process of the children quantitatively.

For the intervention, the CASTOR robot was implemented with the web interface adapted to the present study because the robotic platform has easy-to-adapt programming. The functions adapted in the present study could be performed with the capabilities initially included in the CASTOR robot depending on the difficulties, limitations and needs of the three particular participants. Due to this, the adaptation took one day of programming for the P2 and P3 implementations. Additionally, the addition of a Tablet and the implementation of the pictograms on it. These adaptations were carried out with ease by the research group. However, the interface was made to be used by clinicians after training on how it works. The activities are based on the development of five basic social skills; 1) Focused attention through the identification of objects and engagement with songs played by the CASTOR robot; 2) Following instructions through simple instructions with objects and the performance of actions indicated in songs; 3) Working and procedure memory through the return of the objects used to their initial position and the response to questions related to the songs; 4) Physical and verbal imitation (P3 only physical imitation) by imitating simple movements and dancing with the robot, as well as imitating words and animal sounds; and 5) Recognition of basic emotions by identifying the emotions expressed by the robot and performing the indicated emotions.

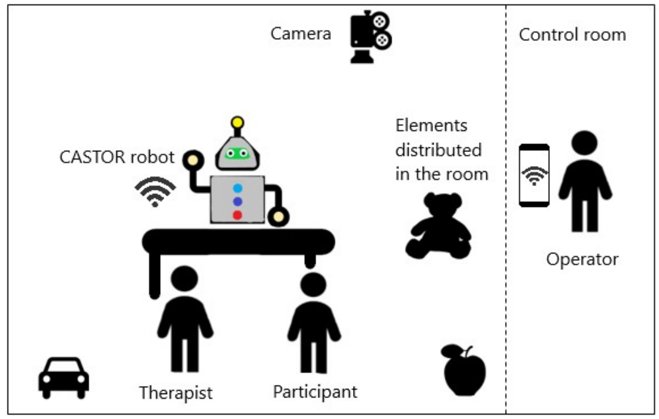

Fig. 1. Physiotherapy room distribution for the CASTOR robot implementation for the three participants.

At the end of all the sessions, the professional evaluation by speciality is carried out again to indicate the level of functionality and the percentage of the evolution of the participants.

IV. Results

The variables evaluated during the sessions are shown in figures 2, 3 and 4. The pre-test and post-test results of the three participants are shown in Table II. A descriptive analysis was made of the four specialities handled in the Howard Gardner Clinic for the participant.

The variables measured by the therapist are shown in figure 2. No constant upward or downward behaviour was found in any three cases. However, sessions 2, 3, and 4 were higher or equal to session 1 in WMP and EI for P1, shown in figure 2A. The same for P2 in FA and WMP variables, shown in figure 2B. Moreover, for P3, the variables that had this behaviour were PI-VI and EI, shown in figure 2C.

Due to the novelty effect, it has been reported previously that some variables may be overvalued in the first session. This, can be observed in P1 in the variables FI and ER, where sessions 2, 3 and 4 had a constant behaviour but lower than session 1. In the case of P, this same novelty effect can be observed, but from session two due to the unfamiliarity with the CASTOR robot. An ascending behaviour is noted with values close to each other (figure 2A). The novelty effect extended to the second session in the variables FI and PI-VI, where from session 3, the scores decreased and became constant, as shown in figure 2B. Likewise, P3 had this same extension of the novelty effect in the variables FA, WMP, ER and P. This can be observed in figure 2C.

P1 for PI-VI, a lower value can be seen in session 3, but sessions 1, 2 and 4 have constant scores, illustrated in figure 2A. P3 had this same behaviour in FI with session 2 (figure 2C).

The time variables are shown in figure 3. P1 and P2 had the impact of the novelty effect on RT similarly, in figure 3A and 3B can be seen a higher value in session one and after that a decrease and more consistent behaviour. P3 had the novelty effect in session two in this same variable; after this, a decrease and constant behaviours are seen in the last two sessions, as shown in figure 3C. In the variable TT, it can be observed that P2 and P3 had higher values than in session one (figure 3B and 3C), and P1 had similar behaviour in the four sessions with similar values, illustrated in figure 3A.

The physical interaction variables are shown in figure 4. It can be observed that all three participants have a higher number of spontaneous physical interactions in all sessions compared to provoked interactions. Moreover, despite maintaining a large number of physical contacts, the CASTOR robot did not have any damage. There were sessions where the robot or therapist caused no interactions for provoked interactions. In the case of P1, the therapist only provoked interactions in session one. In the other three, this variable was zero, as illustrated in figure 4A.

Speciality	P1		P2		P3	
	Pre-test	Post-test	Pre-test	Post-test	Pre-test	Post-test
Physiotherapy	28%	**48%**	18%	**23%**	25%	**30%**
Phonoaudiology	85%	85%	14%	**19%**	8%	**15%**
Psychology	34%	**47%**	24%	**47%**	10%	**15%**
Occupational therapy	18%	**30%**	17%	**20%**	11%	**21%**

TABLE II

PRE AND POST-TEST OUTCOMES OF EVOLUTION PERCENTAGE FOR THE THREE PARTICIPANTS IN THE FOUR SPECIALITIES.

