Implicit Responses for Assessment of Autism Based on Natural Behaviors Obtained Inside Immersive Virtual Environment

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Abstract**—**The late detection and subjectivity of the assessment of Autism Spectrum Disorder (ASD) imposed a difficulty for the children's clinical and familiar environment. The results showed in this paper, are part of a research project about the assessment and training of social skills in children with ASD, whose overall goal is the use of virtual environments together with physiological measures in order to find a new model of objective ASD assessment based on implicit brain processes measures. In particular, this work tries to contribute by studying the differences and changes in the Skin Conductance Response (SCR) and Eye Tracking (ET) between a typical development group (TD group) and an ASD group (ASD group) after several combined stimuli using a low cost Immersive Virtual Environment (IVE). Subjects were exposed to a virtual environment that showed natural scenes that stimulated visual, auditory and olfactory perceptual system. By exposing them to the IVE, subjects showed natural behaviors while measuring SCR and ET. This study compared measures of subjects diagnosed with ASD (N = 18) with a control group of subjects with typical development (N=10) when exposed to three different conditions: only visual (V), visual and auditory (VA) and visual, auditory and olfactory (VAO) stimulation. Correlations between SCR and ET measures were also correlated with the Autism Diagnostic Observation Schedule (ADOS) test. SCR measures showed significant differences among the experimental condition between groups. The ASD group presented higher level of SCR while we did not find significant differences between groups regarding DF. We found high significant correlations among all the experimental conditions in SCR measures and the subscale of ADOS test of imagination and symbolic thinking. Regarding the correlation between ET measures and ADOS test, the results showed significant relationship between VA condition and communication scores.

Keywords**—**Autism, electrodermal activity, eye tracking, immersive virtual environment, virtual reality.

I. Introduction

The scientific literature defines the Autism Spectrum Disorder (ASD) as a biological disorder [1], which is characterized by social, communicative and repetitive behavior impairments [2], [3]. It includes other aspects such as sensory reactivity, play and motor activity, and cognitive deficits [4]. The affection has increased substantially in the last 15 years and it affects around 1 in 100 people in Europe [5]. The families are the first to detect it, at the age of around 36 months, when their child does not use words for communicating what she or he requests [6].

In this respect, the study of social condition about how people process, store, and apply information about other people and social situations and Social Cognitive Neuroscience (SCN) [7], discipline that is concerned with the study of the biological processes and aspects that underlie cognition [8], can provide us objective information about the ASD assessment.

Traditionally, most social cognition theories assumed that humans could deliberate and verbalize accurately their attitudes, emotions and behaviors [9]. The recent advances in SCN are showing that most of the brain processes that regulate our social interactions are implicit processes which occur automatically and out of conscious control and awareness [10]. Implicit measures can define alternative research method and/or technique capable of capturing the implicit brain processes or their underlying results, including brain images, behavior monitoring and psychosomatic results.

That is why there is a growing recent interest in the scientific community about the development of implicit measurement techniques for implicit brain processes that obviate the use of explicit measures [11]. The different techniques used are based on measurements that in turn are related to some implicit process.

In ASD, several implicit measures are being used so far that are based on cerebral and physiological imaging techniques such as functional magnetic resonance imaging (fMRI) [12], near-infrared spectroscopy (fNIRS) [13], electrodermal activity (EDA) [14], EEG [15], eye tracking (ET) [16] and heart rate variability [17]. What these diverse approaches have in common is that they all seek to provide an estimate of the construct of interest without having to directly request the participant for a verbal report.

It should be noted that, on the one hand, the vast majority of related works have only tested a single measurement technique, and not the synchronized use of various measures on the same subject, which, undoubtedly, would increase the reliability of the metrics obtained as it has been recently proposed [18].

The methodologies for taking these implicit measurements can include observing the behavior of the participant in a real scenario or designing experiments in controlled laboratory environments. The main problem with real scenarios is that it

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is not easy to study human responses in real situations due to the experimenter's inability to fully control the stimuli involved in the experience. In contrast, when the research takes place in experimental environments, the ecological validity of the context can be affected.

