J Autism Dev Disord (2014) 44:2230–2243
DOI 10.1007/s10803-014-2107-9

ORIGINAL PAPER

Visuospatial Processing in Children with Autism: No Evidence for (Training-Resistant) Abnormalities

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Published online: 3 April 2014

Abstract Individuals with autism spectrum disorders (ASDs) have been assumed to show evidence of abnormal visuospatial processing, which has been attributed to a failure to integrate local features into coherent global Gestalts and/or to a bias towards local processing. As the available data are based on baseline performance only, which does not provide insight into cognitive/neural plasticity and actual cognitive potential, we investigated how training-resistant possible visuospatial processing differences between children with and without ASD are. In particular, we studied the effect of computerized versus face-to-face visuospatial training in a group of normally intelligent children with ASD and typically developing children as control. Findings show that (a) children with and without ASD do not differ much in visuospatial processing (as assessed by a tangram-like task) and the few differences we observed were all eliminated by training; (b) training can improve visuospatial processing (equally) in both children with ASD and normally developing children; and (c) computer-based and face-to-face training was equally effective.

Keywords Visual spatial · Visualization · School based intervention · Response to intervention · Computer based instruction

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Introduction

Autism spectrum disorders (ASDs) are considered a group of developmental disabilities that can cause significant social, communication and behavioral challenges. People with ASDs handle information differently than other people. However, ASDs are "spectrum disorders," which among other things implies that ASD affects each person in different ways, and the impact can range from very mild to severe. People with ASDs share some symptoms, such as problems with social interaction, but symptoms often vary considerably in time of onset, severity, and exact nature [Centers for Disease Control and Prevention (CDC) 2013]. In acknowledging the significant increase of ASD prevalence from previous assessments, CDC refers to autism as an "urgent health concern" and stresses the need for research that not only deepens our understanding of ASD, but also develops efficient interventions that address both the strengths and weaknesses of affected individuals. The focus of the present study is on the latter by evaluating an intervention that targeted the supposedly atypical visual spatial processing capacity (VSPC) in children with ASD.

Atypical Visual Spatial Processing Capacity (VSPC) in Children with ASD

There is evidence that some individuals with ASD demonstrate atypical VSPCs which can be associated with both strengths and weaknesses in visuospatial cognition. On the one hand, individuals with ASD have difficulty recognizing familiar faces and correctly interpreting facial expressions (Behrmann et al. 2006; Dawson et al. 2005; Gross 2004; Kim and Johnson 2010; Klin et al. 2002; Simmons et al. 2009). On the other hand, they show superior visuospatial skills as compared to typically developing individuals, such as in Embedded Figures or Block Design Tests from the Wechsler Intelligence Scales (WISC) (Bonnel et al. 2003; Happé and Frith 2006; Koyama and Kurita 2008; O'Riordan and Plaisted 2001; Pellicano et al. 2006). Such atypical VSPC have been taken to reflect differences in global versus local information processing. Global information processing refers to the ability to integrate piecemeal information (e.g., 'trees') into a coherent whole ("the forest"), while local information processing refers to the ability to focus on details (e.g., Poirel et al. 2008).

Weak central coherence (WCC) theory (Frith and Happé 1994; Happé 1999) is one of the major, most influential accounts that address the atypical VSPC in ASD. The original concept of WCC assumes that while typically developing children have a natural tendency to integrate visual elements into global perceptual Gestalts (Farroni et al. 2000; Johnson 2010; Quinn and Bhatt 2006; Quin et al. 2002), children with ASD have a bias towards local processing. These focus on details, with corresponding problems in integrating information into a coherent whole.

Moreover, some children with ASD frequently are scoring substantially below average on IQ tests (<70) and demonstrating deficits in executive functions (in working memory, planning, sequencing, set-shifting, and verbal ability), while they outperform typically developing children on the WISC Block Design Test (Happé and Frith 1996; Joseph et al. 2009; Hill 2004; Robinson et al. 2009; Shah and Frith 1993; Stewart et al. 2009). Superior performance of children has also been demonstrated in discrimination tasks (Plaisted et al. 2003), in visual search (Plaisted et al. 1998; O'Riordan et al. 2001; O'Riordan 2004; Jarrold et al. 2005), rote memory (Frith and Happé 1994), and in map learning (Caron et al. 2004).

However, results are often mixed, and some studies suggested that both children and adults with ASD show poorer global processing than matched controls (Behrmann et al. 2006; Grinter et al. 2010; Rinehart et al. 2000; Nakano, Nakano et al. 2010; Wang et al. 2007). Other studies using the same type of task have reported no difference (Brian and Bryson 1996; Hayward et al. 2012; Iarocci et al. 2006; O'Riordan and Plaisted 2001; Ozonoff et al. 1994; Plaisted et al. 1999; Pring et al. 2010; Ropar and Mitchell 2001; Scherf et al. 2008; Van den Broucke et al. 2008). Only recently, however, Perreault et al. (2011) found enhanced global processing in adults and adolescents with ASD. Such mixed results have led to a modification of the original WCC theory. Instead of attributing the atypical VSPC in individuals with ASD to impaired global processing, the theory now claims a "local processing preference" in ASD (Happé and Frith 2006). In fact, Happé and Frith suggest that there is neither impaired global processing nor enhanced perceptual functioning, but a mere preference in ASD to focus more on local than on global information. Note that this theoretical shift from assuming a rather "irreparable" impairment to a mere preference has important implications for training and teaching.

