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Are touch screen technologies more effective than traditional educational methods in children with autism spectrum disorders? A pilot study

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Abstract
Applied Computer technologies can address the needs of individuals with autism spectrum disorders (ASD). Data on the efficacy of assistive technology in ASD is limited, and its effectiveness in supporting and facilitating skill acquisition in this specific population must be still demonstrated. 63 Italian ASD subjects underwent learning activities administered by cardboards or a touch screen support. The support preference was evaluated in a choice trial, and quantitative analysis was performed on items regarding communication and challenging behaviours. Touch devices are attractive especially for males without intellectual disability and a lower communication and cooperation behaviours with the use of touch screen compared with paper support was shown depending on activities. Overall, our data do not confirm the hypothesis that touch screen presentation improves activity completion and behavioural performance for each individual with ASD. Data discourage an indiscriminate use of these devices and suggest analysing with more attention the core ingredients that should shape digital devices when used for people on ASD.

Key words
- autism spectrum disorders
- assistive technology
- touch screen
- structured learning

INTRODUCTION

Individuals with autism spectrum disorders (ASD) present special needs to sustain daily life and skill acquisition that often include external stimulus prompts to initiate, maintain, or terminate a behaviour. In particular, several studies emphasized the preference of this population towards visual stimuli, particularly those delivered via electronic screen [1, 2].

This attitude is supposed to be at the basis of the better use and learning from visual instructions of people with ASD [3-6]. However, some data are in contrast with the hypothesis that individuals with ASD are visual learners [7-9].

In the context of assistive technology, many types of computing systems are becoming more and more important in clinical and educational practice. In particular, enthusiasm towards tools that appear more appealing for users with ASD has led to a large diffusion of computer assistive technology (CAT) in different settings (laboratory, school, home), with the aim of improving language, cognitive, socio-emotional, adaptive as well as academic skills, and potentially allowing the sharing of intervention strategy across all child life environments [10-15]. Notwithstanding such interest, careful evaluation of the effects of these new technologies compared to traditional methods is still required [12, 16-18].

In first studies aimed at evaluating efficacy and validity of CAT for the habilitation of ASD people, researchers reported a positive effect of CAT, with an increase of pair to pair interaction and skill in communication, and a decrease in repetitive and challenging behaviours [19, 20]. Further studies confirmed such a positive effect, with particular relevance of the role of CAT in increasing access to educational programs and decreasing maladaptive behaviours [21-23]. CAT is indeed considered a useful medium to provide learning goals as it offers standard, automatic and predictable instructions, avoiding in vivo social behaviour that might overburden people with ASD [10, 24]. The automation is also an advantage for the trainer in the case of activities and tasks which need high level of repetition [25, 26], and potentially reduces need of individual support at school and/or at work [27].

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Structured intervention packages for ASD such as Treatment and Education of Autistic and related Communication Handicapped Children (TEACCH) [28] and Applied Behaviour Analysis (ABA) [29] place a heavy emphasis on structure and repetition, and on establishing a background environment that children do not find overwhelming. Furthermore, TEACCH and ABA principles involve adapting the behaviour and skill level to suit the subject's personal unique needs. In this framework, CAT appears a useful medium to provide individualized learning goals. Indeed, computer technology allows a wide quantitative and qualitative storage and analysis of data, resulting in an increased availability of examples (figures, words, video, colours and layouts) that educators can introduce in individual programs, and the tracking of each user's progress with the opportunity to modify the difficulty levels as a result [30]. Finally, a large part of the literature on the use of technology by people on the autism spectrum has pointed out its value as augmentative device to support interaction and communication [31]. Rather than "digital bubble", WEB navigation and the development of online dedicated forum appear to be tools useful to advocate, support, and emancipate people on autism empowering them towards social world [32, 33]. However, despite the apparent positive value of the online interaction opportunity, additional studies in this area are necessary to empirically confirm the efficacy and efficiency of the intervention with digital technology taking into account intervention specificity and its implementation by digital device [12, 25, 34].

Among the computer assistive technology, the use of multi-touch screen devices is growing. Despite this, few studies aim to verify if touch screen technology may provide a new way to deliver intervention to young children or to those with severe intellectual disabilities. Overall, studies showed positive effects of the use of multi-touch on challenging behaviour [22] and on active participation to learning programs [35, 36], as well on pair interaction and collaboration [31, 37, 38]. However, a recent review that analysed 34 studies stressed that research on the use of touch screen technology was focused on very basic use of the devices and was carried out on a limited sample of subjects. Furthermore, it was performed especially in school or home setting [39].