Autism Diagnostic Observation Schedule (ADOS) is the most useful instrument for diagnosis of ASD inside a laboratory/clinical environment. ADOS is a semi-structured assessment tool based on the method of direct observation where the therapist evaluates social interaction, play and imagination levels [6].

For a correct assessment of ASD, the therapist cannot ignore the sensory disabilities and overselectivity regarding the stimuli [19]. For this reason, this area of impairment is another domain in this paper and pencil test which can define the severity level of symptoms in each domain.

The downside of this test is that the children may have been taught to respond in a particular way [20]. Some of the assessing situations are probable to happen in the real world, leading to evaluations´ results that may not reflect the participants´ repertoire [21]. For this reason, the research should examine new assessment models based on implicit and objective measures inside controlled environments where the therapist can manage the stimulation degree.

Nevertheless, when subjects are confronted with controlled stimuli that do not include several other variables present in real-life situations, the ecological validity of the assessment tools can be lowered [22].

Virtual reality (VR) emerges as a promising technology that can overcome the aforementioned problems. VR offers the possibility of generating various real situations [23], including social situations that generate bodily experiences in which the body, the environment and the brain are closely related. Consequently, behaviors, attitudes and beliefs can be transferred from reality to virtual world and vice versa and can occur spontaneously and unconsciously, allowing to create and modulate situations with high ecological validity while maintaining high experimental control both in the presentation of the stimuli and in the capture of behavioral performance.

Various technological devices can create a sense of immersion, allowing subjects to have simulated behaviors, perceiving them as real [24] because it uses contextualized environments which show us dynamic and multimodal stimuli [25] where the behavior and neuropsychological responses can be tracked in real time.

It has been shown that the neural mechanisms that humans have when immersed in virtual environments are very similar to the mechanisms that originate in real life [23].

For this reason, VR is being used by neuroscientists to simulate natural phenomena and social interactions and creates interactive and multimodal sensory stimuli, which offers unique advantages over other methodologies of neuroscientific research [26]. The compatibility of VR with human behavior measurement technologies allows researchers to present multimodal stimuli with a high degree of validity and ecological control, while measuring changes in the brain activity.

Recent studies on the state of the art in the use of VR and SCN are proving their usefulness in several domains, such as cognitive neuropsychological assessment, affective induction and social psychology, including ASD for the predictability of the tool [25].

VR provides the therapists' environments where they can control the stimulation, increase it gradually or stop it at any time [27]. The majority of the studies have laid outside the assessment because of focusing on the treatment or training of daily abilities [28], social skills [29], empathy [30] or emotional recognition [31]. In general, the participants showed significant improvement in these abilities when desktop systems were employed. Since ASD children have a higher perceptual hypersensitivity [32] and they can show rejection to particular clothes [33], these studies had opted for desktop versions to avoid the inconveniences caused by VR helmets.

One alternative to VR helmet is cave lime systems or Immersive Virtual Environments (IVE), which are spaces with three projectors in the roof and three walls where the participants look at 3D images inside a monitored and safe environment. They have been applied for improving non-verbal communication [34], attention levels or for relaxing [35]. The IVE used until now were very expensive because they included hand and head tracker and stereoscopic vision. For this reason, we apply in our research a low cost IVE with which we can achieve archive natural interaction and free movement of users.

From these early studies, we can conclude that VR can elicit complex human reactions in children with ASD to virtual stimuli, and manipulation of VR can contribute to the understanding of implicit brain processes related with ASD. This is highly encouraging for the future application of VR to ASD. Previous literature indicate that significant advances have been made in the study of the use of VR for insights into ASD related behaviors. This has largely been unheralded, perhaps because the methodological quality has been limited and the potential for wider dissemination hitherto constrained. The studies have typically been small, negative results are less likely to have been reported, and, in most places, the literature has been distinctly piecemeal. Progress has been understandably slow because hardware and software have been expensive and expertise limited. This is about to change thanks to the commercial availability of low cost VR devices. VR technologies have been poorly applied to ASD. Several social interaction deficiencies related with ASD can be assessed in VR, but robust tests of reliability and validity have been very few; compared with retrospective self-report, VR has the potential to prove a 'gold standard' assessment method for many implicit measures of social cognition in ASD but this has not remotely been tested. To our best knowledge, there is no research reported on the use of VR to study the implicit brain processes involved in social cognition in children with ASD.