Studies using hierarchically structured visual stimuli (e.g., Navon figures: large letters made of small letters; see Navon 1977) revealed that individuals with ASD respond to the global stimulus level more efficiently than controls (López and Leekam 2003; Mottron et al. 1999; Mottron 2003; Mottron et al. 2006; Ozonoff et al. 1994; Plaisted et al. 2003; Hayward et al. 2012; Iarocci et al. 2006; Scherf et al. 2008). As pointed out by Mottron et al. (2006), this does not support the assumption of a deficiency in global context processing in ASD but rather suggests a relative superiority in local processing, with global processing being unaffected. Mottron and colleagues therefore propose an "Enhanced Perceptual Functioning (EPF)" model as an alternative to the (original) WCC account. They assume that "superiority of perceptual flow of information in comparison to higher-order operations led to an atypical relationship between high and low order cognitive processes in autism, by making perceptual processes more difficult to control and more disruptive to the development of other behaviours and abilities" (Mottron et al. 2006, p. 2). In addition, López et al. (2008) have argued that local versus global processing can occur at two levels, a conceptual and a perceptual one, and individual with ASD can show weak central coherence in one, the other, or both. Others suggested that the hypothesis of bias towards local processing reflects a difference between ASD and typical controls in brain structure or functioning, e.g., related to face processing (Critchley et al. 2000; Schultz et al. 2000; Pierce et al. 2001; Hubl et al. 2003). Yet others have attributed the atypical spatial processing in individual with ASD to decreased connectivity between cortical regions (Just et al. 2004; McAlonan et al. 2004) or a tendency to use visual–spatial regions to compensate for higher-order cortical regions (Koshino et al. 2005).

However, as more research accumulates, so do inconsistent findings and unexpected differences with regard to global versus details information processing of individuals with ASD. The inconclusive results can be partly explained by the inclusion of a broad range of ages in the same study (e.g., cases with participants as young as 4 years of age through early adulthood; for an overview see, Happé and Frith 2006). In many studies, exclusively high-functioning individuals with ASD (Asperger's) participants are compared with a healthy control group. As the former do not have clearly defined cognitive impairments, finding significant differences may often not be expected (e.g., Edgin and Pennington 2005). Others have pinpointed the influence of prior knowledge (Mitchell and Ropar 2004) and question formulation (Brosnan et al. 2004), which can result in unexpected or misleading outcomes. For example, Brosnan et al. (2004) reported that participants with ASD were more accurate than controls when being asked whether two lines of an illusion-inducing display “looked the same length” but performed more poorly than controls when being asked whether the lines “were the same length”.

Given the rather static views of earlier theoretical accounts, previous studies assessing atypical VSPC in individuals with ASD were always based on traditional testing procedures—a single time-point of testing. Such a procedure provides valuable information on the baseline abilities or “default” performance of a participant’s VSPC, but fails to assess the potential for change and improvement through intervention and instruction. Assessing this potential seems particularly important early in life, when the brain is most flexible and plastic (Johnson 2010; Dawson 2008). In the present study, we employed a more dynamic approach to see whether interventions at an early age may allow children with ASD to develop perceptual abilities that are comparable or at least more similar to those exhibited by typically developing children. In particular, the main aim of this study was to evaluate the responsiveness of children with ASD to instruction within a short VSPC-enhancing intervention.

Face to Face Versus Computerized VSPC Intervention

Learning in children with ASD is often characterized by its spontaneous and implicit nature, which can lead to mastering very complex material, while they tend to show considerable resistance to learning in conventional ways (e.g., Dawson et al. 2008; Landa 2007; Ogletree 2007). These students have the best chances of success in school through behavioral interventions and within an individualized educational model (Ben Itzchak and Zachor 2007; Cohen et al. 2006; Lord et al. 2005; Magiati et al. 2007). They respond well to a structured learning environment and learn best through consistency and repetition of newly acquired skills and computer-based interventions (CBI) are often conceived as an optimal medium. Proponents of CBI argued that CBI applications allow compensating for verbal and interaction problems, as obvious in individuals with ASD, and overcoming the social, emotional, and communication difficulties associated with ASD while at the same time easing the burden of caregivers (e.g., Newman 2004; Schilling and Schwartz 2004; Myers and Johnson 2007). Undeniably, CBIs are taking on a progressively important role in the research, and the development of effective interventions for people with ASD, such as in literacy (Moore and Calvert 2000; Bosseler and Massaro 2003; Blischak and Schlosser 2003), social communicative skills, and emotion detection (e.g. Bölte 2004; Bölte et al. 2006; Golan and Baron-Cohen 2006; Golan et al. 2009; Goodwin 2008; Wolfberg 2009) or problem solving (Bernard-Opitz et al. 2001).

The overall results of CBIs are promising but vary in terms of significant gains for children with autism (Golan et al. 2009). For example, Bosseler and Massaro’s (2003) application aimed to improve vocabulary and grammar in children with autism. They found significant gains: children identified more items and were subsequently able to recall 85 % of the newly learned items at least 30 days after the completion of training. Bernard-Opitz et al. (2001) implemented a computerized Social Stories program to teach social understanding to children with autism. The children improved more with computerized visual Social Stories than without. Tanaka et al. (2010) used a computer-based game to teach facial recognition skills to children with ASD. After 20 h of intervention with the software, the children showed significant improvements in their ability to recognize mouth and eye features in faces as compared to a control group. Travers et al. (2011) examined the effectiveness of two methods of teaching early literacy skills among 16 preschool children with ASD: a traditional teacher-led group instruction that used alphabet books and a multimedia computer-assisted instruction. They did not found significant differences between the intervention groups, and children demonstrated high rates of attention to task and low rates of undesirable behaviour in both.

