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Girls in Detail, Boys in Shape:

Gender Differences when Drawing Cubes in Depth

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ABSTRACT

The current study tested gender differences in the developmental transition from drawing cubes in two versus three dimensions (3D), and investigated the underlying spatial abilities. Six- to 9-year-old children (*N*=97) drew two occluding model cubes and solved several other spatial tasks. Girls more often unfolded the various sides of the cubes into a layout, also called diagrammatic cube drawing (object design detail). In girls, the best predictor for drawing the cubes was mental rotation (MRT) accuracy. In contrast, boys were more likely to preserve the optical appearance of the cube array. Their drawing in 3D was best predicted by mental rotation (MRT) reaction time and the Embedded Figures Test (EFT). This confirmed boys' stronger focus on the contours of an object silhouette (object shape). It is discussed whether the two gender-specific approaches to drawing in three dimensions reflect two sides of the appearance-reality distinction in drawing, that is graphic syntax of object design features vs. visual perception of projective space.

Key Words: Three-dimensional Cube Drawing, Occlusion, Gender differences in spatial abilities, Appearance-Reality Distinction

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Gender differences are a persisting topic in psychology because biological differences and culturally determined roles interact in ways that are not always transparent (Blakemore, Berenbaum, & Liben, 2009). As reported by Maccoby (1998), it was thought that gender equality could either be achieved by appropriate parenting, or that nature destines the two genders for different roles. Maccoby herself held a middle ground and suggested that boys and girls isolate themselves from each other because they have different ways of playing. She reported that boys would view girls as being weak as they would not respond in kind to direct challenges, while girls would see boys as being too rough and allow them to succeed in monopolizing play space and materials. Amongst children, only few individuals would be accepted by both sexes.

However, in addition to socializing preferences, there are other gender differences. Meta-analyses showed that gender differences in visuo-spatial cognition might stem from men's roaming in large-scale far space, while women's spatial skills were more adapted towards small-scale, near space (Sanders, 2011), possibly not because of gathering as often assumed, but because of the spatial proximity involved in child-rearing (Stoet, 2011).

Other researchers pointed to different strategy preferences of each gender (e.g. Spelke, 2005). For instance, mathematics performance was related to boys' spatial reasoning, but to girls' verbal skills (Klein, Adi-Japha, & Hakak-Benizri, 2010). Even a multi-modal task such as reading can be predominantly correlated with either visual or auditory word memory (Lange-Küttner & Krappmann, 2011). Boys would use a whole network of visual skills when reading written language, while girls would not (Huestegge, Heim, Zettelmeyer, & Lange-Küttner, 2011). Likewise, a non-verbal, quiet task such as drawing may involve verbal labelling of graphic parts (Bremner & Moore, 1984), and a preference for verbal encoding of graphic parts was found in especially monolingual girls (Lange-Küttner, 2011).

Whilst girls in Western countries catch up in science, technology, engineering, and mathematics (STEM) subjects where boys had an advantage, boys appeared not to catch up in language skills such as reading where girls were better (Guiso, Monte, Sapienza, & Zingales, 2008). However, Guiso *et al*. also reported that boys maintained an advantage in geometry. On a spatial task such as mental rotation of geometric objects, the male gender often showed a robust advantage that prevailed even after training, and even when females were given more time (Peters, 2005; Tzuriel & Egozi, 2007).

In the current study, we investigated gender differences in a drawing task of two occluding geometrical objects. From an evolutionary perspective, drawing is one of the most ancient cultural activities. Already some cave paintings show pictorial depth cues such as diminishing size with distance and rotated objects (Lange-Küttner & Green, 2007; Milbrath, 2005, 2009), but they were still mostly two-dimensional. These very early graphic productions have become three-dimensional in the technical design drawings of today. Technical drawings do not only contribute an illustrative factor to abstract knowledge (Fuson & Willis, 1989; Piaget, 1969; Wilder & Green, 1963; Willis & Fuson, 1988), but there is also a necessity for accuracy in a technical drawing that predicted learning and memory in STEM science subjects (Schwamborn, Mayer, Thillmann, Leopold, & Leutner, 2010).