Previous works have proposed using Electrodermal Activity (EDA) as an objective measure of several cognitive deficits associated with ASD [36] or for measuring an atypical cognitive reaction to stimuli [37]. This measure provides a response of neurophysiological underlying processes associated with the sympathetic branch of autonomic nervous system. This all translates into an increase of the unconscious sweating of the individuals when they are in front of stimuli. It has two phases: Skin Conductance Response (SCR) and Skin Conductance Level (SCL). SCR changes are fast and it is the internal response associated with an external stimulus [38]. It is related with alert, vigilance and activation levels [39]. The EDA focused on ASD children has been studied to detect emotional states [40]. The findings with ASD are mixed. The inconsistency of their results may be associated to the existence of different EDA profiles in the experimental subgroups or to the age differences in the sample. Furthermore, each study has focused in a different phase of this measure [14].

Regarding the sensory modalities to which participants are exposed to, few previous studies have analyzed the olfactory perceptions in ASD. Research observed either a disturbance in this sensory channel in ASD children [41] or disturbances in odor threshold and detection [42]. Some of them has found a relation between pleasant odors and emotional reactions [43].

Eye tracking (ET) measures have been used to find gaze patterns that could be related with core deficits of ASD [44] and for training social interaction [45], emotional recognition [46] and communicative skills [47]. The gaze information provides data about social, emotional and cognitive development of children [48]. Delayed face recognition is considered an early predictor of affection [49]. Overall, the duration of fixation (DF) is linked with abnormalities in neural circuits. Dalton et al. found a correlation between the DF and activation of fusiform gyrus in the discriminate activities [50].

Very few previous works have proposed a synchronized use of SCR and ET. These works were focused on the expression of the emotional states though SCR and metrics of pupil dilatation [51] or identification of emotions related to psychosocial measures and gaze patterns [52]. Previous works have been realized in real context, where we lack stimuli control [22] or have exposed the subjects to low immersive stimuli presented in a PC screen, thus affecting notably the ecological validity of the data.

This work is part of a research project whose overall goal includes the assessment and training of children with ASD. In order to find a new model of objective ASD assessment based on implicit processes virtual environments were used together with physiological measures such as SCR, gaze behavior and movement. Also, the project aims to develop natural environments for sensory stimulation training. In particular, the major objective of this study is to contribute to define the differences in the DF and SCR between children from a typical development group (Group 1) and a ASD group (Group 2) after a visual (V), visual and auditory (VA) and visual, auditory and olfactory (VAO) stimulation inside a low cost IVE.

II. Method

A. Participants

The study included 38 participants between the ages of 4 and 7 years divided into two groups. The typical development group (Group 1) included 10 children with typical development while the ASD group (Group 2) was formed by 18 children who have been diagnosed with ASD.

The children with ASD were recruited from Psychotherapy Centers, ASD Associations or Hospital of Valencia (Spain). They provided children's assessment reports with the precious consent of the families. This assessment report included ADOS´ results. This test is used for assessing social and communication behaviors and to determine the severity of symptoms. The scale has five modules, and each one is tailored to the age and communication levels of participants. The rank of age, development or communication levels is wide and it includes cut scores for diagnose. The participants of the typical development group came from a sample management company or targeted mailings disseminated through families of children with ASD.

Concerning the physiological recording devices, user acceptability tests were previously conducted with the subjects. The wristband used for measuring SCR did not cause discomfort to any participants. ET glasses were tolerated by every participant of the typical development group and by 9 of the ASD group. Only 9 children from the ASD group tolerated the SCR wristband and have also been evaluated by ADOS. The rest of the participants had another type of assessment procedure. Only 6 participants tolerated both SCR and ET devices and also had an assessment with ADOS being thus selected for the study. Table I shows the histogram distribution of user acceptability test.