The present study aims to explore if multi-touch screen technology is actually friendly and able to improve compliance during ambulatory education activities with respect to traditional support. The study analysed the preference towards either little card-boards (PA, paper activities) or a multi-touch screen support (TA, touch activities) in a sample of subjects representing the ASD population usually attending local health ambulatory units. Furthermore, activity completion, behavioural performance, and communicative exchange of ASD subjects were assessed in order to evaluate the compliance of individual with ASD undergoing activities provided by means of PA or TA support.

METHODS

Participants

The study was carried out in the Center for Autism and Asperger Syndrome (CASA, ASL CN1, Mondovì, Italy), an ASD specialized outpatient service of the Italian public health system. All the subjects that were resident of Mondovì and were followed by CASA for habilitation intervention in the period 2012-2013 were assessed for enrolment. Exclusion criteria were genetic syndromes or motor disability at clinical examination. In that period, the total of resident patients in the health district amounted to 170, 61 (36%) were followed only for diagnosis or assessment. Among the 109 patients followed by CASA for habilitative intervention, 63 gave the consent to video-recording and data use for research. *Table 1* describes the final sample that included 63 subjects, 55 males (87.3%) and 8 females (12.7%), in the age range 4-32 years. Participants were grouped by means of their school attendance that in Italy is compulsory from 6 to 16 years of age. This number of subjects allows to evaluate small to medium size differences (Cohen d_z = 0.36) in a paired t-test with two-sided alpha = 0.05 and power = 0.80.

All the participants had an ASD diagnosis based on DSM-IV and ICD-10 criteria. The clinical diagnosis was supported by at least one standard assessment tool: specifically, the younger subjects (n. 30) had been evaluated with ADOS (Autism Diagnostic Observation Schedule) [40] while the older ones had been evaluated with other tools such as CARS (Childhood Autism Rating Scale*)* [41]), GARS (Gilliam Autism Rate Scale) [42] and ABC (Autism Behaviour Checklist) [43]. All diagnoses fulfilled the criteria for DSM-5 autistic spectrum disorders. Intelligence quotient was measured by WISC or WAIS (Wechsler, 1974, 1981, 1991), respectively for verbal children and verbal adolescents /adults (n = 46, 73.0%). Intelligence quotient was measured by Leiter (Roid & Miller, 1997) for the non-verbal subjects (n = 17, 27.0%). Adaptive behaviour was assessed by clinical evaluation, that was confirmed by Vineland Adaptive Behaviour Scale [44] where available (n = 43, 68.3%). Based on IQ and adaptive behaviour, subjects were classified in the categories of intellectual disability (ID) according to DSM-5 criteria. The family education level (measured as the higher attained level between parents) was also recorded.

As use of technology is currently allowed in health service for habilitation programs, review by an ethics committee was not mandatory for this kind of study (observational study). However, as stated above, we informed and asked for consent all subjects followed for habilitative intervention, and enrolled only those that accepted to participate.

MATERIALS AND SETTING

The study took place in the CASA center, in two comparable sized ambulatory rooms (about 3m x 4m), each room assigned to a treatment (PA or TA protocol). Both rooms were stimuli free, and furnished with only two chairs and one table. The TA protocol was administered individually by a multi-touch tabletop. The touch-table used in the study was part of CASA provision since 2010. It was suitable for compulsory schoolers/adolescents/adult children, while it was inappropriate for children under 5, due to the table height (25") and to the very large screen (47"). Indeed, to be comfortable in