We investigated this transition from two-dimensional (2D) to three-dimensional (3D) depictions in the development of children. Drawing from a 3D model on to a 2D drawing sheet involves a skill called 3D-2D transformation. Very recent research showed that especially training of spatial dimensional transformations was so successful that females actually closed the gender gap in mental rotation (Feng, Spence, & Pratt, 2007; Tzuriel & Egozi, 2010), which previously proved to be a task where the male gender showed a robust advantage. Hence, dimensional transformations appear to be critical, and in the following sections we explain in some detail how 3D depth can be created on a 2D surface.

Development of Drawing in Depth

The development of the dimensionality of cube drawings was investigated before (Bremner & Batten, 1991; Bremner, Morse, Hughes, & Andreasen, 2000; Caron-Pargue, 1985, 1992; Cox, 1978, 1986; Kosslyn, Heldmeyer, & Locklear, 1980; Minsky & Papert, 1972; Mitchelmore, 1978; Nicholls, 1995; Nicholls & Kennedy, 1992). The current study adds to this research not only because we explicitly considered gender differences, but also because we conducted additional spatial tests in order to investigate the underlying spatial abilities that may contribute to the transition from two- to three-dimensional drawings.

In Western cultures, depicting three-dimensional depth on a two-dimensional sheet of paper is a main aim for children until adolescence. While already pre-schoolers consider the spatial extensions of 3D cuboids when estimating their volume (Ebersbach, 2009), depiction of 3D depth in the pictorial space of drawings only begins at primary school age (Lange-Küttner, 1997, 2004). Depicting depth is the hallmark of a developmental stage called ‘visual realism’ (Luquet, 1927) where the young draughts(wo)man succeeds in creating the visual illusion of the three-dimensional optical impression of the real world on paper. The development of the depiction of depth in drawing is dependent on multiple variables, such as the ability to co-ordinate increasing numbers of objects (Morra, Moizo, & Scopesi, 1988), the drawing of differentiated natural contours and adaptation of the figure size to the pictorial spatial context (Lange-Küttner, 2008, 2009; Lange-Küttner, Kerzmann, & Heckhausen, 2002), as well as the drawing of objects in scenes from different perspectives (Ebersbach, Stiehler, & Asmus, 2010; Lange-Küttner & Green, 2007).

We focused on two aspects of the depiction of depth: The drawing of occlusion of two cubes, and the drawing of a three-dimensional axes system for a cube (i.e. 3D volume).

Occlusion. Occlusion is a technique to create depth by drawing the more distant object as overlapped by the closer object in the foreground (Cox, 1978; Freeman, Eiser, & Sayers, 1977; Lange-Küttner, 1994). One main graphic problem when drawing one object occluding another object is that the graphic Gestalt of the overlapped object is not complete (Lange-Küttner, 1994). To draw this partially visible figure, it is necessary to draw an open and incomplete contour that is attached to the completely visible figure in the front. In this way, the child draws a well-controlled 'operative' rather than a whole 'figurative' scheme (Morra, 1995). It was suggested that children find drawing a partial figure especially difficult because they would have to stop drawing a contour line without closure (Barrett & Eames, 1996; Freeman, 1980). For instance, when asked to draw half a figure, young children could omit a body part, but they could not just draw the left or the right of the figure (Lange-Küttner, 2000). Berti and Freeman (1997) suggested that the difficulty of younger children would be due to a more general immaturity of inhibition, as young children did not only show difficulties in stopping to draw, but also in stopping to eliminate ('deletion spreading').

Volume. Drawing a cube with volume in three dimensions requires the graphic construction of a visually realistic, three-dimensional spatial axes system. This is not acquired until adolescence because oblique and obtuse angles are more difficult to combine than orthogonal 90^{o} degree angles (Lange-Küttner, 1994, 1997).