A. *Participant 1*

P1 increased the evolution percentage in physiotherapy by 20%, occupational therapy by 12% and psychology by 13%. The phonoaudiology speciality remained at an evolution percentage of 85%. Although it did not increase related to

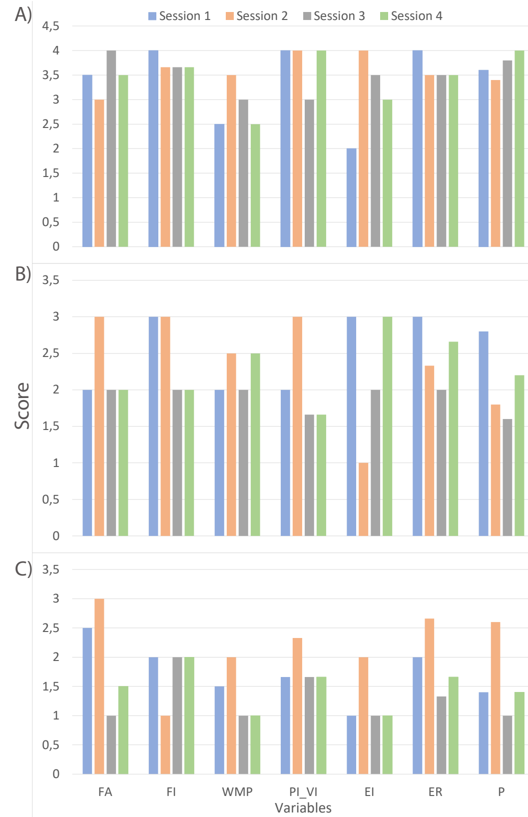

Fig. 2. Variables measured by the therapist: focal attention (FA), follow instructions (FI), working and procedure memory (WMP), physical and verbal imitation (PI-VI), emotions identification (EI), emotional response (ER), and performance (P). A) P1's results. B) P2's results. C) P3's results.

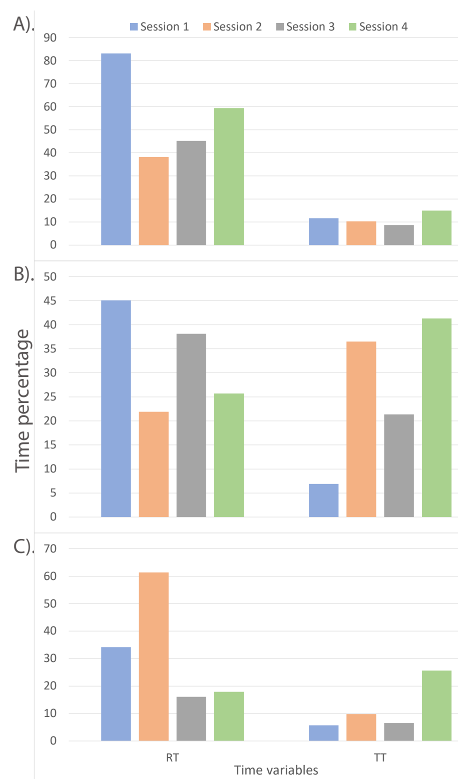

Fig. 3. Time variables outcomes: robot attention time (RT) and therapist attention time (TT). A) P1's results. B) P2's results. C) P3's results.

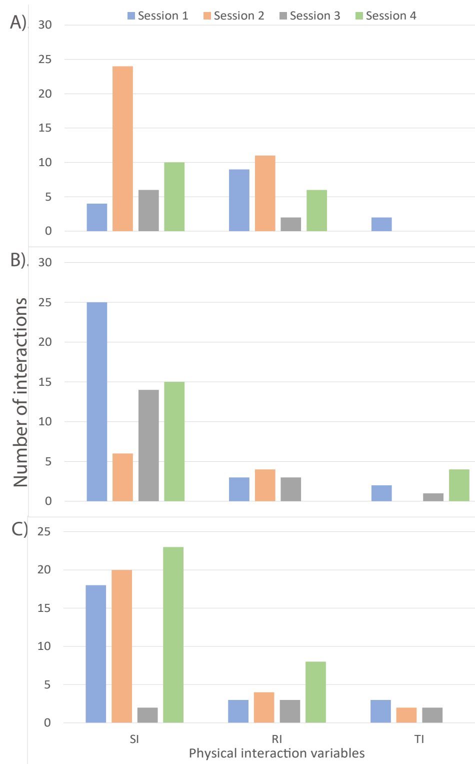

Fig. 4. Physical interaction outcomes: spontaneous interaction (SI), robot-provoked interaction (RI), therapist-provoked interaction (TI). A) P1's results. B) P2's results. C) P3's results.

the pre-test, it had the highest evolution percentage, shown in Table II with the increased values in bold.