Table 1
Description of the subjects participating to the study

	TOT		Diagnosis				Intellectual disability		
			AD	NOS	AS	n.a.	No	Mild	Severe
	n	%[a]	%[b]	%[b]	%[b]	%[b]	%[b]	%[b]	%[b]
Sex									
Male	55	87.3	54.6	32.7	7.3	5.5	16.4	49.1	34.5
Female	8	12.7	25.0	50.0	0.0	25.0	0.0	50.0	50.0
Age range									
PS	9	14.3	66.7	33.3	0.0	0.0	0.0	88.9	11.1
CS	34	54.0	44.1	41.2	5.9	8.8	11.8	52.9	35.3
NCS	9	14.3	55.6	33.3	11.1	0.0	33.3	11.1	55.6
AU	11	17.5	54.5	18.2	9.1	18.2	18.2	36.4	45.4
Diagnosis									
AD	32	50.8					3.1	43.8	53.1
NOS	22	34.9					22.7	59.1	18.2
AS	4	6.3					75.0	25.0	0.0
n.a.	5	7.9					0.0	60.0	40.0
Intellectual disability									
No	9	14.3	11.1	55.6	33.3	0.0			
Mild	31	49.2	45.2	41.9	3.2	9.7			
Severe	23	36.5	73.9	17.4	0.0	8.7			
Family educational level									
Elementary/Middle	19	30.2	52.6	36.8	5.3	5.3	10.5	47.4	42.1
High	31	49.2	48.4	32.3	6.5	12.9	12.9	54.8	32.3
University	13	20.6	53.8	38.5	7.7	0.0	23.1	38.5	38.5

Age range: PS = preschoolers (4-6 years), CS = compulsory education schoolers (7-15 years), NCS = non-compulsory education schoolers (16-18 years), AU = adults (19-32 years).
Diagnosis: AD = autistic disorder, NOS = pervasive developmental disorder not otherwise specified, AS = Asperger syndrome, n.a. = ICD10 F84 subcategory not available.
[a]Percentage computed on the total of subjects (n = 63).
[b]Percentage computed on the subjects belonging to the category indicated in the corresponding row heading.

looking at a screen the subject should sit at a distance where the screen fills 30° of subject's horizontal field of view. Since children under 5 must sit at a maximum distance of about 1.3 ft to be able to perform activities on the touch screen, the resulting optimal screen size should be under 20". Therefore, we used a 17" multi-touch screen in subjects younger than 5yrs. Although all the enrolled subjects were familiar with computers and/or touch devices (such as tablet, IPad, IPod, touch-screen phone), no one of them had previously seen and used the multi-touch tabletop.

Autism specialized operators administered the PA protocol by set of cardboards specifically made for this study using ARASAAC (Portal Aragonés de la Comunicación Aumentativa y Alternativa, http://arasaac.org/index.php) pictograms and uppercase letters. The operators supervised and assisted both TA and PA procedures and provided specific helps when necessary (see procedure description).

Both PA and TA protocol included four activities: (1) visual discrimination (VD), (2) classification (CL), (3) word-picture pairing (WPP), and (4) picture-picture pairing (PPP) (see *Table 2A* for a detailed description). Activities included in the protocol were chosen based on two main considerations: the activities are those usually delivered during ambulatory intervention; they can be implemented on touch screen support. Indeed, they are structured and almost self-explaining, they require and utilize only visual (CL, PPP) or visual and auditory sensory channels (VD, WPP), and they can be organized according to different level of complexity, thus preventing the occurrence of challenging behaviours due to boredom and/or annoyance possibly linked to the skill intensity demand. Four levels of complexity tailored on subject's age and IQ were defined for each activity: a) *low* (administered to n = 21 subjects), b) *medium-low* (administered to n = 21 subjects), c) *medium-high* (administered to n = 10 subjects) and d) *high* (administered to n = 11 subjects). Complexity levels and sample distribution according to complexity level, ID and age range are described in *Table 2A* and *2B*.

Procedures

Activities were presented to all subjects in the following order: VD, CL, WPP, and PPP. VD, CL, and WPP were delivered on both PA and TA, while PPP was pre-

Table 2A
Classification and description of activities included in the PA and TA protocols

Task	Description	Complexity level
VISUAL DISCRIMINATION (VD)	Verbal prompt: touch and give images corresponding to the operator request.	The four levels differ for number and size of objects that must be discriminated (the smaller the object, the more difficult the level)
CLASSIFICATION (CL)	One half of the picture cards lie on the table and the subject must associate each card with the image presented by the operator. Number and type of categories differ throughout trials.	Low level – two classification categories, in each category proposed pictures are equal. *Basal* trial: pictures are very different each others; *Intermediate* trial: pictures are different in colour; *Advanced* trial: pictures represent very similar objects. Medium-low level – three classification categories based on the geometric shape. Colour works as disruptive stimulus. *Basal*, *Intermediate*, and *Advanced* trials employ increasingly similar shapes. Medium-high level - three classification categories. *Basal* trial: home objects classification; *Intermediate* trial: food classification; *Advanced* trial: animals classification. High level – Classification of abstract categories. *Basal* trial: pictures and emotions; *Intermediate* and *Advanced* trials: abstract concept images.
WORD-PICTURE pairing (WPP)	Verbal prompt: touch the image corresponding to the operator request. The complexity of verbal prompt differs through the trials. ("Dog", "Touch the dog"; "Touch the barking animal"; "Touch the animal that gives a hearty welcome to its owner").	Images are increasingly similar to each other.
PICTURE-PICTURE pairing (PPP)	The subject must overlap images that are equal. The number of and similarity between images that must be paired increases through the trials.	Images are increasingly similar to each other.

