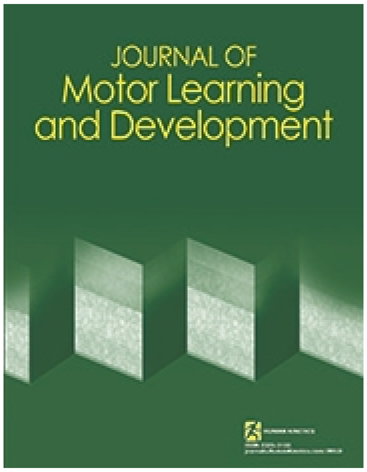

Fine Motor Skills and Unsystematic Spatial Binding in the Common Region Test (CRT): Under-Inclusivity in ASD and Over-Inclusivity in ADHD

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ABSTRACT

Introduction. The Common Region Test (CRT) is useful for predicting children's visual memory as individual object-place binding predicted better object memory while objects-region coding predicted better place memory.

Aim. The aim was to test children with ASD and ADHD with regards to spatial binding in the CRT.

Methods. (1) 19 children with autism spectrum disorder (ASD), (2) 20 children with attention-deficit hyperactivity disorder (ADHD), (3) gender-matched chronological age (CA) and (4) verbal mental age (MA) typically developing (TD) children as control groups were tested with the CRT and Bender Gestalt tests (N = 117).

Results. Children with ASD and ADHD showed more unsystematic coding than TD children. This was due to lower fine motor skills, and in children with ADHD also because of reduced verbal naming. Almost all children with ASD presented the less mature under-inclusive Type I unsystematic coding which included object-place binding, while children with ADHD showed the overinclusive Type II unsystematic coding that was overriding the Gestalt-like properties of proximity and similarity.

Conclusions. It was demonstrated that the CRT is a useful screening instrument for ASD and ADHD that shows that their spatial categorization varies in their unsystematic visuo-spatial classification due to fine motor skill deficiencies.

199 words

KEY WORDS Common Region Test (CRT); Bender Gestalt Test; ASD; ADHD; spatial binding strategies; fine motor skills

Unsystematic spatial binding in the Common Region Test (CRT):

Under-Inclusivity in ASD and Over-Inclusivity in ADHD

The current study investigates the progression from allocating one object to one place towards allocating several Gestalt-matched objects to a common region (Lange-Küttner, 2006), in typically developing children and those with special needs, controlling for fine motor skills. Gestalt principles are perceptual grouping processes first discovered by Wertheimer, Köhler and Koffka. The problem with visual perception is that it 'rhymes' what of the finely pixelated image that the eye is seeing belongs together as a unit. The motto of Gestalt theory that 'the whole is different to the sum of its parts' rejects the notion of veridical perception. On the one hand, visual perception is seen as fallible to illusions, especially about object size in depth perception (Whitwell, Buckingham, Enns, Chouinard, & Goodale, 2016), on the other hand, visual perception is seen as a positively creative process of the human mind because there are emergent processes when a qualitatively new Gestalt is identified that is composed of otherwise quite unremarkable parts. But rather than a completely random process, Gestalt theory assumes that visual grouping processes follow a number of Gestalt principles. For instance, grouping by proximity is important for numerosity judgments, e.g., the more dots are clustered together, the more likely it is that the actual number is underestimated (Im, Zhong, & Halberda, 2016). Grouping by similarity is, for instance, important for perceptual judgments during reading due to similarity of letters such as d and b, or rn and m (Marcet & Perea, 2018). Thus, Gestalt principles can play a role in children's core academic subjects such as math and reading.

Moreover, the Gestalt psychologist Palmer (1992) suggested that there is a higher-order Gestalt principle of Common Region. He used a Wertheimer array with three rows of dots, see **Figure 1**, upper left figure. In the first row, dots were equal insofar as they were of the same appearance and distance, in the second row, pairs of dots were closer together which tests the Gestalt principle of proximity, and in the third row, pairs of dots were of different colour which resembled the Gestalt principle of similarity. Palmer (1992) reported that adults would (a) always attribute a smaller before a larger region and (b) explicit spatial boundaries would override the Gestalt properties of the stimuli. He concluded that the attribution of spatial boundaries would constitute a higher-order Gestalt principle of Common Region than the traditional Gestalt principles.

This theory of Common Region boundaries was tested with children. Children were asked to draw a circle around those dots which they believe belong together. It was found that 4- to 5-year-old children often draw a circle around each dot, see **Figure 1**, upper right figure, while in 7- to 8-year-olds, already a majority may draw circles around the pairs which share the same colour or proximity (Lange-Küttner, 2006), see **Figure 1**, lower right figure.

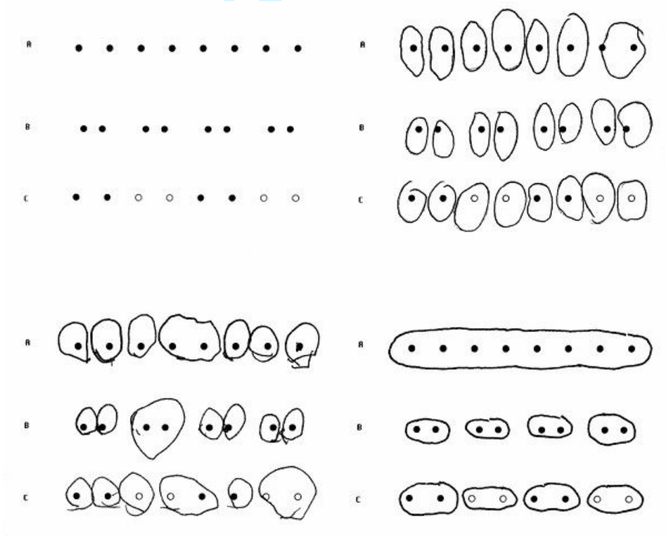


***Figure 1* Spatial boundaries drawn by children in the Wertheimer array of dots (Common Region Test).** The stimulus sheet is illustrated on the upper left. Young children, typically between the ages of four and six years show object-place binding (upper right), however as age increases, object-region binding of matching objects dominates (lower right). Unsystematic coders (lower left) show both types of spatial binding (Lange-Küttner, 2006, with permission of the author and the British Psychological Society).

There are also children who sometimes allocate a place to an individual dot, sometimes a region to two matching dots in a pairwise fashion, and then also to dots which do not share common features, see **Figure 1**, lower left figure. These children were called unsystematic coders because they follow neither a clear system of object-place binding, nor a clear system of objects-region binding. Most often unsystematic binding is a transitional pattern from object-place binding to objects-region binding (Lange-Küttner, 2010b).