The change towards explicit 3D axes systems was shown to follow quite distinct stages. Initially children draw pictures without any spatial axes, that is, they draw just objects in empty space. Nevertheless, there can be implicit spatial relations between objects in their drawings, such as left-right and up-down spatial relations (Light & Humphreys, 1981; Light & MacIntosh, 1980). This is followed by the use of explicit horizontal spatial axes, a ground line and a sky line. On the ground line figures are now lined up rather than distributed across the page (Ebersbach & Hagedorn, 2011). The sky line is a first denotation of an (upper) spatial constraint (Hargreaves, Jones, & Martin, 1981). It was suggested that this spatial system goes some way to recapture early mankind's conviction that the earth is a plate (Vosniadou & Brewer, 1992). Thereafter, children begin to draw areas (Lange-Küttner, 2006, 2010a, 2010b). This can take the form of a bird's eye perspective, that is, a top-down view on a spatial field where human figures can become reduced to stick figures (Lange-Küttner, 2009). Finally, in a further advance, some children go on to construct a visual perspective where spatial axes of the areas converge into a viewpoint.

Young children denote a cube by drawing one square (Mitchelmore, 1978). Nevertheless, when young children copy a real cube with six coloured sides, they often draw all these colours into this one square showing that they imply the entire cube with all sides (Moore, 1986). Later on, initially one other and then several sides are added to this one square. Finally, all, or all visible, cube sides are made explicit, and integrated into a three-dimensional cube drawing (see the scoring manual in Table 2 in the Methods section). We recruited 6- to 10-year-old children to test this gradual dimensional unfolding of the sides of a cube and the transition towards depth depiction.

Gender Differences in Drawing and Spatial Abilities

Gender differences in the drawing of three-dimensional objects were not often reported. This could have happened because in some research areas gender differences are not routinely reported, while in other research areas, gender differences may be magnified (Denmark, Russo, Hanson Frieze, & Sechzer, 1988). We know, however, that girls specify more detail in human figure drawings than boys (e.g. Goodenough & Harris, 1950; Lange-Küttner, Kerzmann & Heckhausen, 2002).

Liben (1975, 1978, 1991) found that the drawing performance in *horizontality* tasks (variations of the Water Level Test) and *verticality* tasks (e.g. trees standing on a flat vs. slanted ground) was correlated in boys of kindergarten and school age, up to adolescence, but not in girls. Liben concluded that boys appeared to solve the tasks using a Euclidean space concept, while girls may have known the concept, but did not apply it in the drawing tasks. Furthermore, in more recent studies, boys were focusing on drawing object silhouettes (Lange-Küttner, 2011; Lange-Küttner*, et al.*, 2002), while girls were more concerned with drawing nameable object parts. We also know that boys in the autistic spectrum show above-average three-dimensional drawing skills (Ropar & Mitchell, 2002; Ropar & Peebles, 2007).

In contrast to drawing research, numerous studies showed gender differences in tests that assessed more explicitly spatial abilities. For instance, when children were asked to draw a horizontal line into a tilted bottle in the *Water Level Test (WLT),* male participants scored higher than females in all age groups (Kalichman, 1986; Liben, 1974, 1991; Morra, S. , 2008; Sholl, 1989; Sholl & Liben, 1995; Thomas & Lohaus, 1993; Vasta & Liben, 1996). When adults decided whether two rotated objects are the same in the *Mental Rotation Test (MRT),* there were robust gender differences in favour of men (Linn & Petersen, 1985; Silverman, Choi, & Peters, 2007; Voyer, Voyer, & Bryden, 1995), unless stimuli were rotated ‘animate’ human figures (Alexander & Evardone, 2008). Evidence on gender differences in children in this task is mixed. Some studies found gender differences in mental rotation (Heil & Jansen-Osmann, 2008a; Kerns & Berenbaum, 1991; Vederhus & Krekling, 1996; Voyer, 1995; Wiedenbauer & Jansen-Osmann, 2008), while others did not (Frick, Daum, Walser, & Mast, 2009; Kosslyn, Margolis, Barrett, Goldknopf, & Daly, 1990; Quaiser-Pohl, 2003).