Recently, Pennington (2010) reviewed 15 articles that utilized experimental or quasi-experimental designs and included a total of 52 participants about teaching academic skills using CBI. Pennington concludes that despite the fact that all studies reported an increase in academic skills, the small number of studies and participants which consider CBI as best practice, the results must be taken with caution. Ramdoss et al. (2011) reviewed 12 studies using CBI for literacy competency improvement in 94 students with ASD. They suggested that both the wide variety of literacy skills targeted by instruction and the heterogeneity of the participants make it difficult to identify the variables that determine the effectiveness of CBI.

In summary, advantages of CBI over traditional Face to Face methods are unclear. At least some individuals with ASD express more interest in computers than manipulative material and are less resistant to computers than to teachers, or even prefer computer instruction to personal instruction (e.g., Koppenhaver and Erickson 2003; Williams et al. 2002).

The Current Study

The emphasis of previous research within WCC (Happé and Frith 2006) and EPF (Mottron et al. 2006) theory was on assessing atypical VSPC in individuals with ASD and on finding out whether global and/or local information processing are impaired, superior, or unaffected. As the available studies assessed the performance of individuals with ASD at just a single point in time, their findings reflect baseline abilities, and the fact that often only high functioning individuals with ASD were considered represents a further restriction. Whether and how normally intelligent children with ASD are affected is unclear and whether spatial cognition can change through intervention and instruction is unknown.

Furthermore, existing interventions (face to face or CBI) were mainly targeting literacy, social communicative skills, face recognition, or emotion detection of individuals with ASD. To our knowledge, there is not any game-based training or intervention that addresses the atypical VSPC in ASD. However, given the evidence for the trainability of VSPC in typical developing children (for an overview see Uttal et al. 2012), it is not unreasonable to assume that systematic training might modify the hypothetical spatial processing biases in individuals with ASD. Accordingly, we conducted the present study with three main aims in mind.

First, we investigated to what extent VSPC of children with ASD might be subject to change as a results of practice on a visuospatial task. To the degree that children with ASD could be trained to improve on VSPC, so the idea, efficient training programs for ASD children could be developed. Second, we evaluated the responsiveness to two kind of instruction: In a "Computer" training group (COMP) the main instructions were presented by means of a computer program while in a "Face to Face" group (FtF) a human teacher was tutoring. Our third aim related to the fact that our task to assess local versus global biases in processing spatial information (as some others, but not all) required skills in mental rotation, i.e., in manipulating and transforming mental representations of objects and their spatial characteristics. It has been shown that some individuals use a holistic mental rotation strategy to solve visuospatial tasks, such as cube comparison problems, while others employ a step-by-step strategy instead (Cherney and Neff 2004; Geiser et al. 2006; Glück and Fitting 2003)—often with better performance related to the former than to the latter. Recently, Falter et al. (2008) found that individuals with ASD are faster than non-autistic individuals at mental rotation involving three-dimensional geometric shapes, while Soulières et al. (2009) did not find any difference between autistic and non-autistic adults. To address that issue, we investigated whether children's performance would differ between a sub-test (test A, see below) that did not require to mentally rotate (representations of) visual stimuli forms and a sub-test that did (test B). In addition to these three major aims, we also explored whether higher demands on global or local processing would reveal group differences in performance, and whether these differences might predict training performance.

To address these aims, we compared non-high-functioning children with ASD to typically developing children on a visuospatial task that we developed and validated in healthy children in a previous study (Chabani and Hommel 2013). The visuospatial task used, called the "TangSolver", is a modified version of tangram game (see below). In the original tangram game, the objective is to create a specific shape by assembling seven classical geometric forms. The forms used in the tangram game and figure construction require breaking up completed patterns into its component parts, which makes the task comparable to figure construction of the WISC Block Design Test. However, in contrast to the Block Design Test or similar standard tests that do not allow or encourage training, the "TangSolver" was developed for that exact purpose.

Method

Participants

Forty-eight children diagnosed with ASD (42 boys and 6 girls; mean age = 124.04 months, SD = 12.29) were recruited from two special educational schools in the Netherlands. The necessary requirement for admission in both schools is a formal diagnosis of ASD according to DSM-IV criteria (meeting the three primary areas defined by DSM-IV), which provided us with the relevant diagnostic information. The exclusion criteria for this group were: relevant vision impairments; behaviour, verbal and comprehension problems (such as inability to comprehend the instructions of the experimental tasks); and IQ scores below 70 or above 120. The full scale of intelligence scores (FIQ), Performance IQ and Verbal IQ scores were obtained from the children's files. In addition, a control group of 96 typically developing children (40 boys and 56 girls; mean age = 105.3 months, SD = 10.04) with no specific academic, learning or behavioural problems was recruited from a number of regular primary schools. Participation was voluntary, and all parents/caretakers signed informed consent prior to participation in the study.

Instruments

VSPCC The TangSolver application developed for, and tested in a previous study (Chabani and Hommel 2013) was used for both assessment and training of participants' VSPC. This application contains three modules: TangSolver-Try-out, TangSolver Test, and TangSolver Training. TangSolver is an adapted version of the tangram game

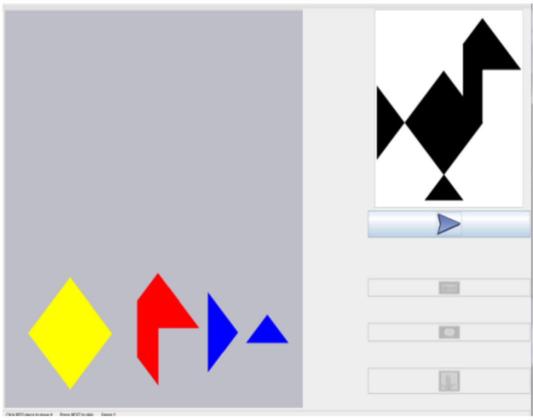

Fig. 1 An exemplar of the TangSolver test and training screen

that consists in arranging seven geometrical forms to construct a large variety of shapes.