However, in two studies with large UK samples of *N*=132 and *N*=252 children, object-place binding decreased as predicted, and pairwise binding increased as predicted, but unsystematic binding was fluctuating across age groups (Lange-Küttner, 2006). Because unsystematic binding was not just transitory, another coding system was developed. Two types of unsystematic binding were scored: Type I of unsystematic spatial binding consisted of coding individual and common region at the same time. It was predicted that the Type 1 should be a transitory pattern. Type II of unsystematic binding would not be a transitory pattern as it consisted of dots being bound into common regions but overriding their Gestalt properties. This new coding system for the unsystematic binding patterns revealed that indeed Type I unsystematic binding decreased with age, from 72.2% at 4 years to 23.8% at 10 years, while the Type II unsystematic binding increased from 27.3% at 4 years to about 76% at 9 and 10 years. Thus, unsystematic binding can be either a transitory (Type I) or a habitual (Type II) phenomenon. At the time, it was presumed that Type II unsystematic binding would occur because the perceptual appearance of the dots was disregarded and not because children were unable to perceive similarity and proximity.

The Common Region Test (CRT) proved to be useful for predicting children's visual memory; object-place binding predicted better object memory and objects-region binding predicted better place memory (Lange-Küttner, 2010a, 2010b, 2013). In these studies, there were only few unsystematic coders who were excluded from the visual memory analyses. The CRT was predictive when children learned to remember new shapes in different places, but not when they learned repeated shapes in always the same places (Lange-Küttner &

Küttner, 2015). Thus, smart advanced spatial binding helped to conceptualize novel visual information.

The CRT involves children's drawing ability and thus a short review of research on the relation between drawing and intelligence is provided here. The human figure drawing is used to screen for IQ and learning disability in children (Lange-Küttner, Küttner, & Chromekova, 2014; Naglieri, 1988). In children's human figure drawing, with age, individual body shapes become integrated into a natural contour (Lange-Küttner, 2011; Lange-Küttner, Kerzmann, & Heckhausen, 2002). Drawing of the human figure is often seen as a culture-fair test. A well-controlled recent study of 5- and 6-year-old children showed that IQ assessment with the Wechsler Intelligence tests revealed socio-economic differences, while the Draw-A-Person test did not (Willcock, Imuta, & Hayne, 2011). Willcock et al. found especially weak drawings in 11.2% of children who nevertheless showed an IQ above 70. They also found 7.2% of children who were good in drawing the human figure but showed a low IQ. Thus, the role of talent and motor skills is not to be underestimated.

A twin study investigating 7752 pairs showed that about 30% of the variance in drawing ability at age 4 was inherited, correlating .33 with the intelligence factor *g* (Arden, Trzaskowski, Garfield, & Plomin, 2014). However, drawing across ages from age 4 until 14 correlated only at .20 with *g*. This was most likely the case because drawing undergoes a major developmental change from drawing objects with simple defining features to drawing small, visually realistic, space-embedded objects (Lange-Küttner, 1997, 2004, 2009).

Excellent identification of a shape in the context of visual noise in the Embedded Figure Test (EFT) predicts visual realism in drawing (Chamberlain & Wagemans, 2015; Lange-Küttner & Ebersbach, 2013). There are various theories for the change from object-centred intellectual realism to space-centred visual realism (Lange-Küttner & Thomas, 1995), with the most recent ones focusing on developmental increases in working memory capacity

(Morra, 2002) and the role of motor abilities and inhibition (Lange-Küttner, 1998; Simpson et al., 2019; Tabatabaey-Mashadi, Sudirman, Khalid, & Lange-Küttner, 2015).

The Current Study

We investigated whether the CRT may be a good screening instrument for children with autistic spectrum disorder (ASD) and children with attention-deficit hyperactivity disorder (ADHD). Both ASD and ADHD are neurodevelopmental disorders that are more common in boys (Loomes, Hull, & Mandy, 2017; Wichstrøm et al., 2012). ASD can be diagnosed fairly early at age 3. ASD prevalence rates have increased from about 1.5% in the US in 2012 to about 2.2% in 2014 (Lyall et al., 2017). This low prevalence rate still implies that for each set of 100 children, two children will have ASD. ADHD is usually much later diagnosed, mainly because all young children can be initially inattentive and motorically very active, but sleep problems show already at similarly young age in ADHD (Bundgaard, Asmussen, Pedersen, & Bilenberg, 2018). The prevalence of ADHD in the US is 8.4% to 9.4%, that is in each set of 100 children nine children would have ADHD (Danielson et al., 2018). The authors find that almost two thirds are on Ritalin medication and slightly less than half received behavioral treatment. Given these prevalence rates, it becomes very likely that in a US primary school with 500 children, one could encounter 10 children with ASD and 45 children with ADHD. Thus, a screening test for either of these neurodevelopmental disorders would provide valuable initial information that could lead to further testing and diagnosis.

Autistic spectrum disorder (ASD) is characterized by deficits in social-emotional reciprocity, non-verbal communication, and social skills (American Psychiatric Association, 2013). In addition, restricted interests, repetitive behavior and motor movements, and an unusual interest in the sensory aspects of the environment are typical of ASD. ASD can occur with or without accompanying intellectual or language impairment or other disorders

(American Psychiatric Association, 2013) hence we controlled the sample for verbal IQ in addition to a control group that was matched on chronological age.

Children with ASD do not only have gross motor problems in balance and ball skills (Whyatt & Craig, 2012), they also have difficulties with fine motor skills which show in their handwriting, especially in the shape of letters (Fuentes, Mostofsky, & Bastian, 2009). This occurred independently of age, gender and IQ. Also problems with copying and planning movements are common at any age in children with ASD (Simermeyer & Ketcham, 2015).

Drawing development can be different in some gifted children with autism who draw visually realistic from the very beginning (Selfe, 1977). Identifying embedded figures can be superior in individuals with autism (Mitchell & Ropar, 2004) who often show poor language and communication skills. However, while autism seems to spawn superior visual shape identification, when combined with well-developed language ability (Asperger), this advantage disappears (Ropar & Mitchell, 2001). This is another reason why we matched children with ASD and TD children on verbal IQ.

Moreover, children with ASD often do not show mature categorizing (Plaisted, 2001). They often focus on individual items and small detail but this was unrelated to planning and executive function (Booth, Charlton, Hughes, & Happé, 2003). Hence, we hypothesized that children with ASD would show object-place binding in the CRT because they tend to have a bias towards distributed local details (Chamberlain, McManus, Riley, Rankin, & Brunswick, 2013) and smaller rather than larger categories (Alderson-Day & McGonigle-Chalmers, 2011). We expected that children with ASD would be more likely to encode object-place units because they are more sensitive to first-order rather than second-order visual information (Simmons et al., 2009) and common region is a second-order Gestalt principle. Based on the systematizing-empathising hypothesis of Baron-Cohen (Baron-Cohen, Ashwin, Ashwin, Tavassoli, & Chakrabarti, 2009) we did not predict unsystematic binding in the CRT as individuals with ASD would be adept in systemizing and thus should show a systematic approach in this task.

Attention-deficit/Hyperactivity disorder (ADHD) is characterized by inattention or motoric restlessness that cannot be explained by oppositional behavior, defiance, hostility or failure to understand tasks and instruction (American Psychiatric Association, 2013). The symptoms need to occur in more than one setting, that is school, home or with friends, and they need to interfere with academic achievements.