Importantly, there is increasing evidence that females use local detail-centred strategies rather than a global approach when judging identity of objects rotated in the context of overall space (Gootjes, Bruggeling, Magnée, & Van Strien, 2008; Heil & Jansen-Osmann, 2008b; Hirnstein, Bayer, & Hausmann, 2009; Hugdahl, Thomsen, & Ersland, 2006). From this perspective, a female disadvantage in mental rotation would be a secondary result of a more ‘small-scale’ approach involving the processing of more object details, which in turn would increase cognitive load, as the system would be cluttered with processing component parts instead of assessment of direction.

We also included the *Embedded Figures Test (EFT)* where participants have to detect a simple geometrical figure whose shape *boundary* is hidden within in a non-sense spatial context that obliterates easy recognition, see Figure 2 (Karp & Konstadt, 1963; Witkin, Moore, Goodenough, & Cox, 1977; Witkin, Oltman, Raskin, & Karp, 1971). The EFT yielded individual differences which were due to culture, gender and working memory. For instance, in a study with a large cross-cultural sample, participants from East Asia and Russia detected fewer embedded figures - and hence showed more field-dependence - than participants from Western States, while gender differences were not significant (Kühnen *et al.*, 2001). However, mostly male autistic people showed better performance - and hence less field dependence - in the EFT than neurotypical gender-matched controls (Jolliffe & Baron-Cohen, 1997).

With regards to children, the EFT significantly correlated with working memory, with field-independent children showing higher digit spans (Guisande, Soledad Rodríguez, Almeida, Tinajero, & Fernanda Páramo, 2008). While 10-year-old boys and girls did neither differ on EFT performance nor on self-esteem, all self-esteem measures were negatively correlated with the EFT in girls, but positively with boys (Bosacki, Innerd, & Towson, 1997). In research on visual memory, some boys focused on spatial region boundaries already at the young age of seven years and showed superior spatial memory (Lange-Küttner, 2010a). A perceptual focus on boundaries is conceptualized as contour extraction, and a vast array of literature exists for contour extraction in machine vision (e.g. Li, Manjunath, & Mitra, 1995). Hence, it was expected that the EFT may be a more important variable for the graphic constructions of boys in comparison to girls.

In short, our hypothesis was that when drawing cubes in depth, girls would be using an approach that focuses on small details, while boys would apperceive and conceptualize the shapes of the cubes in a larger spatial context. We gave the children two occluding Rubik's cubes to depict that were painted in a uniform colour so that the coloured details of the Rubik's cubes were concealed, and only subtle segments on the surface structure remained. Hence, this was a conservative approach, as details would be less salient: Occlusion of two similar objects is more difficult to depict than occlusion of two dissimilar objects, because contrasting objects can be kept more easily apart in perception in order to arrange them behind each other on the page (Morra, Angi, & Tomat, 1996).

Method

Participants

The age means of the four age groups of 6-, 7-, 8- and 9-year-old mainly Caucasian children (*N*=97) are listed in Table 1 separately for each gender. Children were from a middle class population in a medium sized town in Germany. They were randomly selected from several schools and participated on a voluntary basis with informed consent of their parents.

Material

Drawing Task. Two Rubik's cubes were painted uniformly with a natural wood-brown colour so that the individual elements were merged into a homogeneous surface structure. In the drawing task, the child was asked to depict the two plastic 7cm × 7cm × 7 cm cubes (Fig. 1) exactly as they looked. They were placed one directly behind the other, with partial occlusion, on a table, in a distance of about 30 cm from the child. The two cubes were positioned so that the top, the front and one side face of each cube were visible from the child's point of view. The surface of each face of the cubes included a 3 x 3 grid (i.e. 9 small separate squares).