TABLE I
User Acceptability Test Results

Sample	Typical Development Group (Group1)	ASD Group (Group 2)
EDA Wristband	10	18
Eye Tracking Glasses	10	9
ADOS-EDA		9
ADOS- Eye Tracking		6

The researchers informed families about the study's objective and the devices to use and they gave us their written approval before joining the research started. The parents could withdraw the participant from the research at any time.

We conducted a mixed design that includes groups (2 levels: Control Group and ADS Group) as between subjects' factor and stimulation (3 levels: Mean Visual Stimulus (VX), Mean Visual and Auditory Stimuli (VAX) and Mean Visual, Auditory and Olfactory (VAOX). We had measured the SCR and DF of the ET device in each stimulation conditions and these were counterbalanced. Table II shows a summary of experimental design.

B. Environment

The 3D virtual environments were developed using Unity3D software and projected in an immersive room with a total volume of 4 x 4 x 3 meters. The room was equipped with 3 projectors that have a 4,000 lumens bright. The sound system used was Logitech Speaker System Z906 500W 5.1 THX Digital. Fig. 1 represents the Olorama Technology™ [53],. It is a wireless device for odor stimulation that features 12 scents arranged in 12 pre-charged channels, which can be chosen and triggered by means of a UDP packet. The device is equipped with a programmable fan that spreads the scent around. Both the intensity of the chosen scent (amount of time the scent valve is open) and the amount of fan time can be programmed.

TABLE II
EXPERIMENTAL DESIGN

Condition	Stimuli	Abbreviation GSR/ ET	Exposure Time	Signal
Baseline	Forrest and relaxing music		120 sec.	SCR and DF
Mean Visual	Greeting	VX/ ET.VX	153 sec.	SCR and DF
Mean Visual and Auditory	Dancing	VAX/ ET.VAX	153 sec.	SCR and DF
Mean Visual, Auditory and Olfactory	Eating	VAOX/ ET.VAOX	153 sec.	SCR and DF
TOTAL TIME			479 sec (9,65 m)	

Fig. 1 Olorama Device

The IVE experience occurred in 9 minutes and 65 seconds and had 4 phases. Fig. 2 represents the first phase where the participant saw images of a forest and heard a relaxing music. This stimulation was considered the baseline.

Fig. 2 Illustration of the environment in the baseline

In the second phase, subjects were exposed to only visual stimulation (VX) by mean of a street environment where an avatar turns up from the left side of the immersive room and he/she goes to the central wall. Here he/she acknowledges the participant and then leaves through the right wall. Both a boy avatar and girl avatar were used in each condition.

During the third phase, visual and auditory stimulation (VA) were presented in the form of an avatar that turned up from the left side to the central wall while dancing the song "Last Dance" of Dona Summer. Fig. 3 shows a participant interacting with IVE in VA condition.

Finally, in the fourth phase, the participant was stimulated in the three modalities: visual, hearing and olfactory (VAOX). An avatar turned up from the left side of the immersive room and he/she went to the central wall. Here he/she ate a butter cake while the Olorama device threw a butter odor. Fig. 4 represents an avatar eating in the VAO condition.

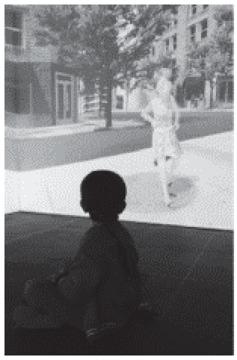

Fig. 3 Illustration of the VA stimulation while the avatar is dancing

Fig. 4 Illustration of the VAO stimulation while the avatar is eating

C. Measures

Fig. 5 represents the Empatica E4 wristband [54]. It is a wearable wireless device designed for continuous and real-time acquisition. It is also capable of measuring photoplethysmography (from which heart Inter-Beat-Interval is derived), temperature, and acceleration through a 3-axis accelerometer.