A systematic review of 45 studies showed that more than half of children with ADHD have difficulties with gross and fine motor skills (Kaiser, Schoemaker, Albaret, & Geuze, 2015). Children of the ADHD inattentive subtype show more impairment of fine motor skills, slow reaction time, and online motor control than the hyperactive children. Medication with Ritalin has an effect on the parietal cortex that controls spatial field perception (Liotti, Pliszka, Perez, Kothmann, & Woldorff, 2005). Medication also helped children with a combined ADHD/Developmental Coordination Disorder diagnosis to improve on drawing accuracy (Flapper, Houwen, & Schoemaker, 2006). Remarkably, also training of motor skills and manual dexterity appears to successfully mediate cognitive function in children with ADHD (Ziereis & Jansen, 2015). Hence, we investigated the CRT's association with the Bender Gestalt tests which included sub-tests on fine motor skills, visual perception, copying (visual mapping) and recall (visual memory) (Brannigan, 2003).

There are few studies on drawing development in children with ADHD. They were found to be less skilled in drawing the hands of a clock (Ghanizadeh, Safavi, & Berk, 2013). There was no difference between children with ADHD and typically developing children when drawing familiar figural objects such as figures and houses (Booth et al., 2003), and their drawing abilities were better than those of children with learning disabilities (Perets-Dubrovsky, Kaveh, Deutsh-Castel, Cohen, & Tirosh, 2010). These results make sense as children with ADHD do not have low scores on *g* but on executive functions (Schuck & Crinella, 2005). Different to children with ASD, those with ADHD show deficits in visual cognition measures such as spatial span and visual search (Ferrin & Vance, 2012). A prospective study showed that children with ADHD show deficits in executive function, design fluency, spatial organization, and visual memory (Robinson & Tripp, 2013). Thus, one could hypothesize that children with ADHD would be more likely to show an unsystematic approach. Because children with ADHD pay less attention to detail (Song & Hakoda, 2012), we expected a global rather than a local bias.

METHODS

Participants. The sample of *N*=117 school children from various schools in South-West London, UK, took part in the study, mainly White English (55.8%) and Asian (36.7%) children. Children from other ethnicities were Black English = 4.2% and Other White = 3.3%. Mainstream London UK schools were Teddington, Waldegrave, Stanley Primary, Christ's, Hampton, Hounslow Town Primary, Heston Community and Primary, Twickenham Academy, Orleans Park, Heathland, Matthew Arnold, St. Paul's Catholic College, Stanwell Fields Primary, Wellington Primary and Guildford.

Children with ADHD and ASD had been referred to special needs schools after a diagnosis was carried out by consultant psychiatrists and consultant clinical psychologists in the Child and Family Health Services of the UK National Health Service (NHS). NHS Child and Family Services must follow an assessment protocol before a child can be referred from a mainstream to a special school, the more so since mainstream UK schools are integrative schools which have special educational needs (SEN) teachers who can provide individualised tuition. Hence, the degree of severity of the neurodevelopmental disorder must have been so severe that the children could not attend mainstream schools even given the availability of support by specialised SEN teachers. The special needs schools were Strathmore, Lindon Bennett and Grey Court in London, UK.

The diagnoses carried out by the NHS Child and Family Services were additionally validated by the authors with rating scales. In order to control co-morbidity, both children with an ASD and ADHD in the special schools were assessed on both of the following scales. The inclusion criterion for the sample of children with ASD was a score of above 30 in the Childhood Autism Rating Scale CARS 2 (Schopler, Van Bourgondien, Wellman, & Love, 2011), non-autistic scores are in the range of 15-30 (see also Grice et al., 2005). Children with ASD had an average Cars raw score of $M = 36.0$, with a range of $M = 33.5$ to $M = 40.9$. Children with ADHD had an average Cars raw score in the normal range of $M = 19.2$, from $M = 16.5$ to $M = 24.0$.

The inclusion criterion for children with ADHD was the 80th percentile as a cut-off point of the Du Paul ADHD Rating Scale (DuPaul, Power, Anastopoulos, & Reid, 1998). Because ADHD must be diagnosed in two settings, there is a Du Paul (H) home scale which is rated by parents and a Du Paul (S) school scale which is rated by teachers. For this current sample, the correlation between the two scales was $r = .86$, $p < .001$ for children with ADHD, but $r = .28$, $p = .253$ for children with ASD. For children with ADHD, the mean Du Paul S score was $M = 30.30$ and the Du Paul H score was $M = 31.65$. For children with ASD the mean Du Paul S score of $M = 2.26$ and the Du Paul H score was $M = 1.95$, within the normal range. The clinical groups were not on medication.

The typically developing (TD) children did not have a known psychiatric or special needs diagnosis as per information of their mainstream schoolteacher. If there would have been children with lower and manageable levels of ASD or ADHD in the mainstream schools, these children would have been allocated a SEN teacher who would have facilitated integrative schooling, but this was not the case.

The clinical groups were gender-matched one-to-one with the control children. There was one control group with the same chronological age (CA) and another control group with the same mental (verbal) age (MA) (see **Table 1**). If one of the clinical groups performed lower than the group matched on chronological age, one could conclude that there is a developmental delay as the clinical group would be behind their same-aged peers. However, if the clinical group would be behind the verbal mental age matched group, one could conclude that the reason for the deficit would not be a general developmental delay, but a more specific deficit. In this study, we measured verbal mental age with British Picture Vocabulary Scale (BPVS) (Dunn, Wheiton, & Pintilie, 1982).

Children with a mental age below 6 years were excluded from the study. Children not in command of English were not tested because rudimentary communication between the child and experimenter was necessary for consent and task instructions. The ASD group and controls consisted of 17 boys and 2 girls. The ADHD group and controls consisted of 15 boys and 5 girls. The CA match of the clinical groups with the control groups is listed in **Table 1**.

Table 1 Special Needs and Control Groups' Mean Age

Special Needs	Age in Months	Control Groups	Age in Months	*p*-value
ASD (n=19)	116	ASD MA Control (n=19)	130	.000
		ASD CA Control (n=19)	116	1.00
ADHD (n=20)	160	ADHD MA Control (n=20)	164	1.00
		ADHD CA Control (n=20)	160	1.00
N=39		N=78		Total N=117

Note. MA = mental age, CA = chronological age.

The age range of the ASD group was 7;0 to 15;3 (years; months), of the ASD MA control group 7;5 to 15;0 and of the ASD CA control group 7;0 to 15;3. The age range of the ADHD group was range 8;9 to 16;4, of the ADHD MA control 9;4 to 16;10 and of the ADHD CA control group 8;9 to 16;4. The mean age of the two clinical samples differed, t (37) = -4.76, $p < .001$, with the ADHD group older than the ASD group, but the age ranges of the two clinical groups were comparable. With respect to matched BPVS vocabulary scores, p-values in **Table 2** show that there no significant difference between the ASD and ADHD groups with either of their two control groups. However, as expected, the clinical groups showed lower performance on non-verbal intelligence scores and Bender fine motor skills.