Previous studies have often utilized the Block Design task (e.g. Shah and Frith 1993) to assess global/local processing, a task in which individuals use red and white blocks to reproduce a target design. Target designs are often un-segmented, which taps into the capacity to analyze a whole into parts, while segmented designs are considered to assess the ability to assemble parts to form a whole. In the present study, we used segmented and unsegmented pictures. To assess global versus local processing, we considered local processing to be closely related to form size—mainly the number and sizes of corners or sides. We created composed forms by combining more than one classical geometric form. Thus, the same shape or picture could be constructed of either many small or of few large puzzle pieces. We will refer to these simple and composed forms as master pieces (MPs). An example of a MP could be the combination of a square and a triangle or a standard geometric form, such as a triangle. The same shape could thus be constructed by assembling 4, 5, 6 or 7 MPs. These constituted our four difficulty levels, ranging from L1 (four MPs) to L4 (seven MPs). One could consider the construction of figures requiring fewer MPs (larger forms and fewer edges) as tapping more global aspects of VSCP, while figures requiring more MPs (smaller forms and more edges/local characteristics) as assessing more local aspects. See Fig. 1 for an example of TangSolver Test and Training screens.

The *TangSolver-Try-out* assessed participants' skill in manipulating the computer mouse and provided practice in rotating and flipping forms. The task in this module consists in moving the forms placed at the centre of the working window according to requested placements. The try-out comprises of three parts requiring dragging, rotating, and flipping, respectively; it was not time limited and participants could practice until the mouse manipulation was satisfactory.

The *TangSolver Test* assessed participants VSPC prior to and after training. It was composed of two subtests that differed in the possibility to move MPs: Subtest A allowed only dragging the pieces (which we considered to not require mental rotation; see Chabani and Hommel 2013) while Subtest B allowed dragging, flipping and rotating the pieces—which made that test more diagnostic for the individual mental-rotation capacity. Each subtest contained eight items. The items were similar in terms of difficulty with two items at each of the four difficulty levels. MPs used in pre/post-test were all in one colour, in contrast to the three colours (blue, yellow, and red) used for the training items. The pre-test and the post-test were time-limited (max. duration 1:30 min/item). However, children who were quick (task completion $\leq$ 1:30) could make use of the "Next" bottom press, which displayed the following item. For children who were slow (task completion $>$ 1:30), a window asking, "Do you need more time? Yes–No" appeared, which allowed them one extra minute, after which the next item appeared automatically. Each test took 10–20 min, depending on how much extra time was used.

Training material The aim of the training was to support the participant when s/he could not solve the problem independently by providing different types of hints (verbal or nonverbal). The two training modalities we considered (COMP and FtF) required the development of manipulative material for FtF training groups and of a computer application (TangSolver Training) for COMP training. For the FtF group, the MP was made of tick plastic and placed on a white board (see Fig. 2), while training in the COMP group was similar but displayed on computer screen. Both types of training used six different items similar to those used in the pre/post-test. To facilitate the learning through drill and practice, the content had to be scaffolded and sequenced. Accordingly, each training items was composed by its four difficulty levels, meaning that a training item could be done with 4, 5, 6 and 7 MPs. MPs were in three colors (blue, yellow, and red), which provided more options for constructing different types of hints and facilitating the learning by making analogies.

Design and Procedure

This study used a between-subject design that involved a pre-test, a two-session training period, and a post-test, with two experimental training groups. The two experimental groups (typically developing children = TD and children with ASD = ASD) were matched as much as possible for age and their pretest score and were assigned to COMP training and FtF training.

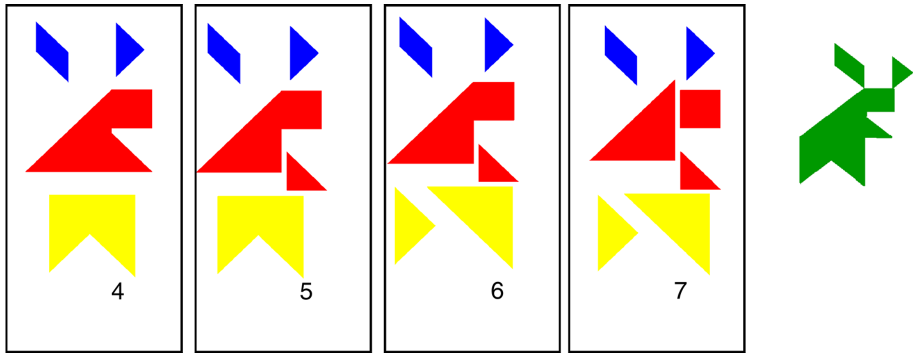

Fig. 2 An exemplar of the manipulative material

During the first and last session, all children's VSPC capacity was assessed by means of the TangSolver test. However, before starting the pretest all children received training on how to drag, rotate and flip with the computer mouse. Children were trained and tested in separate rooms at their own school.

The Training Procedure

After the pre-test, children in both groups received two training sessions of approximately 35–40 min, which were planned over a period of 3 months. However, for some children with ASD who had difficulty sustaining activity throughout an entire session, we postponed and rescheduled training on another day. As neither the time for completing the task nor the use of hints was limited, rescheduling should not pose a problem. The posttest session was planned 2–3 weeks after the last training session.

While children received training on the same six items similar to those used in the pre-test at each of the four difficulty levels, the two types of training differed with respect to the material used (computer vs. manipulative material) and the manner the children were tutored. The computer group practiced on computers and guidance was exclusively through visual cues, while in the FtF group, learning was individual and occurred in the presence of one assessor per child. Both training groups started with the easiest level (four MPs) and progressed to the most difficult level with five, six, and seven MPs of the same item, respectively.