PA: paper activities; TA: touch activities

Table 2B
Frequency of subjects according to the complexity level of the activity, ID and age range

		Age range				
Complexity level	**ID**	**PS 4-6 years**	**CS 7-15 years**	**NCS 16-18 years**	**AU 19-32 years**	**Tot**
Low	No	0	0	0	0	0
	Mild	9	0	0	0	9
	Severe	0	11	0	1	12
	Tot	*9*	*11*	*0*	*1*	*21*
Medium-low	No	0	0	0	0	0
	Mild	0	16	0	0	16
	Severe	0	1	4	0	5
	Tot	*0*	*17*	*4*	*0*	*21*
Medium-high	No	0	2	0	0	2
	Mild	0	2	1	0	3
	Severe	0	0	1	4	5
	Tot	*0*	*4*	*2*	*4*	*10*
High	No	0	2	3	2	7
	Mild	0	0	0	4	4
	Severe	0	0	0	0	0
	Tot	*0*	*2*	*3*	*6*	*11*
TOT		***9***	***34***	***9***	***11***	***63***

PS = preschoolers; CS = compulsory education schoolers; NCS = non-compulsory education schoolers; AU = adults

sented only on the activity support (either PA or TA) chosen by the subjects. Before starting each trial, the operator displayed to the subject how to perform the specific activity. The visual and auditory prompts foreseen for VD and WPP activities were supplied during PA modality by the operators, and during TA by a synthetic voice. During both activities, protocol permitted the following prompts: proximal indication, display of the task, and physical guidance. At the end of each activity, visual (smile emoticon) and/or auditory stimulus (synthetic voice) were provided to the subject on the TA, while on the PA the visual and auditory reinforcements were provided by the operator.

Treatment sessions were recorded by a video recording system and then the videos were analysed and scored by two operators. Frequencies of the following behaviours were collected *(see Table 3)*: Uncooperativeness, number of non-collaborative behaviour episodes (Uncoop); Stereotypies, number of stereotyped, repetitive or sensory behaviours (Stereo); Helps, number of helps (i.e. pointing at the correct answer, modelling, physical guidance, verbal help) needed to accomplish the activity (Help); and Communication ability, number of spontaneous communication acts (Ca). Behavioural quantitative scoring was performed by means of a preset scoring form by each operator. Time needed to complete the activity (Duration) was also recorded, using a chronometer.

Design

The study followed a crossover design. Each subject performed the first three activities (1st: VD, 2nd: CL, and 3rd: WPP, same sequence for all subjects) both on PA and TA supports. To control for learning effects, both sequences of treatment administration were considered (PA followed by TA, PA-TA; TA followed by PA, TA-PA). Each subject was randomly assigned either to PA-TA or to TA-PA sequence. The whole group of subjects was thus partitioned in two subgroups, namely the subgroup of subjects randomly assigned to the sequence PA-TA (n = 33, 53.4%) and those assigned to TA-PA (n = 30, 46.6%). The two subgroups did not differ with respect to sex, diagnosis, presence/degree of mental retardation and complexity level of the task (data not shown).

Statistical analysis

Quantitative variables are synthesized by mean and standard error of the mean (SE), median and range (minimum, maximum), while categorical variables by absolute and percentage frequencies.

The binomial test was used to evaluate if the proportion of subjects choosing TA support in performing the PPP activity was significantly different from the chance level (0.50, i.e. 50%), in the overall group of subjects and within each subgroup based on sex, autism diagnosis, intellectual disability, and order of support administration. A logistic regression analysis was also performed to determine which factor(s) among sex, age class, autism diagnosis, intellectual disability, and order of support administration was/were independently associated to the choice of TA support for the picture-picture pairing activity.