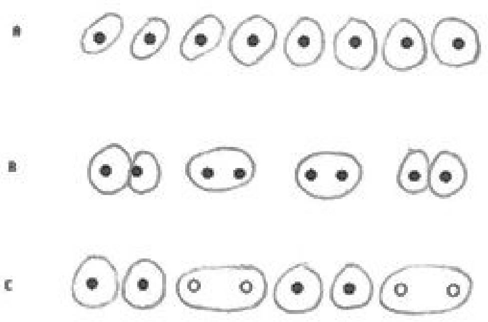
Table 2 Special Needs and Control Groups' Mean Intelligence and Fine Motor Scores

Special Needs Groups	Scores *M*	Control Groups	Scores *M*	p-value
ASD (n=19)	BPVS = 123	ASD MA Control (n=19)	BPVS = 123	1.0
	RCPM = 23		RCPM = 29	.000
	Bender = 9		Bender = 15	.000
		ASD CA Control (n=19)	BPVS = 119	.633
			RCPM = 30	.000
			Bender = 15	.000
ADHD (n=20)	BPVS = 162	ADHD MA Control (n=20)	BPVS = 162	1.00
	RCPM = 28		RCPM = 30	.116
	Bender = 15		Bender = 17	.052
		ADHD CA Control (n=20)	BPVS = 159	1.00
			RCPM = 33	.000
			Bender = 18	.001
N=39		N=78		Total N=117

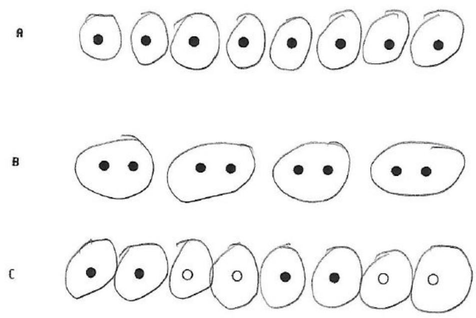
Note. BPVS= British Picture Vocabulary Scale, RCPM = Raven Coloured Progressive Matrices, Bender = Bender Gestalt Test II

Apparatus and Material

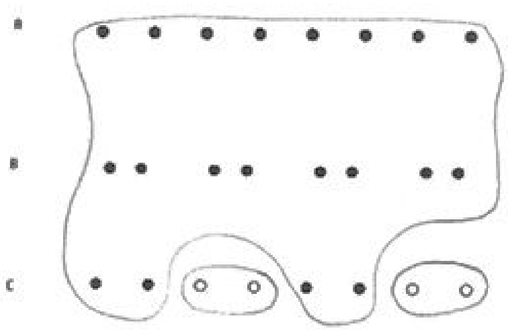
Common Region Test (CRT). This test was given once on one sheet of paper, with three rows of dots: row A, B and C, see Figure 1. Row A consisted of equidistant dots, row B were pairs of dots that were closer together than the other pairs of dots (proximity) and row C were equidistant but pairwise coloured dots (black/white) (similarity) (Lange-Küttner, 2006). Children were given the following instruction: "Please draw a circle around those dots which you think belong together". Children were tested individually by the second author. Scoring of the CRT was based on whether children had drawn a circle around individual dots (object-place binding) (score 1), matching dots (objects-region binding) (score 3) or whether there was a combination of approaches (unsystematic binding) (score 2). The second author rated all the drawings, see the supplementary file. The first author rated copies of all drawings independently without having sight of the classification by the second author. Rules for Type I and Type II unsystematic ratings were discussed. Final interrater reliability for the 117 drawings was 99.1%. One remaining disagreement was settled in a discussion. There were 59 CRT drawings or 50.4 % of the total sample with unsystematic binding. These drawings were allocated a Type I or Type II unsystematic binding score, see **Figure 2**.



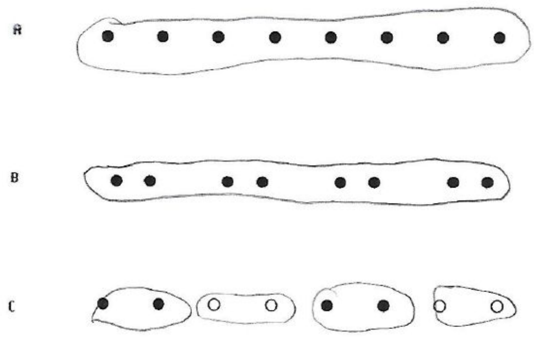
Type I Unsystematic binding – ID10 – TD girl



Type I Unsystematic binding – ID46 - ASD boy



Type II Unsystematic binding – ID7 – TD boy



Type II Unsystematic binding – ID34 – ADHD girl

Figure 2. Examples of Type I (upper row) and Type II (lower row) unsystematic CRT binding. Type I unsystematic binding shows object-place binding along with attribution of matching objects into one region. Type II unsystematic binding shows no object-place binding, but instead unsystematic region binding overrides the common features of proximity or similarity that pairs have in common.

Type I consisted of binding object-place and objects-region at the same time. Type II consisted only of objects-region binding, but larger region, ‘overinclusive’ groupings were overriding the salient Gestalt stimulus properties. Thus, both types are unsystematic combinations of spatial binding, but one includes under-inclusive, while the other includes over-inclusive spatial groups. Thus, for rating the occurrence of unsystematic spatial binding, two simple rules were developed. The first rule was that as soon as there are one or more object-place bindings in the CRT, it must be classified as Type I unsystematic binding. The second rule was that if there is no object-place binding and the regions are conceptualised for objects that do not have common features and/or regions are allocated across rows, it is coded as Type II unsystematic binding.

The **Bender Visual Motor Gestalt (II)** test (Brannigan, 2003) was used to evaluate visual-motor integration skills, comprising of four sub-tests. These Bender sub-tests consist of a number of figures whose scores are added up for correct responses into a raw score. The ***Bender Motor Test*** included one sample item and 12 figures (four test items with three figures per item). Children were instructed to 'Draw a line connecting the dots without touching the borders'. For the ***Bender Perception Test***, children were asked 'Select the design that best matches the design in the left column' (ten designs). During the ***Bender Copy Test***, children were presented with picture cards one at a time. The instruction given was: 'Copy each drawing onto the sheet of paper'. Each design was scored in accordance to the Global Scoring System, where a score of 0 indicated no resemblance, 1= slight-vague resemblance, 2= some-moderate resemblance, 3= strong-close resemblance and 4= perfect resemblance. The ***Bender Recall Test*** was administered immediately thereafter. Children were instructed: 'Draw as many of the designs that you can remember'.

The **British Picture Vocabulary Scale (BPVS)** (Dunn, Wheiton, & Pintilie, 1982) was used to assess verbal intelligence. The BPVS consists of six training plates and 32 item plates (each plate has four pictures). Children were presented with one plate at a time and instructed to point at the picture corresponding to the test word said by the examiner, for example: 'Please tell me which picture best shows the word bucket'. The test was conducted as described in the test manual but without an abortion criterion, that is all responses were tested and counted.