Fig. 5 The researcher placing Empatica E4

SCR signal was pre-processed and analyzed. The SCR analysis toolbox Ledalab (V3.4.8) [55], executed under Matlab (2012a) [56] was used for the entire process. Pre-processing consisted on two phases: (1) low-pass Butterworth filtering at 2.5Hz, in order to limit the signal according to the energy of the SCL and SCR components [57]; and (2) visual diagnostic of artefacts and their corrections using "spline" interpolations with 1-second pre/post periods around the artefacts. Analysis was based on the Continuous Decomposition Analysis (CDA) method [58] in order to extract the SCL and SCR components. Finally, all values were standardized using an adaptation of the Venables and Christie formula [59] that allows negative values in order to reduce inter-subject differences.

The Tobi Glasses Pro 2 [60] recorded the data about ET. Fig. 6 shows wireless ET glasses, which allows tracking the participant´s gaze while they are freely moving inside the IVE. The device contains cameras, which provide information about participant's eyes movement and participant's field of vision in the center of the glasses. The device has a sample rate of 25 Hz and a 1920x1080 pixels resolution. That translates into a field of view of 82° horizontally and 52° vertically. The data were transmitted via Wi-Fi from the glasses' wireless pocket to the Biometric Software Imotions v. 6.2 [61]. The software exported ET data and was used to add automatic marks for the more important moments in the study.

Fig. 6 Eye Tracking device Tobi Glasses Pro 2

D. Ethical Standards

The authors declare that they have no conflict of interest. The Ethical Committee of the Research Institute of the Polytechnic University of Valencia (Spain) has given us their approval.