As for the behaviours collected through the scoring form during the card-based and the computer-based activities, the Intraclass Correlation Coefficient (ICC) was used to measure the interrater reliability between the operators that collected data. Coefficient up to 0.20 was interpreted as slight/poor agreement, from 0.21 to 0.4 as fair agreement, from 0.41 to 0.6 as moderate agreement, from 0.61 to 0.8 as substantial/strong agreement, and from 0.81 to 1.0 as almost perfect agreement (Landis & Koch, 1977). The ICC between the two operators was always high (strong to perfect) when considering stereotyped behaviours, duration of the activity, helps needed and communication ability, while it was lower (moderate to substantial) when evaluating the uncooperativeness *(Figure 1, panels A-C)*. Due to the overall good level of concordance, data from the two operators were averaged for each behaviour in each activity, and the averages were used in the following analyses.

Differences in the behaviours collected during the card- and the computer-based activities were analysed by multivariate analysis of variance (MANOVA) followed by Student paired t test. Specifically, in order to assess the effect of activity support on the overall behaviour within each activity we used a MANOVA model including activity support (PA *vs* TA) as within-subject factor and the whole set of variables (Uncooperativeness, Duration of the activity, Stereotypies, Helps needed, Communication ability) collected within the specific activity (VD, CL, WPP) as multivariate outcome. Secondly, at the aim of assessing the effect of activity support on the specific behaviour across all the activities performed we applied a different MANOVA model, including activity support (PA *vs* TA) as within-subject factor and the specific behavioural score collected in the different activities (VD, CL, WPP) as multivariate outcome. When a significant effect of activity support was found, the paired t test was performed to compare PA *vs* TA separately within each activity and for each dependent variable; Bonferroni's correction was applied to control for multiple testing (15 comparisons, pairwise alpha = 0.0033). Cohen's d (or d_z in case of paired t test) was computed as a measure of the observed effect size (values for d or d_z around 0.20 can be roughly interpreted as a small effect, around 0.50 as a medium effect, and around 0.80 as a large effect). MANOVAs were also repeated including sex, age (pre-schoolers, 4-6 years; CS = compulsory education schoolers, 7-15 years; NCS =

Table 3
Behavior's category and examples

Category	Example
Uncooperativeness (Uncoop): number of non-collaborative behaviour episodes	Go away from the task Push away the object Problem behavior Adult intervention
Stereotypies (Stereo): number of stereotyped, repetitive or sensory behaviours	Stereotypies that interfere with the task execution Stereotypies that don't interfere with the task execution Sensory interest Repetitive behaviors
Helps needed (Help): number of helps needed to accomplish the task	Helps allowed: Pointing at the correct answer, modelling, physical guidance, verbal help
Communication ability (Ca): number of spontaneous communications	Ask for help Make questions Share Comment

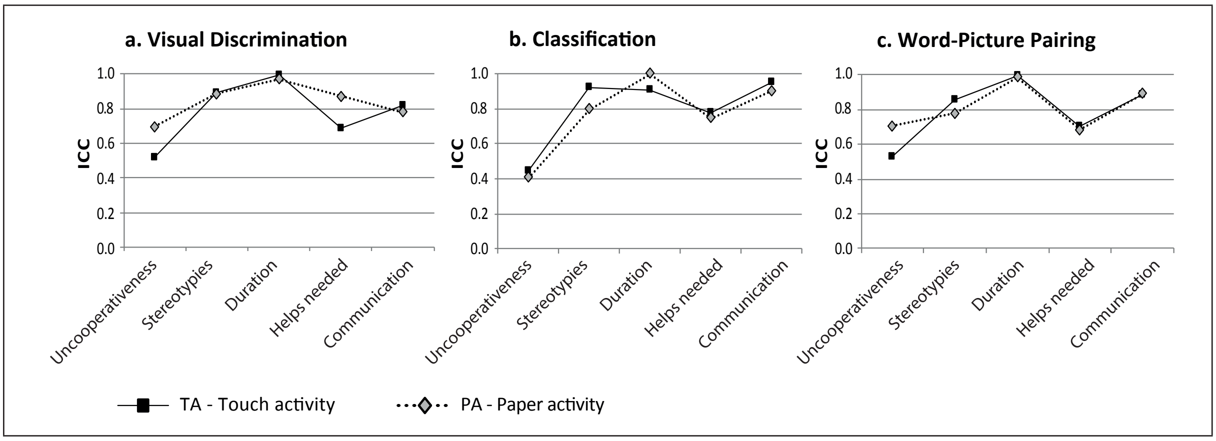

Figure 1
Intraclass correlation coefficient (ICC) between operators on the behaviours collected during visual discrimination, classification, and word-picture pairing activities (Panels a-c)

non-compulsory education schoolers, 16-18 years; AU = adults, 19-32 years), autism diagnosis (AD = autistic disorder, NOS = pervasive developmental disorder not otherwise specified), and intellectual disability (no, mild, severe), as between-subject factors, to assess the interaction of such characteristics with activity support, on subjects' behaviour during the activities.