B. Participant 2

P2 increased in all four specialities. Physiotherapy had a rise of 5%, phonoaudiology had an increase of 5%, and occupational therapy had an increase of 3%. The speciality with the highest evolution percentage was psychology with 47%. The speciality with the most significant difference in the pre-test with 23%, as shown in Table II with the increased values in bold.

C. Participant 3

P3 increased in all specialities. For physiotherapy, he obtained the highest evolution percentage with 30% and an increase of 5%. Phonoaudiology had an increase of 7% and psychology an increase of 5%. Occupational therapy had the most remarkable difference with an increase of 10%, as shown in Table II with the increased values in bold.

V. Discussion

In this study, the division of the results per participant is fundamental to understanding the different results the application of social robotics could have in each case due to their specific characteristics. This is because each case has a different application method due to the adaptations made for P2 and P3. Within the pre and post-test results, an increase was found in all specialities except in speech therapy of P1. However, an evolution percentage of 85% was obtained, and it was maintained in the post-test. This participant who did not obtain an increase is the participant who meets the inclusion and exclusion criteria and who did not need any adaptation for the application in the sessions. *Taheri et al.* [6] indicate the importance of dividing the results into the different characteristics of the individuals. They are divided into high-functional and low-functional children, and in some differences in the groups, they are divided as individuals to specify the details of the outcomes. They conclude that a robot is a tool that contributes to music teaching in high-functioning participants. This indicates that the results were different according to the level of ASD. However, all participants obtained progress in assessing ASD and social skills performed at the end of the implementation with the NAO social robot. Likewise, in the present study, specific skills were evaluated and depending on the participant and their characteristics, the results had different behaviours.

An increase in attention to the therapist was obtained in all three participants, but P2, whose implementation was adapted using pictograms and sign language, showed greater visual attention to the therapist than P1 and P3. P1 performed better in the variables measured by the therapist which could be due to the communication difficulties of P2 and P3 due to their comorbidities (hearing sensitivity and lack of speech). Finally, P3 had the highest number of physical interactions per session because he communicated with the robot through touch. In addition, a total of 239 physical interactions were obtained, without causing any damage to the CASTOR robot, regardless of the type of interaction (rough or smooth).

Palestra et al. [17] present a method of communication with children with ASD through the implementation of the social robot NAO. This, generates the possibility of improving the methods of communication during therapy sessions in the case of participants such as P3, where through a method of selection of words and images, participants can communicate their needs, strengthening their speech and communication therapy sessions. Likewise, this study presents an adapted robotic method, which considering the results, strengthened P3 in their speech therapies (Phonoaudiology). Additionally, it was possible to implement and reinforce other therapy areas such as occupational therapy, psychology and physiotherapy.

Finally, it was possible to perform the necessary adaptations for P2 and P3 quickly. This demonstrates that in terms of usability, the CASTOR robot can adapt to the various interventions in which it can be used without damage. This supports what was stated by *Berk-Smeekens et al.* [8], who indicate that the uniqueness of the participants generates a broad implementation that encompasses a large number of skills or a specific and personalized implementation to the needs of each child. The CASTOR robot can be used in those broad implementations and those personalized.

The discussion and feedback obtained from therapists, parents and clinic managers are not presented in the present study. However, among the comments obtained after the end of each session and at the end of the study, there were comments about the participant's moods on the day of implementation. Some days the participants were distracted, in a bad mood or sad. However, the implementation was performed in any of the cases, and acceptable results were obtained, indicating that although the participant's mood does affect, this did not generate setbacks in the results. The CASTOR robot can adapt according to the participant's mood being adaptive implementations.

VI. Conclusion and future work

The implementation was made in three study cases. The results are divided into the variables measured by the therapist, time variables, physical interaction variables and the pre and post-test results.

In the post-test results, the three study cases improved or maintained the percentage of the evolution of the specialities evaluated in the Howard Gardner Clinic. This means that the robotic implementation helped improve the social skills assessed in the Clinic, independently of the participant's characteristics and the adaptation made. It is possible to speak of a technological contribution by evolving the web interface for handling the robot in terms of software. In the case of the adaptations made for P2, a tablet was added and adapted to the structure, protocol and implementation of the CASTOR social robot. The code and detailed images of the resulting web interface can be found on the CASTOR project github. These adaptations were made across the board for participants with these characteristics that are included in the comorbidities associated with ASD. In addition, the CASTOR robot demonstrates its adaptability to 2 case studies and can be adapted to more participants with different characteristics easily and quickly.

In addition, the CASTOR social robot implemented in the therapies was not damaged during the application in the three case studies, even though there were a total of 239 physical interactions in only four sessions per participant. To conclude, this demonstrates the usability of the CASTOR robot in terms of adaptability. Additionally, due to the unique qualities of the participants within the ASD, the participants had different behaviours in the variables measured by the therapist, time variables, and physical interaction variables.

However, we intend to evaluate the CASTOR robot in general ASD therapy settings with a more significant number of participants in future work. A future implementation with a significant number of participants with comorbidities would be made too. In addition, it is intended to be evaluated in other therapeutic environments due to its functional and usability qualities found in the present study.

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