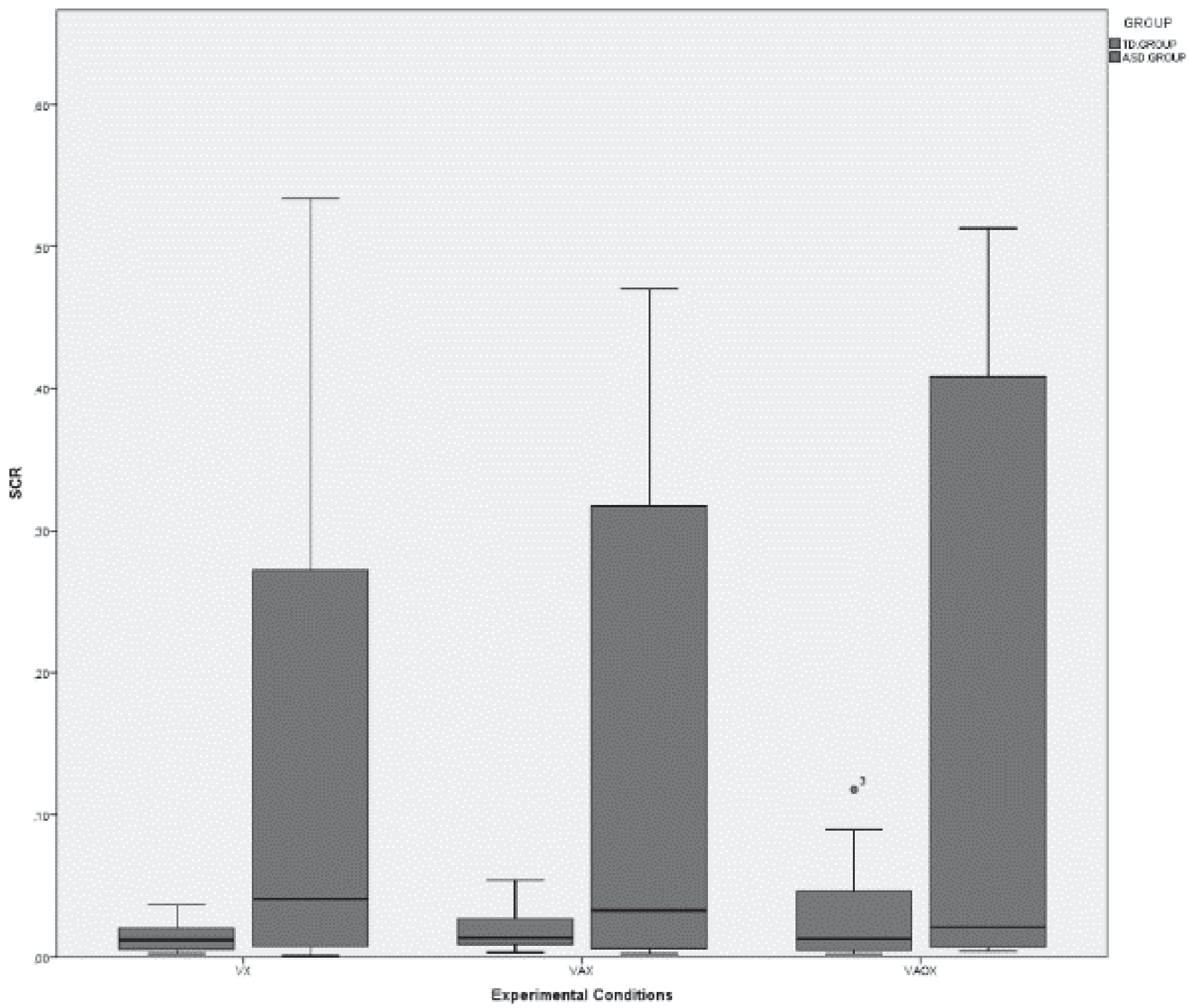

Fig. 7 Comparison of the SCR levels in the different conditions between groups

III. Procedure

When subjects arrived, their families completed written information about the study and gave us their written consent. Then, they completed a survey with personal information included: complete name, birth date, sex, age, ASD assessment, date of assessment Questionnaires' Assessment, other pathology, school type and stimulation center.

Afterwards, the researchers showed the Empatica E4 and Tobii Glasses 2 to the participants. The wristband device was placed in contact with the skin in the non-dominant hand.

Then we put on the ET glasses and proceeded to calibrate the device. The calibration was the only one point. Finally, the participant entered the immersive room where he/she was always accompanied by his/her parents while exposed to the experimental conditions (about 10 minutes) as described previously.

IV. Results

IBM SPSS Statistics Bate 22 was used for analysis. We focused on SCR because it refers to EDA activation of the participant after a stimulus (Christie, 1981) [39] and DF because it provides cognitive load and emotional reaction. Mixed analysis of variance were used to find the main effects of the stimulus and individual regarding the SCR and DF measures. Next, One-Way ANOVAs were conducted to test whether the SCR responses and DF changed according to the exposure condition (VX, VAX and VAOX). The Pearson Correlation was applied for researching the relation between experimental conditions and ADOS scores on both these measures. The level of significance was set at $\alpha = .05$.

Results indicated a marginal main effect for stimulus $F(2, 54) = 2.818$, $p > .05$, and there was a significant main effect for individual $F(27,54) = 49.475$, $p < .01$.

We studied the comparison among the conditions of stimulation. The results showed significant differences between VX (mean ± SE= 0.098 ± 0.007) and VAOX conditions (mean ± SE= 0.123 ± 0.007) $p < .05$.

One-way univariate ANOVA was used for studying the differences between Group 1 and Group 2 in each VX, VAX and VAOX conditions in SCR measures (Fig. 7). The results showed that in VX condition the Group 2 showed higher electrodermal activity (mean ± SD= 0.14± 0.164) than the Group 1 (mean ± SD= 0.01± 0.010), $F(1, 26) = 6{,}11$, $p = .020$. There were significant differences in VAX condition between the Group 2 (mean ± SD= 0.16± 0.185) and the Group 1 (mean ± SD= 0.01± 0.015), being the higher values observed in the Group 2, $F(1, 26) = 5.92$, $p = .022$. Equally, the Group 2 (mean ± SD= 0.17± 0.209) showed higher levels of SCR than the Group 1 (mean ± SD= 0.03 ± 0.040) in VAOX condition $F(1, 27) = 4.43$, $p = .045$.

We searched for correlations among the experimental conditions and ADOS scores regarding SCR measures. We only had nine participants who had been diagnosed using ADOS questionnaire in our sample. Thus the sample descended from N=18 to N=9 for research correlation (see Table 1).