The instruction (Verbal hints) in FtF groups consisted of teacher type guidance such as "are you sure those are the correct pieces?", "maybe you should try with these pieces!" to modelling. The guidance was gradually reducing as the learner's expertise increased. The visual hints with manipulative material were as the segmented structure used in the Block Design Test (showing the solution-figure with apparent breaking lines). In the computerized tasks, the child was guided though different visual hints—the segmentation consisted in highlighting MPs step by step. The visual hints ranged from unicolor segmented figures to segmented figures that fit the MPs colors. For those needing more support, learning was facilitated by making the puzzle directly on the top of the figure. In this way, children could easily see which MPs were missing.

Scoring

During the pre- and post-test, time-on-task scores were calculated: the time taken to complete the task. They were considered to represent the persistence in "going through" in the face of difficulty (but see the Discussion for some caveats). Moreover, accuracy scores were calculated to represent the total number of correctly placed pieces per item, and a tasks-completed score counted the number of tasks being completed (1) or not (0). The data collected during the training are not reported in the present paper.

Results

We used an alpha level of .05 for all statistical tests. Before assessing the effect of training, we first checked for pre-experimental differences between members of the two training conditions (Comp and FtF) within each experimental group (TD and ASD). We considered three dependent variables, the pre-test scores of Time on Task, Accuracy, and Tasks Completed, and added the WISC scores (verbal, performance and total) for the ASD group. Within both experimental groups, no significant pre-training differences were found (see Table 1 for an overview). Second, we checked whether the training groups (COMP and FtF) were comparable across the experimental groups. *T* tests on the three main dependent variables (*df*-adjusted in cases of a significant Levene's test of equal variances) showed reliable group differences for the two COMP training conditions for Time on Task, $t(41.4) = 4.32$, $p < .001$, and Accuracy, $t(39.97) = 2.46$, $p = .01$, but not for Tasks Completed scores, $t(39.58) = .67$, $p > .5$. That is, ASD children were faster, but less accurate than TD

Table 1 Pretest (pre-yoking) scores of Time on task, accuracy, and tasks completed score of groups (TD = typical children, ASD = children with ASD) and characteristics of ASD participants, as a function of training condition (COMP vs FtF)

		COMP		FtF		Diff. COMP/FtF		
		M	SD	M	SD	T	*df*	*p*
TD	Pretest scores							
N (Comp/FtF) = 41/42	Time on task (s)	1,820.8	394.6	1,745.6	527.23	.74	81	.46
	Accuracy	45.7	14.36	44.55	12.9	.38	81	.75
	Tasks completed	5.7	2.7	5.3	2.7	.71	81	.48
ASD	IQ score							
N (Comp/FtF) = 25/24	VIQ	94.81	11.81	93.53	11.20	.32	31	.75
	PIQ	94.82	17.77	94.24	18.41	.10	32	.93
	FIQ	94.95	15.43	92.29	14.12	.54	34	.60
	Pretest scores							
	Time on task (s)	1,305	509.87	1,388.1	409.7	.63	47	.53
	Accuracy	34.64	19.43	44.63	22.89	1.64	47	.106
	Tasks completed	5.16	3.7	5.96	4.03	.72	47	.47

VIQ Verbal IQ scores, *PIQ* Performance IQ scores, *FIQ* Full-Scale IQ scores

Table 2 Descriptive statistics of pre- and post-test of time-on-task, accuracy and tasks completed scores per group (TD = typical children, ASD = children with ASD) and training condition (COMP and FtF) after yoking

		Time on task (s)				Accuracy				Tasks completed			
		Pretest		Posttest		Pretest		Posttest		Pretest		Posttest	
		M	SD	M	SD	M	SD	M	SD	M	SD	M	SD
Subtest A													
TD	COMP	849.67	190.58	722.46	542.13	18.25	4.79	32.13	8.58	3.08	1.41	4.21	1.79
	FtF	712.75	240.60	593.58	229.95	22.13	6.11	37.58	2.98	3.33	1.55	4.96	1.73
ASD	COMP	642.58	227.05	607.00	201.99	21.58	11.26	32.17	8.81	3.42	2.02	5.25	2.03
	FtF	679.67	192.87	655.83	243.28	20.00	11.11	32.71	8.75	3.17	1.95	4.96	2.05
Subtest B													
TD	COMP	721.58	232.55	704.67	154.24	18.79	6.72	31.96	8.70	2.38	1.61	4.04	1.55
	FtF	643.46	204.90	690.13	276.02	21.75	8.67	34.88	11.95	2.54	2.06	4.00	2.04
ASD	COMP	696.54	308.19	657.08	264.91	16.04	10.14	33.46	7.47	1.96	1.94	4.21	2.21
	FtF	708.50	277.78	706.29	194.98	18.21	11.38	32.67	9.60	2.79	2.21	4.29	2.03

children, which is in line with previous studies (e.g., Caron et al. 2006; Shah and Frith 1993; Jolliffe and Baron-Cohen 1997). For the FtF training conditions, the only significant group difference was found for Time on Task, $t(58) = 3.06$, $p = .003$, while there was no effect of Accuracy, $t(31.5) = -.015$, $p = .9$, or Tasks Completed, $t(35.45) = .7$, $p = .48$.

To deal with these pre-experimental differences we yoked the subjects in the two groups on the basis of their pre-test data, which left us with a smaller subset of the entire sample but allowed us to equate pre-experimental performance appropriately. We yoked participants by considering the best match of pre-test scores for each of three dependent measures (Time-on-task, Accuracy, and Tasks Completed), across the training conditions (COMP and FtF), this reduced the sample to N = 83. Table 2 provides the resulting descriptive statistics.