The **Water Level Test (WLT)** is a measure of spatial perception that involves detecting spatial relationships with respect to a spatial reference system. Subjects have to draw a horizontal water level into pictures of half-filled bottles that were tipped to different degrees with respect to a horizontal ground line. Younger children usually use the bottle itself as local reference and draw the water level as a parallel to the bottom of the container. Older children, in contrast, use the spatial context of the bottle as a reference and draw the water level as parallel to the table (Ackermann-Valladao, 1987; Dodwell, 1963; Larsen & Abravanel, 1971; Piaget & Inhelder, 1956). Pictures of seven bottles were presented in different orientations with respect to the ground. The seven trials were scored as correct if the level drawn did not deviate more than 8° from the horizontal (Lohaus, Kessler, Thomas, & Gediga, 1994), and converted into a % correct score.

The **Mental Rotation Test (MRT)** requires the imaginary rotation of an object in order to decide whether it is identical to a standard. The more an object is rotated with respect to the standard, the longer it takes a person to decide whether the two objects were identical (Shepard & Metzler, 1971). Young children usually solve the MRT slower than adults (Berg, Hertzog, & Hunt, 1982; Funk, Brugger, & Wilkening, 2005; Geiser, Lehmann, Corth, & Eid, 2008; Kail, 1985; Kosslyn, *et al.*, 1990). Thus, reaction time (i.e. the time between the onset of the presentation of the trial and the onset of a child's response) was additionally measured using a stop-watch. The Mental Rotation Test (MRT) consisted of eight abstract figures as designed by Shepard and Metzler (1971). The number of correct responses was converted into a % correct-score.

In the **Embedded Figures Test (EFT)**, participants have to detect a simple shape (e.g., a triangle) that is hidden within in a complex non-sense geometrical drawing (Karp & Konstadt, 1963; Witkin, *et al.*, 1971). To succeed, one has to ignore the spatial context of the hidden shape. Poorer performers in this test are evaluated as 'field-dependent' (Pascual-

Leone, 1989; Witkin, *et al.*, 1977). While field-dependence is a source of individual differences in adults, younger children show higher scores of field-dependence than older children or adolescents (Amador-Campos & Kirchner-Nebot, 1997). The Embedded Figures Test (EFT) comprised of eight tasks that were adapted from the Children's Embedded Figures Test (Witkin et al., 1971; for an example see Fig. 2). The number of correct responses was converted into a % correct-score and reaction times were recorded.

Procedure

Children were tested individually in a separate room in their school environment. They received a small reward after their participation. The session always started with the drawing task, followed by the spatial tests, which in turn were in random order. All tasks were presented as paper-and-pencil versions.

Introductions to each task. All three spatial tests had an introductory phase where performance feedback was given, different to the test phase thereafter.

The WLT was introduced by showing the child a real bottle presented upright and half filled with water. The experimenter pointed towards the water level in the bottle and named it to illustrate the term 'water level'. Then, the real bottle was removed and the first WLT trial started.

The MRT started with presenting two practice trials. First, the child saw two identical 3-dimensional L-shaped objects, constructed of four blocks of LEGO©. One object was 90° horizontally rotated. The child was asked to look at the two objects and to decide whether they were identical. The second example was a Shepard-Metzler figure that was not part of the main test.

The EFT was introduced as a detection game that required to find a hidden figure in a complex drawing and to trace it with the finger. After two practice trials using simple examples (e.g., a triangle in a square) and providing feedback, the child completed the tasks of the main test. Children were told in both the MRT and the EFT to respond as fast and as exact as possible.