For all statistical tests p values < 0.05 were considered statistically significant. Differences whose significance level was $0.05 < p < 0.10$ were mentioned if they were coherent and in agreement with other statistically significant results.

RESULTS

Support preference (TA vs PA)

Table 4 describes the results from binomial test performed on the preference of support for the PPP activity. Overall, subjects showed a preference towards

Table 4
Preference between PA and TA support in the Picture-Picture pairing activity, according to sex, age range, administration turn, intellectual disability, and ASD categories. Binomial test is reported

Group		PA		TA		Binomial test p (two tails)
		n	%	n	%	
OVERALL	63	24	38.10	**39**	**61.90**	**0.0769**
Sex						
Male	55	19	34.55	**36**	**65.45**	**0.0300**
Female	8	5	62.50	3	37.50	0.7266
Age range						
PS	9	6	66.67	3	33.33	0.5078
CS	34	14	41.18	20	58.82	0.3915
NCS	9	1	11.11	**8**	**88.89**	**0.0391**
AU	11	3	27.27	8	72.73	0.2266
Administration turn						
PA-TA	33	13	39.39	20	60.61	0.2962
TA-PA	30	11	36.67	19	63.33	0.2005
Intellectual disability						
No	9	0	0.00	**9**	**100.0**	**0.0039**
Mild	31	16	51.61	15	48.39	1.0000
Severe	23	8	34.78	15	65.22	0.2100
Diagnosis						
AD	32	15	46.88	17	53.13	0.8601
NOS	22	6	27.27	**16**	**72.73**	**0.0525**

PA = paper activity; TA = touch activity
Age range: PS = preschoolers (4-6 years), CS = compulsory education schoolers (7-15 years), NCS = non-compulsory education schoolers (16-18 years), AU = adults (19-32 years).
Diagnosis: AD = autistic disorder, NOS = pervasive developmental disorder not otherwise specified.

Table 5
Logistic regression analysis on Picture-Picture pairing activity

Independent factors	OR	95% CI		p
		lower	upper	
Sex				
Males	1			
Females	0.18	0.03	1.07	0.059
Diagnosis				
AD	1			
NOS	3.17	0.87	11.55	0.081

OR = odd ratio; CI = confidence interval; p = level of statistical significance
Diagnosis: AD = autistic disorder, NOS = pervasive developmental disorder not otherwise specified.

TA support (61.9% *vs* 38.1%, p = 0.077), significant in males (65.5% *vs* 35.5%, p = 0.030), in compulsory education schoolers (88.9% *vs* 11.1%, p = 0.039) and in subject ts with typical intellectual functioning (100% *vs* 0%, p = 0.004). PDD-NOS subjects too show a preference towards TA support that just felt short of statistical significance (72.7% *vs* 27.3%, p = 0.052). In parallel, the remaining subgroups of subjects did not show a significant preference towards either PA or TA support. Interestingly, the sequence of treatment administration did not affect the preference towards TA support, chosen by 60.6% of the TA-PA subjects and by 63.3% of the PA-TA subjects (p > 0.20 for both).

The logistic regression, performed to determine which factors were independently associated to the preference towards TA support in the PPP activity, confirmed the role of sex and autism diagnosis in affecting TA preference, even if the corresponding p-levels just missed statistical significance (p = 0.059 and 0.081, respectively) *(Table 5)*.

Behavioural response

The MANOVA performed within each activity showed a significant effect of the support on the overall subject's behaviour in the CL and WPP activities, while no effect was observed in the VD activity. The MANOVA performed on each behaviour across activities pointed out significant increase due to TA support in non-collaborative acts (Uncooperativeness), Duration, Helps needed, and a decrease in Communication ability, while Stereotypies do not appear to be significantly affected by the support. Specifically, based on paired t test results, TA support appeared to significantly increase non-collaborative acts (Cohen's d_z = 0.42) and Helps needed (Cohen's d_z = 0.83) during CL activity, and Duration (Cohen's d_z = 1.12) during WPP activity (for statistical details, see *Table 6*).