As pointed out earlier, our main interest was whether and where changes from pre- to post-test occurred, and whether they were differently pronounced in the two groups and the two training conditions. To identify these effects, we analyzed each of the three dependent measures (Time On Task, Accuracy and Tasks Completed score) by means of a four-way ANOVA for repeated measures with Session (pre- and post-test) as the within-participant factor, and Training Condition (Computer and Face to Face), Groups (TD and ASD), and Sub-test (subtest A and B) as between-participants factors. The theoretically most interesting result pattern would consist of a two-way interaction involving Session and Training Condition and higher-order interactions including Group or Training condition. We will group the outcomes of the three ANOVAs according to their theoretical relevance and implications.

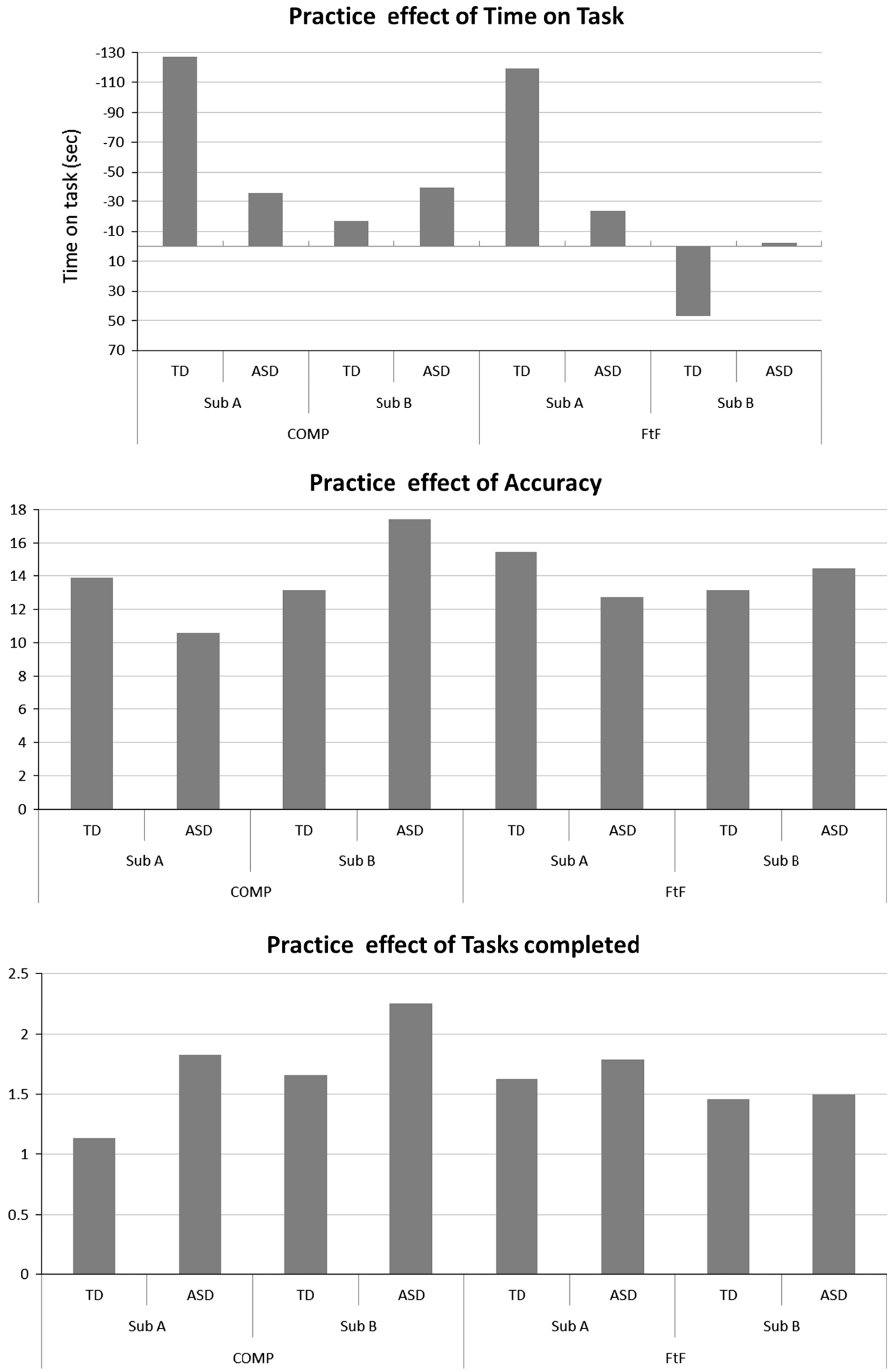

Fig. 3 Practice effects (post-test minus pre-test) on time on task, accuracy and tasks completed

Training Effects in TD and ASD Children

Our first question was whether and how the training would change performance from pre- to post-test and whether these changes would be more pronounced in TD than ASD. Figure 3 provides an overview of the training effects as a functions of the groups and the various conditions. We first assessed these issues without considering main effects of, or interactions involving Training Condition and Sub-test (see below).

Time on task There was neither a main effect of Session, $p = .14$, nor a significant interaction with Group, $p = .60$, suggesting that both groups were equally unaffected by training.

Accuracy The highly reliable main effect of Session, F(1, 92) = 274.8 $p < .001$, $\eta p^2 = .75$, was not modified by Group, $p = .94$, indicating that both groups improved through training.

Tasks completed Again, the main effect of Session, F(1, 92) = 95.14, $p < .001$, $\eta p^2 = .50$, was not modified by Group, $p = .27$, indicating that both groups benefitted equally from training.

Effects of Training Method (Computer Versus Face to Face)

Our second question was whether training-related changes would be mediated by the Training Condition (COMP and FtF). We assessed this issue by focusing on main effects of, and interactions involving Training method.