The **Raven's Coloured Progressive Matrices (RCPM)** test (Raven, 1998) was used to measure non-verbal IQ. This test consists of 36 item plates, split into three sets of 12 item plates each. One plate at a time was presented and children were required to point at the correct pattern (out of six choices) with the instruction: 'Point to the missing piece that best fits the puzzle'. A raw score was tabulated by adding the number of correct responses.

Diagnostic measures. In the special schools, the diagnostic session entailed the completion of the Childhood Autism Rating Scale (CARS2) (Schopler et al., 2011) and the ADHD Rating Scale-IV (DuPaul et al., 1998) determining the intensity of the symptoms. Age-based standard scores were obtained for the CARS2-ST and the ADHD Rating Scale. Both rating scales were administered according to the testing procedures in the manuals.

The **CARS2-ST** consists of 15 items relating to symptoms relevant for a diagnosis of autism. The items measure variables such as emotional and visual response, verbal communication, restricted interest, and anxiety. Teachers were asked to rate the child on a scale from 1 to 4.

The **DuPaul ADHD Rating Scale-IV** (home version completed by parents and school version by teachers) included two symptom subscales: Hyperactivity-Impulsivity and Inattention with nine items each. The items were rated on a 4-point scale (0= never/rarely, 1= sometimes, 2= often, 3= very often).

Procedure. The study was approved by the University Ethics Committee according to the guidelines of the British Psychological Society. Parents received an info sheet and signed a consent form before the session. Children were individually tested in a classroom of the school which was not used during this time. Children were asked and agreed to take part at the beginning of the session. They all began the session with the CRT, followed by the Bender-Gestalt Test, BPVS and the RCPM tests.

RESULTS

The raw data file is deposited on the website of the Open Science Foundation https://osf.io/y6nu4/files/. The CRT analysis was first carried out with Chi-Square for all typically developing children. Thereafter, children with ASD were compared with their MA and CA controls, and children with ADHD were compared with the MA and CA controls. Correlations were computed to control for the role of visuo-motor abilities in the CRT.

Typical development of CRT spatial binding. Data of the typically developing children (which later serve as MA and CA controls for the clinical groups) were divided into five age groups of fifteen 7-8-year-old, nineteen 9-10-year-old, eleven 11-12-year-old, sixteen 13-14-year-old and seventeen 15-16-year-old children.

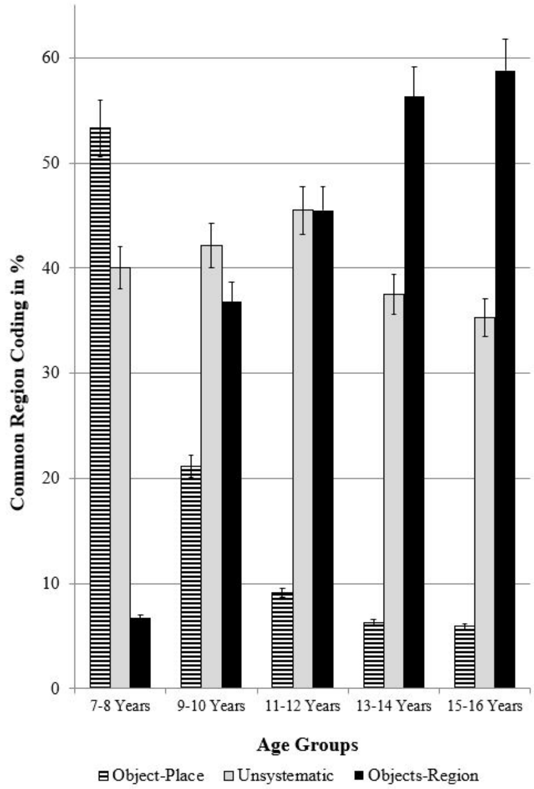


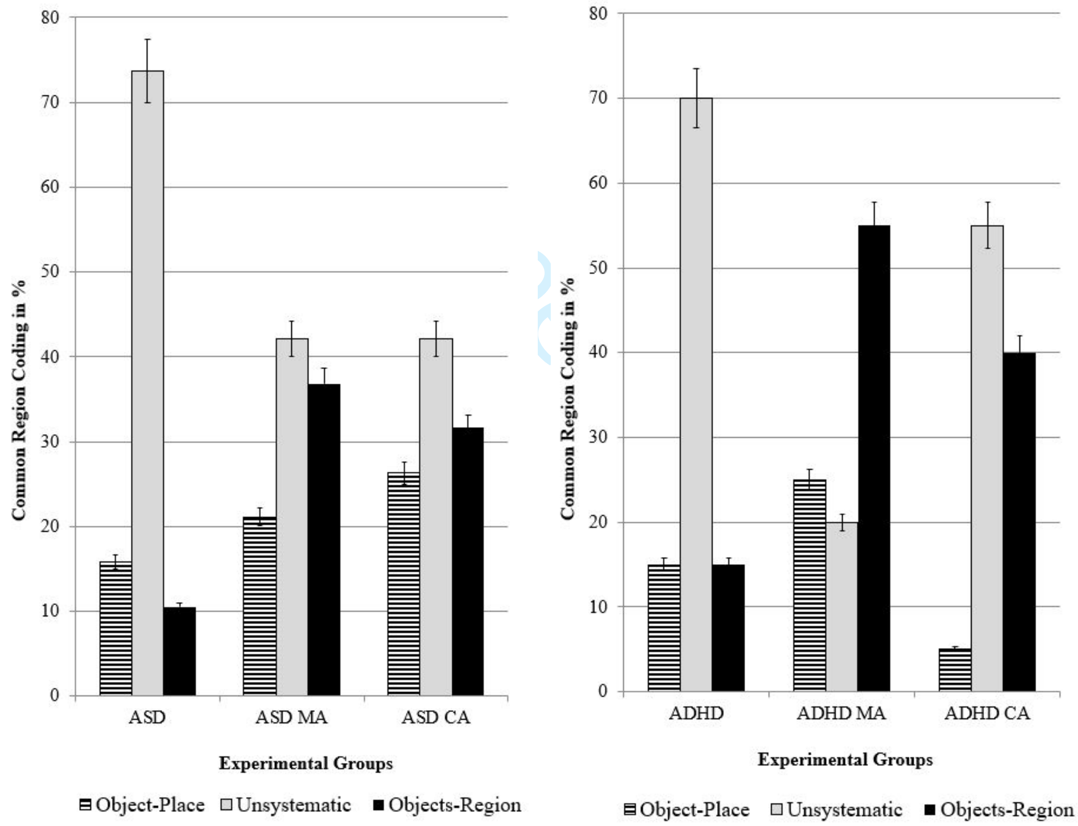
Figure 3. Allocating spatial boundaries in the Common-Region-Test (CRT) (*N*=78)

Chi-square analysis was carried out for these five age groups by CRT score (range 1-3). The progression from object-place to object-region binding was highly significant, χ^2 (8, 78) = 19.56, *p* = .012, phi = .50, see **Figure 3**. Object-place allocation is the most prevalent in 7-8-year-old children, but the strategy becomes less frequent in older age groups. Correspondingly, common region binding increases with age. However, the percentage of unsystematic binding hovers around 40% in each age group. Of the 31 unsystematic coders, 22.6% (*n*=7) showed Type I and 77.4% (*n*=24) showed Type II unsystematic binding. Chi-square analysis was carried out for the five age groups by CRT unsystematic Type I/II variable and showed there is no abating with age of unsystematic spatial binding, χ^2 (4, 31) = 5.02, *p* = .285, phi = .40.