The effect of activity support was not significantly affected by sex, age, autism diagnosis and intellectual disability.

DISCUSSION

Our study contributes to the evaluation of touch-screen technology as teaching support during cognitive-behavioural intervention for persons with ASD. We enrolled a large number of subjects representative of the population usually attending Italian ASD specialized local health units, that included both sexes, and belonged to the main ASD sub-categories as defined by DSM-IV, and to different levels of intellectual impairment. Finally, we used a crossover design to compensate the lack of a control group, and though this may still impair generalization of the results, it appears to improve the methodological approach in this research field.

The evaluation of multi-touch screen technology, including tabletop, should necessarily take into account the value of this device in supporting educational ac-

Table 6
Results of multivariate (MANOVA, first line and first column) and univariate (t test, body of the table) analyses on behaviors observed during activities provided on PA or TA support (overall group)

			VD			CL			WPP		
			PA	TA	Effect size	PA	TA	Effect size	PA	TA	Effect size
			mean ± SD	mean ± SD	d_z	mean ± SD	mean ± SD	d_z	mean ± SD	mean ± SD	d_z
	MANOVA										
	across activities	*across behaviors*	*W(1,61) = 0.8790*	*p = 0.1834*		***W(1,61) = 0.5179***	***p < 0.0001***		***W(1,61) = 0.3063***	***p < 0.0001***	
Uncooperativeness	***W(1,61) = 0.8358***	***p = 0.0137***	0.19 ±0.70 *t(62) = 0.0887*	0.20 ± 0.70[a] *p = 0.9296*	*0.01*	**0.29 ± 0.70** ***t(61) = 3.3281***	**0.75 ±1.20a** ***p = 0.0015****	**0.42**	0.26 ±0.72 *t(61) = 0.8763*	0.35 ± 0.92[a] *p = 0.3843*	*0.11*
Stereotypies	*W(1,61) = 0.9667*	*p = 0.5689*	2.17 ± 5.21 *t(62) = 0.4387*	2.35 ± 6.21 *p = 0.6624*	*0.06*	4.83 ± 9.43 *t(61) = 0.0758*	4.89 ± 11.25 *p = 0.9399*	*0.01*	2.13 ± 3.81 *t(61) = 1.2965*	3.05 ±6.74 *p = 0.1997*	*0.16*
Duration	***W(1,61) = 0.4185***	***p < 0.0001***	64.52 ± 36.33 *t(62) = 0.1357*	65.21 ± 41.55 *p = 0.8925*	*0.02*	187.5 ± 63.58 *t(61) = 1.8320*	208.8 ± 104.4 *p = 0.0718*	*0.23*	**61.26 ± 18.08** *t(61) = 9.0780*	**102.5 ± 37.06** ***p < 0.0001*****	***1.15***
Helps needed	***W(1,61) = 0.5690***	***p < 0.0001***	1.75 ± 2.95 *t(62) = 0.9795*	2.05 ±2.92 p = 0.3311	*0.12*	**2.02 ± 3.52** ***t(61) = 6.5444***	**4.87 ± 5.41** ***p < 0.0001*****	**0.83**	1.62 ± 2.56 *t(61) = 1.2921*	2.14 ± 3.51 *p = 0.2012*	*0.16*
Communication ability	***W(1,61) = 0.8762***	***p = 0.0489***	1.69 ± 2.11 *t(62) = 2.2901*	1.02 ± 1.48 *p = 0.0254*	*0.29*	6.23 ± 10.86 *t(61) = 1.5855*	4.23 ± 6.23 *p = 0.1180*	*0.20*	2.60 ± 4.39 *t(61) = 0.2663*	2.45 ± 3.63 *p = 0.7909*	*0.03*

VD = visual discrimination; CL = classification; WPP = word-picture pairing. PA = paper activity; TA = touch activity. Duration= total duration of the task from assignment up to completion. SD = standard deviation; MANOVA = multivariate analysis of variance; W = Wilks' lambda; t = t test statistics; p = significance level; * p < 0.05 and ** p < 0.01, with Bonferroni's correction. For more detail, see the Methods section.

tivities by a low-cost, shareable (home, school, ambulatory), and adaptable intervention strategy that may also be able to reduce stigma among peers. However, this advantage from a social and 'economic' point of view should parallel the advantage at the individual level in supporting activities and reducing challenging behaviours that are widely reported to affect completion of learning trials.