Time on Task There was no hint to a main effect of, or any interaction involving Training. The only effect that approached significance ($p < .1$) was an interaction of Group and Training on Time on Task, $p = .057$, indicating that the ASD groups were doing about equally well under COMP and FtF training (651 vs. 688, respectively), while the TD groups tended to be better under COMP than FtF instruction (750 vs. 660, respectively).

Accuracy There was no hint to a main effect of, or any interaction involving Training, all *p*s > .18.

Tasks Completed The only reliable effect involving Training method was a three-way interaction of Training, Group, and Sub-test, F(1, 92) = 7.12, $p = .009$, $\eta p^2 = .072$. Separate ANOVAs revealed that Group and Sub-test interacted in the COMP condition, F(1, 46) = 6.61, $p = .013$, $\eta p^2 = .13$, but not in the FtF condition, $p = .44$. Under FtF training, performance was roughly comparable for the TD group (4.1 and 3.3 for sub-test A and B, respectively) and the ASD group (4.1 vs. 3.5). In contrast, under COMP training, the difference between the sub-tests was much smaller in the TD group (3.6 and 3.2) than in the ASD group (4.3 and 3.1). However, as this effect was not modified by session, F = 0, it is more likely to reflect pre-experimental group differences than true effects of the training method.

Mental Rotation Capacity

Our third question was whether and how performance would differ between sub-test A, that did not rely on mental rotation, and sub-test B, that did. We assessed this issue by focusing on effects involving the Sub-test factor.

Time on Task There was not any effect reaching or approaching significance, including the main effect of Sub-test, $p = .7$, and the interaction Sub-test, Group, and Training, $p = .2$.

Accuracy The main effect of Sub-test F(1, 92) = 4.08, $p = .046$, $\eta p^2 = .04$, was modified by a significant interaction of Session, Group, and Sub-test, F(1, 92) = 5.36, $p = .023$, $\eta p^2 = .055$. TD participants performed and improved equally over sessions in both sub-tests (from 20.2 to 34.9 in sub-test A and from 20.3 to 33.4 in sub-test B). ASD participants showed comparable performance in sub-test A (improvement from 20.8 to 32.4) but started off from a lower baseline in sub-test B (improvement from 17.1 to 33.1). Importantly, an ANOVA of the post-training data only did not show any effect of Group or Sub-test, *p*s > .26, suggesting that the training eliminated all possible pre-experimental differences.

Tasks Completed Apart from the main effect of Sub-test, F(1, 92) = 49.7, $p < 001$, $\eta p^2 = .35$, and the (presumably less interesting) three-way interaction of Training, Group, and Sub-test discussed in the previous section, there were no reliable effects involving the Sub-test factor, *p*s > .12.

Global Versus Local Visuospatial Processing

In addition to our three main research questions we were also interested to see whether the TD and ASD groups would differ regarding global versus local visual processing, and whether such differences, if any, would change after training. To be able to compare our findings to the WISC Block Design Test we restricted this analysis to Time on task and Tasks completed scores. As described above, we considered the L1 data to represent global processing and the L4 data to represent local processing, while the data from the L2 and L3 conditions were dropped. Based on these L1 and L4 data we then reran the ANOVAs but added a fifth factor representing Global/Local processing. This resulted in two five-way ANOVAs with the three within-participant factors Session (pre- and post-test), Sub-test (A and B), and Global/Local processing, and the two between-participant factors Training condition (COMP and FtF) and Group (TD, and ASD). Given that the effects of Session, Sub-test, Training condition, and Group were discussed already, we will focus on the effects including the Global/Local factor.

Time on Task There were four reliable effects: a main effect of Global/Local processing, F(1, 92) = 67.87, $p < 001$, $\eta p^2 = .43$, that was modified by two-way interactions with Group, F(1, 92) = 7.31, $p = 008$, $\eta p^2 = .074$, Session, F(1, 92) = 8.35, $p = .005$, $\eta p^2 = .083$, and Sub-test, F(1, 92) = 10.93, $p = 001$, $\eta p^2 = .106$. The interaction with Group was due to that TD and ASD groups were roughly comparable in global processing (152 vs. 140 in TD and ASD, respectively) while the TD group spent considerably more time on the local processing part of the task than the ASD group (250 vs. 189). The interaction with Session revealed that practice did not affect local processing (222 vs. 218 from pre- to post-session) but reduced time on task regarding global processing (170 vs. 122). The interaction with Sub-test showed that the two sub-tests differed regarding global processing (126 vs. 166 for sub-test A and B, respectively) but not regarding local processing (226 vs. 214).

Tasks Completed There were three significant effects including the Global/Local factor: The main effect of Global/Local processing, $F(1, 92) = 375.58$, $p < .001$, $\eta p^2 = .803$, was modified by a two-way interaction with Group, $F(1, 92) = 10.79$, $p = .001$, $\eta p^2 = .105$, and a four-way interaction with Session, Sub-test, and Training condition, $F(1, 92) = 4.70$, $p = .033$, $\eta p^2 = .05$. The two-way interaction was due to that the ASD group outperformed the TD group in local processing (.39 vs. .60 for TD and ASD, respectively), $t(94) = 2.45$, $p = .016$, while the two groups were comparable in global processing (1.5 vs. 1.4), $t(94) = 1.02$, $p = .31$ (n.s.). The four-way interaction reflected a theoretically less interesting pre-experimental difference. Separate analyses on the global and the local data showed that Session, Sub-test, and Training produced a reliable interaction for the global condition, $F(1, 92) = 5.93$, $p = .003$, $\eta p^2 = .06$, but not for the local condition, $F < 1$. Next, we analyzed the global data separately for the pre- and the post-training session, which showed that Sub-test and Training interacted significantly in the pre-training session, $F(1, 92) = 4.53$, $p = .04$, $\eta p^2 = .05$, but not in the post-training session, $p = .29$. As it turned out, the task-completed scores for sub-test B were comparable for the two training conditions (1.2 and 1.3 for COMP and FtF, respectively) while the score for sub-test A was higher in the COMP than in the FtF condition (1.7 and 1.5).