CRT spatial binding in children with ASD and ADHD. To investigate the development of the CRT in each of the three groups (TD, ASD, ADHD), we computed two-tailed non-parametric Spearman's rho correlations which are applicable for both continuous and ordinal variables. Thereafter, we calculated chi-square analyses which compared performance in the CRT in the ADHD and ASD groups, respectively, with their gender-matched MA and CA control groups, followed by chi-square analyses with only unsystematic coders to compare the CRT Type I and Type II errors.

The p-level of the non-parametric two-tailed correlations (Spearman's Rho) between the CRT and age in months was Bonferroni corrected, p = .05/3 = .017. The correlation was significant for TD children, *r* = .41, *p* < .001, but in the clinical groups, the correlations of the CRT and age were not significant. Children with ASD showed a correlation of *r* = .29, *p* = .229, and in children with ADHD the correlation was *r* = .24, *p* = .313. Advanced common region binding can appear quite early in development at 6 years in boys (Lange-Küttner, 2010a). In the current study, common region binding was so delayed that it had not appeared until age 11 in the ADHD group and until age 13 in the ASD group - while the youngest TD child to show common region coding was 7 years old.

The Chi-square test of the CRT in children with ASD and control groups shows that with 73.7%, unsystematic binding was the most frequent response pattern in the clinical group, **Figure 4A**. Nonetheless, there was no significant difference to the control groups, χ^2 (4, 57) = 5.70, p = .223, phi = .32, because unsystematic coders were also in the majority in the two control groups, although showing more frequent common region binding.



(A) ASD (n=57) (B) ADHD (n=60)

Figure 4. Allocating spatial boundaries in the Common-Region-Test (CRT) by (A) children with ASD and control groups and (B) children with ADHD and control groups

The same chi-square analysis of children with ADHD and their controls by CRT yielded a significant result, χ^2 (4, 60) = 12.57, p = .014, phi = .46. **Figure 4B** shows that also the children with ADHD were in the majority unsystematic coders (70.0%). However, the controls differed from each other: In the vocabulary-matched MA control group, common region binding was clearly the most frequent CRT pattern. In the CA control group, common region binding occurred more often than in the ADHD group, but there was a considerable proportion of unsystematic coders.

Because the percentage of unsystematic coders was so high in both clinical groups, we then analysed only unsystematic coders (*n*= 59) in order to investigate the type of unsystematic coding. The chi-square test of the CRT unsystematic Type I/II variable by ASD/Control groups was significant, χ^2 (2, 30) = 14.00, p = .001, phi = 68. Almost all (13 out of 14 or 92.9%) children with ASD showed Type I unsystematic binding with occasional object-place bindings, while this was rare in both ASD MA controls (2 out of 8 or 25%) and ASD CA controls (2 out of 8 or 25%).

The chi-square analysis of the ADHD/Control groups by CRT unsystematic Type I/II variable showed no significant differences, χ^2 (2, 29) = .365, p = .833, phi = .11. The majority of these three subsamples showed Type II unsystematic binding (ADHD 71.4%, MA controls 75%, and CA controls 81.8%) with a dominance of over-inclusive spatial binding.

To test whether the non-verbal intelligence of the clinical groups was correlated with unsystematic spatial binding, we ran two-tailed correlations between unsystematic spatial binding and the Raven score. The p-level of the non-parametric two-tailed correlations (Spearman's Rho) between the CRT and age in months was Bonferroni corrected, p = .05/3 = .017. Children with ASD showed a significant correlation between the Raven score and unsystematic spatial binding, r = -.64, p = .003, while in children with ADHD, there was no correlation at all, r = -.01, p = .968. Likewise, in typically developing children, the correlation between the Raven scores and unsystematic spatial categorization was not significant, r = .09, p = .439. Correspondingly, regression analysis was only significant for children with ASD as unsystematic binding in the CRT significantly predicted the Raven scores, $R = .62$, $R^2 = .38$, $p = .005$. All children with ASD who had Raven scores lower than 25 showed unsystematic coding.

The overall chi-square analysis with the pooled control samples of just unsystematically binding children in relation to the CRT unsystematic Type I/II was highly significant, χ^2 (2, 59) = 20.85, $p < .001$, phi = .59, see **Figure 5**.

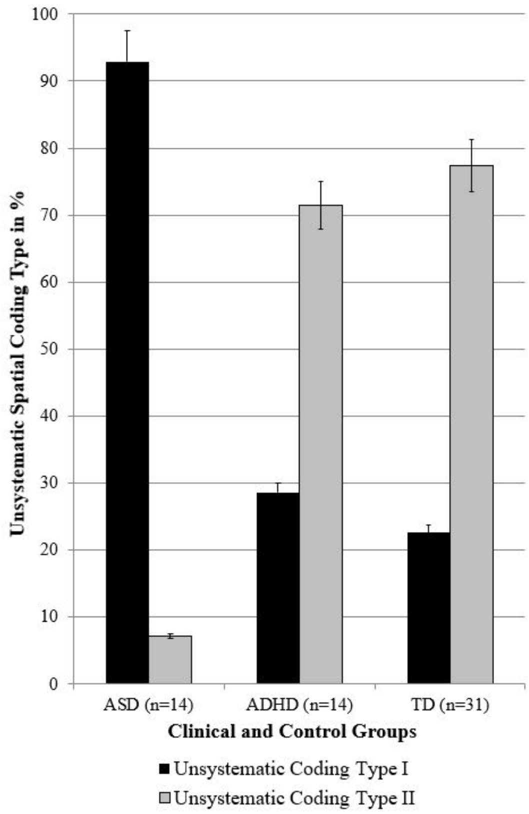


Figure 5 Type I and II unsystematic of allocating spatial boundaries in the CRT by ASD, ADHD and TD control groups (*N*=59). Type I involves both object-place and objects-region binding, while Type II involves region binding which overrides the salient stimulus properties of proximity and similarity

Almost all children with ASD showed the immature Type I unsystematic object-place binding, while children with ADHD and the typically developing children showed an almost identical proportion of overinclusive region binding overriding salient Gestalt properties of the Wertheimer CRT stimuli.

CRT and the Bender Gestalt Test. We then analysed correlations for the whole sample between the four Bender scores, Bender perception, Bender motor, Bender copying, and Bender recall scores with the CRT and the CRT unsystematic Type I/II variables.