The use of technology for children on ASD is supported by the idea that these children have a natural affinity for technologies that can support learning and social interactions [6, 15, 45, 46]. In our study, when the subjects had to choose PA or TA to perform the picture-picture pairing activity, more than 60% of them chose TA, but the preference was significantly evident only in high functioning male subjects, and, as a trend, in individuals with a PDD-NOS diagnosis.

One further point assessed in the present study is whether in a ASD population sample TA elicits aspects of behaviour that can be considered positive for and/or coherent with the accomplishment of the task. We used duration of the activity as a proxy of the ability to fulfil the task, and oppositional and avoiding behaviours and helps needed to carry on the activities as a measure of the level of cooperation elicited by the support during the activity session. Our results show that TA negatively affects duration of WPP activity that is almost twofold with respect to PA. A lower compliance with TA support was also suggested by the increase of uncooperative behaviours and helps needed to fulfil the task during CL activity. Finally, present data suggest that the use of PA and TA in delivering activities is not influential on the number of stereotypies emitted. However, demographic and diagnostic characteristics did not appear to influence behavioural response to TA. This suggests that individual dimensional traits (i.e.: temperament, motivation, etc.), rather than categorical, could be more important in moderating the behaviours elicited by the two activity supports. Recently, it has been emphasized that skills and environment for which technology-based intervention has the potential to serve as support, as well as preference of both users and professionals, have to be taken into consideration [47, 48].

Communication, and in particular spontaneous communication, represents a domain of behavioural impairment that needs to be empowered in the majority of people on ASD. Indeed, results from the present study do not definitely support the facilitative role of TA showing, in same case, a negative effect on spontaneous communication. However, the TA procedure used in the present study appears insufficient to elicit a different quality of learning compared to PA. It is possible that the tasks on which the TA *vs* PA relative efficacy was assessed here are intrinsically weak in eliciting spontaneous communication. TA technology could be advantageously used to support other learning strategies such as collaborative learning [38, 46, 49], or in different activities such as leisure or social interaction [12, 31, 37]. Some studies, performed on the use of multi-touch tabletop in session of augmentative alternative communication (AAC) learning [31] or multiplayer activities [38, 49-51], appear to demonstrate that increase in social interaction is one of the main goals attained from interactive session around the tabletop. Furthermore, the role of rewards or visual strategy applied appears relevant in terms of child engagement. A recent study compared "mand" acquisition (following Applied Behavioural Analysis techniques "mand" is an operant that describes the ability to ask for what you want), in three preschool-aged males with ASD, across three different displays in two iPad AAC applications. Interestingly, the study evidenced that AAC display and design elements may influence "mand" acquisition, as preschoolers did not performed equally across different AAC displays and configurations, but also that these elements should be chosen taking into consideration individual propensity and learning characteristics [52].

Implications

Although provisional and based on a short-term evaluation, our results show that multi-touch screen tabletop is attractive, but only for selected subsets of participants. In addition, results do not confirm the hypothesis that touch screen presentation improves activity completion and behavioural performance for each individual with ASD, discouraging an indiscriminate use of these devices. The individual variability in response to CAT technology, confirmed in our study, may account for the inconsistency among results published in the scientific literature, besides the heterogeneity among aims, protocols, and CAT applications.

An important limitation of our study is the cross-sectional design that does not allow assessing differences in learning progression between activities presented on TA *vs* PA supports. Prospective long-term studies are required in order to evaluate the long-lasting effects of multi-touch screen use on preference of the subjects and on changes in their behavioural outcomes during learning session.

Author contribution

FB participated in the design and implementation of the study, performed the measurement, and helped to draft the manuscript; AV participated in the design of the study and interpretation of the data, and drafted the manuscript; FC participated in the design of the study, conceived and performed the statistical analysis, participated in the interpretation of the data, and drafted the manuscript; GMA conceived and supervised the study, participated in the interpretation of the data, and helped to draft the manuscript. FC and GMA act as equivalent co-senior authors. All authors read and approved the final manuscript.

Compliance with ethical standard

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All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. Informed consent was obtained from all individual participants included in the study.

Conflict of interest statement

There are no potential conflicts of interest or any financial or personal relationships with other people or organizations that could inappropriately bias conduct and findings of this study.

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