Drawing Evaluation. Two independent raters scored the cube drawings with regards to development of volume and occlusion with a manual that was created following previous research (Bremner & Batten, 1991; Cox, 1986; Lange-Küttner, 2009; Mitchelmore, 1978; Vinter & Marot, 2007; Vinter, Puspitawati, & Witt, 2010) (see the scoring manual in Table 2). If the two cubes in the drawing showed different levels in 3D appearance, the more advanced cube projection system was scored. With regard to the scoring of occlusion, no cases of transparent occlusion drawing (i.e. intersection) occurred. Children were drawing the cubes either separately, or with correct partial occlusion. The interrater reliability was $r = .91$ for volume, and $r = .88$ for occlusion. Furthermore, the number of details in the front face of the front cube was counted (9 parts were correct = maximum score). The nine square parts on the front cube face could also be denoted with dots or strokes like a surface texture, see Figure 4B. Only the front side of the front cube was evaluated in this way because each and every child had drawn at least one square to represent each cube. When children had drawn two juxtaposed squares for the cubes, the more accurately drawn square was evaluated.

Results

Data were analyzed for the entire sample, and/or separately for boys and girls using the same analyses with a split-sample procedure.

Drawing. Drawing the cubes in three dimensions showed a significant development with age, χ^2 (9, $n = 97$) = 18.85, $p < .05$, see Figure 3A. While one-face and two-face cube drawings decreased with age, diagrammatic fold-outs and viewpoint perspective depictions increased with age.

Boys and girls drew viewpoint perspective equally often; hence this stage was omitted from the following Chi-square analysis. Considerably more boys depicted the cubes with two faces in an orthogonal manner (Level 2, $z < .05$, corrected with Bonferroni), while girls were more likely to draw the cubes as diagrammatic fold-outs ($z < .05$, corrected with Bonferroni) (Level 3, see examples in Figure 4), χ^2 (2, n = 83) = 6.30, $p < .05$, see Figure 3B.

Drawing occlusion increased with age, but this was not significant in the total sample, χ^2 (3, n = 97) = 6.33, p = .097. The split-sample analysis showed that in boys, occlusion did not increase with age, χ^2 (3, n = 49) = 2.28, *ns,* because only 17 out of 49 (34.7%) boys drew occluded cubes. The remaining 32 boys (65.3%) drew the two cubes separately. In contrast, 26 of 48 girls (54.1%) drew occluding cubes, with a clear age trend, χ^2 (3, n = 48) = 9.58, p < .05. Chi-square analysis showed that this difference between boys and girls in the frequency of drawing occlusion was near significance, χ^2 (1, n = 97) = 3.73, p = .054.

Drawing the cube in 3D volume and drawing occlusion went hand in hand: Those children who drew the cubes separately were also more likely to draw just the front face, while those children drawing occlusion were more likely to draw also cube volume, χ^2(3, n = 97) = 27.74, $p < .001$.

With regard to surface detail, some children did not draw any parts of the surface grid of the cubes, while in the drawings of other children, parts proliferated. Hence, the variable with the count of the parts of the front face of the cube was dichotomized into, (1) into those children who ignored the subtle surface structure, and (2) those children who had endeavoured to depict the small squares of the surface grid. The sensitivity to surface detail changed with age, χ^2(3, n = 97) = 11.50, $p < .001$, see Table 3A. Binomial tests showed that 6-year-olds were more likely to attend to the surface structure, while 8-year-olds were more likely to ignore the surface structure. Gender was not significant, χ^2(1, n = 97) = .25, *ns*, that is both boys and girls were equally likely to attend to surface grid details.

Of the 44 children who drew details of the front face, ten (22.8%) drew the correct amount of details, that is nine small squares. Of the remaining 34 children, six children

(13.6%) drew fewer details and 28 children (63.6%) more details. The average number of surface details of those children who drew an incorrect amount was 28.6 parts (6-year-olds), 26.7 parts (7-year-olds), 19.8 parts (8-year-olds) and 15.8 parts (9-year-olds). Although the number of details approached the correct value with age, the age effect did not reach significance. The small number of children who were accurate in the depiction of the nine parts in the front cube face were also more likely to draw in 3D, while those who were inaccurate were less likely to draw in 3D, $\chi^2(3, n = 44) = 11.65, p < .01$. Adding those children to the Chi-square analysis (see Table 3B) who had *not* reacted towards the cube surface did not eliminate the significance, $\chi^2(6, n = 97) = 14.87, p < .05$. Their insensitivity towards surface detail was not related to drawing cube volume, as observed and expected frequencies were similar. These analyses were an important control of the effect of the subtle monochrome detail on the cube surface.