In the 78 typically developing children, three of four correlations between Bender scores and the CRT (two-tailed Spearman's Rho, Bonferroni-adjusted p-level is .05/4 = .012 per group) were significant, Bender motor $r = .38$, $p = .001$, Bender copying $r = .35$, $p = .002$, and Bender recall scores $r = .41$, $p < .001$. A multiple regression with the CRT as dependent variable and Bender scores as predictors, $R = .50$, $R^2 = .249$, $p < .001$, showed the Bender motor score as the only significant predictor for the CRT, $beta = .353$, $t = 2.88$, $p = .005$. Typically developing children showed no significant correlations of the Bender scores with either type of unsystematic CRT binding, $p_s > .400$. This picture looks very different for children with special needs. Children with ASD showed neither significant correlations between the Bender tests and the CRT, $p_s > .179$, nor for the two types of unsystematic binding in the CRT, $p_s > .404$. We also did not find significant correlations between any of the Bender scores and the CRT scores, $p_s > .106$, in children with ADHD. However, their unsystematic binding showed a significant correlation with the Bender motor scores, $r = .76$, $p = .002$. We plotted the means in the three samples in **Figure 6**. Note that the scale for the children with ASD ranges from 1-9, for children with ADHD from 0-11, and for TD children from 7-12. **Figure 6** shows that the significant correlation would have occurred because there was a clear cut between those children with ADHD with low and high Bender motor scores: Only those above a score of 8 were using the more mature Type II unsystematic CRT binding.

We computed a univariate ANOVA with the Bender motor score as dependent variable, and the three groups as independent factor to compare the Bender motor score between these groups. There was a significant group difference, F (2, 117) = 53.79, $p < .001$,

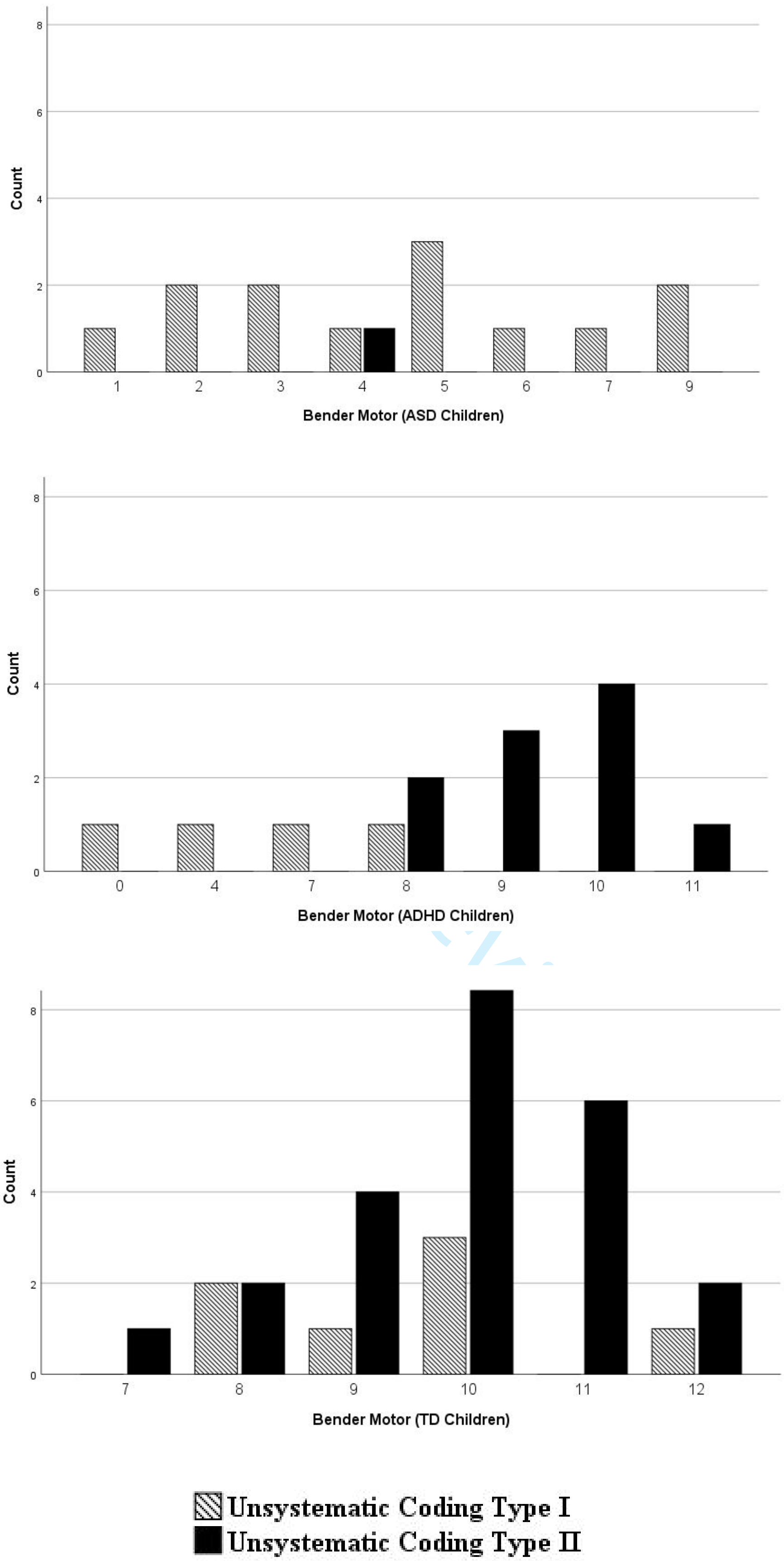


Figure 6 Association between Type I (grey) and II (black) Unsystematic CRT binding and the Bender Gestalt Motor Score (*N*=59).

$\eta^2 = .49$. Pairwise comparisons within the model showed that each group significantly differed from all others, $p_s < .001$, that is, the children with ASD had the lowest mean (M = 5.26), the children with ADHD had a higher mean (M = 8.25) and the TD children had the highest mean (M = 10.24) for the Bender Gestalt Motor scale.

DISCUSSION

The current study investigated allocation of spatial regions to dots which were arranged according to Gestalt principles of proximity and similarity (Common Region Test, CRT, Lange-Küttner, 2006) by children with ASD and ADHD. As such, this is a new contribution to the literature. Most previous research used Navon figures which is a letter built from either the same small letters (congruent) or different small letters (incongruent) to investigate whether children with ASD would show a 'local preference' (Koldewyn, Jiang, Weigelt, & Kanwisher, 2013). The current study uses another visuo-spatial configuration, the Common Region Test (CRT) which varies the interrelations between the stimuli in terms of equality, proximity, and appearance. Moreover, because the CRT is a drawing task, we controlled the impact of fine motor skills using the standardized Bender Gestalt test.

As expected, object-place binding decreased and objects-region binding increased in typically developing children. Based on previous research, we had hypothesized that children with ASD would show more object-place than objects-region binding and that this approach would be rather systematic. This hypothesis was confirmed as children with ASD were showing object-place binding like very young children, but it was not a systematic approach. Instead, object-place binding was interspersed in an unsystematic Type I strategy because it contained only some occurrences of object-place binding.