Discussion

The three major aims of this study were to see whether normally developing children and children with ASD would benefit from a short visuospatial training, and whether they would benefit equally, whether the kind of instruction would modulate training effects, and whether training effects would be modulated by the demands on mental rotation. In addition, we explored whether normally developing children and children with ASD would differ in conditions with higher demands on either global or local processing, and how such possible differences would relate to training effects.

With respect to the first question, the results are straightforward: both groups clearly benefitted from the training and they benefitted equally. The two groups were rather comparable from the beginning and the yoking procedure made them even more comparable, so that the training effect is a rather pure measure of the learning potential in the two groups. If so, we can conclude that children with ASD have the same potential to learn as typically developing children have, but that similar performance might come with a higher cognitive cost, at least with respect to the visuospatial skills assessed in this study. It is true that the positive training effects were restricted to accuracy and task completed scores, while time on task was unaffected. However, it is important to consider that time on task is a relatively complex variable that integrates task difficulty (with longer time reflecting greater experienced difficulty), motivation (with longer time reflecting more effort and endurance), and strategy (with shorter time reflecting more insight into one's limited skills). This makes the interpretation rather difficult and it is possible that practice affects the different subcomponents in different ways (e.g., Travers et al. 2011). Moreover, as we did not include a control condition without practice, we cannot exclude that at least part of the practice affects might be unrelated to learning and are thus independent of instruction. And, indeed, we by no means suggest that such practice-unrelated effects cannot or should not occur. However, our main argument here is that single tests of visuospatial performance do not provide a valid assessment of an individual's true abilities, and that practice with a task helps to get a more comprehensive and more realistic picture. This practice may generate or trigger both practice-specific and practice-unspecific processes that are helping the true performance potential to unfold. Once this is achieved, children with and without ASD do longer seem to differ in their VSPC, at least as assessed in this study.

With respect to our second question, we can say that there was no systematic impact of the instruction method and none of the two instruction-related effects we obtained was modulated by session. That is, there are no reasons to assume that computer training would be in any way less effective than face-to-face training (e.g., Koppenhaver and Erickson 2003; Pennington 2010; Ramdoss et al. 2011). We suspected that computer training might be more suited for participants from the ASD groups. Even though no reliable effect supported that expectation, it is interesting to see that the best performance that the ASD group showed was in the more difficult sub-test B, and in fact the best performance that this group showed overall, was obtained in the computer-instruction condition; see Fig. 3. Thus, even though it seems safe to conclude that face-to-face interaction does not provide any specific benefit as compared to computer instruction, it can be conceived that computer instruction has benefits for individuals with ASD (e.g., Williams et al. 2002).

As to our third question, the only hint to a disadvantage of mental rotation capacities in ASD children was the relatively poor accuracy in the pre-interventional measure on the rotation-intensive sub-test B. However, this disadvantage was entirely eliminated after practice, suggesting that our intervention was successful in revealing the full potential of ASD children in visuospatial tasks. This observation is consistent with findings from Soulières et al. (2009), who did not find significant group difference. However, it might be interesting to note that studies showing an advantage of individuals with ASD in mental rotation (Falter et al. 2008) used computer-generated 3D images, while our study employed 2D material. This leaves the possibility that tasks using 3-D material are more successful to reveal an advantage of individuals with ASD.

As to our fourth question, it is fair to say that we could not find any evidence that ASD children might be systematically impaired with respect to either global or local processing. In fact, the only two effects that involved the Group factor suggest an advantage of ASD children in local processing: while the ASD and TD groups were comparable on the more global task, ASD children were faster and more accurate on the more local task. The time on task effect is somewhat ambiguous. It might indicate greater speed but it may also reflect less effort. The latter interpretation would fit with the often pronounced impulsivity and the lack of self-regulatory capacity in ASD (e.g., Prizant et al. 2006; Robinson et al. 2009). In contrast, the benefits related to accuracy provide support for the assumption of a "local processing preference" in ASD (Happé and Frith 2006), even though our findings might also be consistent with the assumption of a more structural local-processing benefit.

Taken altogether, our findings provide strong evidence for the trainability of visuospatial processing in both normally developing children and children suffering from ASD. We found a few processing advantages for ASD children, which were stable across training, and a few disadvantages that were eliminated by training. Given the relatively heavy emphasis that theoreticians have placed on the role of visuospatial processing differences in explaining autism, these findings might be considered surprising. In any case, they demonstrate that single-timepoint testing might overestimate processing differences and underestimate the cognitive/neural plasticity in disadvantaged or cognitively challenged groups. They also highlight the importance of cognitive training in exploring the true potential of participants (e.g., Pennington 2010; Ramdoss et al. 2011). We acknowledge that our findings are preliminary and note that more research on the functional implications of different outcome measures and training regimes is necessary. There is also certainly need for extension to longer training periods, which may help to get deeper insight into how visual spatial functions are related to deficits in the processing of social and emotional information.

Acknowledgments We are very grateful to the children, teachers, schools that participated in this study and as well to all students for their assistance in recruiting, testing children, collecting data. Access to the application used can be obtained by request from the first author. This research was supported by The Netherlands Organization for Scientific Research (NWO), Mozaiek Grant (#017.004.005) entitled "A Computational Visual Spatial Response to Intervention model".

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