We found high significant correlations among all the experimental conditions (between VX and VAX, $r = .942$, p (one-tailed) $< .05$; between VX and VAOX, $r = .904$, p (one-tailed) $< .05$; between VAX and VAOX, r =. 978, p (one-tailed) $< .05$). There was a significant relationship between Imagination scores and all the experimental conditions (between imagination and VX, $r = .864$, p (one-tailed) $< .05$; between imagination and VAX, $r = .957$, p (one-tailed) $< .05$; between imagination and VAOX, $r = .990$, p (one-tailed) $< .05$).

Regarding the DF measures, the sample increased from N=10 to N=11 in the Group 1 and descended from N=18 to N=12 in the Group 2 because of the intolerance of some of the children to the ET device. We found a significant effect for stimulus $F(2, 42) = 0.595$, $p < .05$, but not for individual $F(21,42) = 2.002$, $p > .05$ (see Fig. 1).

The One-way univariate ANOVA revealed that there were not significant differences between groups in the experimental conditions in the DF measures.

We searched for correlations among the DF measures and ADOS domains scores, but we only had six participants who tolerate the ET device and had been diagnosed using ADOS questionnaire in our sample. Thus, the sample descended from N=12 to N=6 for research correlation. There was a significant relationship between ET.VAX condition and Communication scores, $r = .934$, p (one-tailed) $< .05$; between ET.VAX condition and Social Interaction $r = .788$, p (one-tailed) $< .05$ and ET.VAX condition and total scores $r = .838$, p (one-tailed) $< .05$.

V. Discussion

This study examined SCR as a valid measure for defining physiological profiles between neurotypical and ASD children in a IVE. We found that there was a different pattern of activation in each group. Thus, there are different profiles of EDA depending of the child [62]. When the stimulation increased through the experimental conditions, the SCR levels also increased and it was higher in ASD children. These results are coincident with Lovaas et al. who claimed that ASD children tended to show stimulus overselectivity, which means they respond to a limited number of signs from their environment. The results demonstrated that healthy children could respond to all cues equally, while autistic children could respond to only one stimuli at a time [19]. This stimulus processing pattern could explain our data as the ASD group presented significantly higher EDA levels with sound and odor stimuli. These results are in accordance with recent works that detected SCR increment when ASD participants were exposed to sound stimulation levels [63] and the relationship between SCR and the severity of ASD symptoms [14].

The higher EDA levels when the ASD children were exposed to the odorous stimuli are in accordance with previous works that studied the relation between SCR measures and odor processing in ASD children. The findings showed that children with ASD were more smell sensitive than typical developing children [64]. The learning process could explain these results because ASD children have been participating in therapeutic intervention, where they have learnt to respond in presence of stimuli such as greetings or sounds [21]. Even so, the SCR can be in the future a robust indicator of ASD.

Regarding the duration of fixation, a measure which is related to the engagement to a stimulus, previous work such as Bakele et al. found similar results. They did not find significant differences between neurotypical and ASD children, although the ASD group had lower duration of fixation than the controls [65].

We found a relation between SCR in all experimental conditions and the Imagination and Symbolic Play domain in ADOS scores. This correlation could be related with divergent thinking, because for imagination we need to develop a divergent thinking [66]. Overselectivity and divergent thinking together could be an explanation why we found a correlation between the Imagination and the SCR scores. If they are focused on a specific part of the stimulation, then they will have problems to analyze it and consequently, the divergent thinking could also be affected [66].

Finally, the relation among Communication, Social Interaction and SCR measures are in accordance with the research of Chita-Tegmark. M., J. R. Irwin and L. Brancazio. They related the gaze pattern of ASD children with impairments in communicative [47] and social capacity [45].

These findings should be replicated with a large number of participants for drawing better conclusions.

Despite the limitations, we consider that future researchers could improve IVE and create an appropriate context in which therapists might be given the chance to assess children in individual, natural and safe environments. Psychological measures, together with IVE, can be used for objective assessments of children while they are immersed in a real life type environment, without compromising their security; these children often feel overwhelmed by the variety of stimuli in the real world.

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