For children with ADHD we hypothesized that they would show a rather unsystematic approach to objects-region binding but would show no object-place binding. Also this hypothesis was fully confirmed, but we could find such Type II unsystematic coding also in the typically developing children. That this overinclusive pattern also occurred in the group of same-age mainstream school children is not entirely surprising. Performance on visual attention tests such as matching familiar figures and visuo-motor tracking can converge between children with ADHD and typically developing children under cognitive load (Tirosh, Perets-Dubrovsky, Davidovitch, & Hocherman, 2006).

However, while unsystematic spatial binding in the typically developing children amounted to 39.7%, it was much higher with more than 70% of unsystematic binding in both groups with special needs. We evaluated the Type I unsystematic CRT binding as under-inclusive and immature because individual object-place units do not include matching items and are usually created only by 4-5-year-old children. In contrast, we evaluated the spatial pattern that children with ADHD created as over-inclusive because items were included in a spatial group even though their features did not match. This unsystematic and overinclusive binding strategy should not be evaluated as immature. In fact, Piagetian developmental psychologists hold the assumption that operational intelligence would override, control and direct Gestalt-like fast impressions (Field or F-factor) (Pascual-Leone, 1989; Piaget, 1969). Over-inclusiveness from this perspective would imply a rejection of the relevance of superficial features such as similarity in colour or proximity in spatial position for classification. However, categorical judgment and neat classification of input is at the heart of learning, whether in Piaget's concrete and formal-operational thought (Piaget, 1969), or in neural networks (e.g. Elman et al., 1996). This has also been described as the bias-variance dilemma (Geman, Bienenstock, & Doursat, 1992) where special items may not be identified if not individually categorized, but if many individual items are appreciated in this way, processing is easily overburdened and becomes slow. Over-inclusive categorisation in children was neither based on proximity and similarity, but rather on a random embrace-all mental disposition. Thus, persisting object-place binding in the CRT during development would constitute a local bias (Cardillo, Menazza, & Mammarella, 2018), but overinclusive objects-region binding would constitute a global bias (Song & Hakoda, 2012).

For children with ADHD, we also found an effect of naming on the CRT. Children with ADHD showed significantly more unsystematic spatial categories than the language-ability matched MA control group. Naming and labelling in drawing is important as it enhances canonical depictions which reveal meaning and function of objects (Hartley & Allen, 2015). Under- and over-inclusivity can also be observed in the development of children's verbal classifications (Callanan & Markman, 1982).

Moreover, we could demonstrate that fine motor skills distinguished between the clinical and the control groups. We could confirm previous research that predicted that children with ADHD would show a lack motor skills and manual dexterity which mediates cognitive performance (Ziereis & Jansen, 2015). In the current study, typically developing children showed significant correlations between the CRT and several Bender Gestalt scores, with the Bender Motor score as the best predictor for the Common Region Test. This was not the case for the clinical groups, but a notable significant correlation of .76 between unsystematic coding and the Bender motor score in children with ADHD was observed. Data visualization of unsystematic CRT coders showed a cascading effect of the motor score impact on spatial categorization. Most of the children with ASD had very low motor scores and underinclusive Type I CRT binding, while in children with ADHD, a score of 8 or higher on the Bender Motor scale was related to the overinclusive Type II CRT binding. In both the typically developing children and those with ADHD, a Bender motor score of 10 showed a peak with the highest number of unsystematic Type II binding. Thus, one can conclude that low fine motor skills considerably contribute to unsystematic spatial categories in the Common Region drawing task.

Hence, a sensory-motor origin of the local processing bias (e.g. Happé & Frith, 2006) was confirmed as low Bender Gestalt motor scores and local object-place units coincided. Fine motor skill delays can already be found in infants (Choi, Leech, Tager-Flusberg, & Nelson, 2018) and pre-school children (Yu et al., 2018) at high risk for autism. A deficit in fine motor skills becomes most obvious at age three (Garrido, Petrova, Watson, Garcia-Retamero, & Carballo, 2017) when children begin to draw. Most previous research on autism and drawing focused on autistic children with savant talent who show an early onset of visually realistic drawing which skips the phase when children are drawing symbolic icons. However, first, not all children with ASD have a talent for drawing (Eames & Cox, 1994), second, a local bias was also found in the drawings of gifted, typically developing children (Drake, Redash, Coleman, Haimson, & Winner, 2010). Thus, it can be concluded that detailed encodings such as object-place bindings can be based on an option for a local bias that children have at their disposal: It can be a result of a limited choice due to lower fine motor skill and spatial reasoning, or a deliberate choice given other options.

We matched the clinical and the control groups on the BPVS verbal intelligence test that required naming of object pictures which was appropriate for our aims and objectives, however, a limitation was that the groups were not matched on non-verbal intelligence. Fine motor development does correlate with intelligence in pre-school children (Yu et al., 2018). Nevertheless, we could correlate the Raven Progressive Matrices test with unsystematic spatial categorization. Only in children with ASD, unsystematic under-inclusive object-place binding was related at -.64 to their pattern seriation ability in the Raven test. Choi et al. (2018) showed that development of fine motor skills in young children at risk for ASD correlated .60 with the performance IQ and .41 with the verbal IQ. In contrast, over-inclusive spatial object-region binding of children with ADHD was correlated at .76 with motor scores in the Bender Gestalt test. However, this did not imply that motor skills were not important in children with ASD. On the contrary, their fine motor skills were so low that no variance showed which could have been predictive for their unsystematic spatial binding.

The role of fine motor skills in cognition begins already in infancy when interactions with objects are fine-tuned in repeated perception-action loops and object naming (Corbetta, DiMercurio, Wiener, Connell, & Clark, 2018). Perceptual-motor contingencies are important and consist of distinct elements, sensory input, sensory integration with past or stored information, motor interpretation, movement activation and feedback (Goodway, Ozmun, & Gallahue, 2019). Goodway et al. see fine motor skills as an integral part of gross motor skills, while other authors found fine motor skills to be distinct from gross motor skills (Bondi et al., 2020, online). One could argue that one limitation of the current study is that both the Common Region test and the Bender Gestalt test are both pen-on-paper tests. Follow-up research may use the long-established Purdue Pegboard test to assess fine motor skills (Gardner & Broman, 1979), although with the proviso that this test does not require shape representations like the Bender Gestalt test. For instance, Poole et al. (2005) found that boys usually have slower fine motor skills than girls, and this occurs independently of their socio-economic status (Brito & Santos-Morales, 2002). The current sample consisted of mainly boys so it would be interesting in future research to identify the reasons for differences in fine motor skills between boys as well as ways for improvement. Van Abswoude et al. (2019) trained fine motor skills in children of the same age as in the current study and found that working memory was required to follow instructions, but the amount of fine motor learning was not predicted by cognitive capacity. It will be important to see whether fine motor skills training (Vinter & Detable, 2008) can help children with ADHD and ASD to overcome their unsystematic spatial categorizations.

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