Spatial Measures. Group means, standard deviations and *F*-test results are listed in Table 4. Boys showed a trend towards improvement with age on mental rotation (MRT), while in girls this effect was significant. Also other significant age improvements, in the EFT (accuracy and reaction times), the MRT (accuracy only) and the WLT in the total sample were mainly carried by girls' improvements. While boys had a very small advantage in spatial accuracy over girls at 6 years in all three tests, their advantage was not increased further in the older age groups. The only spatial ability to show a trend for a gender effect was mental rotation where the younger girls tended to be less correct until to age 8.

Prediction of 3D Drawing by Spatial Skills. The impact of spatial abilities on 3D drawing was first analyzed with a correlational analysis (Spearman's Rho). Thereafter, in order to identify the best predictor for drawing the cubes in three dimensions, a linear multiple regression analysis was run, also separately for boys and girls, with occlusion and the cube volume score, respectively, as dependent variables.

Correlations. In girls, drawing of both cube volume and occlusion correlated with the same spatial abilities: EFT (accuracy and reaction times) and MRT (accuracy) (see Table 5, correlations above the diagonal). MRT reaction times had close to zero correlations with drawing in girls. Instead, MRT and EFT reaction times were significantly correlated with each other. Those girls who were fast in the MRT tended to be fast in the EFT, too.

In contrast, in boys, drawing cube volume was significantly correlated with the EFT (accuracy) and the WLT (see Table 5, correlations below the diagonal). Drawing cube occlusion correlated only with MRT reaction times; boys with short MRT reaction times were more likely to draw occluding cubes. MRT reaction times also correlated significantly with the amount of detail; boys who showed faster reaction times in the MRT were drawing more front face cube detail than boys with slower MRT reaction times. In contrast, MRT and EFT reaction times had a close to zero correlation. Boys tended to be fast on the MRT independently of how much time they took in the EFT.

Regressions. In order to identify the best predictors, two regressions were run, with the dependent variable cube occlusion (Table 6) and cube volume (Table 7), respectively. Predictors were the spatial abilities EFT, MRT and WLT, and the number of details in the front face of the cube as a task control variable. Age in months was included as a predictor not only in order to control for chronological age in this children sample, but also as a variable that captures the maturation and gradually increasing information processing capacity in children.

Occlusion. While no predictors for occlusion for the total sample reached significance, $F(7, 96) = 1.85$, $p = .088$, $R = .46$, $R^2 = .13$, in the split-sample, different predictors were explanatory for boys and girls, see Table 6. In girls, only the MRT *accuracy* predicted 40% of the variance in the drawing of occluding cubes, $F\ (7, 47) = 3.43$, $p = .006$, $R = .61$, $R^2 = .38$, see Figure 5A. In contrast, in boys, only the MRT *reaction time* was a significant predictor explaining 31% of the variance when drawing occluding cubes, see Figure 5B, although the regression model itself was not significant, $F(7, 48) = .91$, *ns*., $R = .37$, $R^2 = .13$. Hence, the split-sample regressions showed that mental rotation was the most important predictor for drawing occlusion, and more so in girls than in boys. This impact of mental rotation was even more remarkable as age did not play a role in the prediction of the graphic construction of occlusion.

Volume. In the multiple regression with cube volume as the dependent variable involving the total sample, the EFT explained 25% and age in months 31% of the variance, $F(7, 96) = 4.77$, $p < .001$, $R = .52$, $R^2 = .27$. However, in the split-sample, these predictors were not explanatory in the same way for boys and girls. In girls, neither the EFT nor age significantly predicted the drawing of cube volume. Instead, again MRT accuracy was a significant predictor explaining 31% of the variance for girls' drawing of occluding cubes, $F(7, 47) = 2.79$, $p = .018$, $R = .57$, $R^2 = .33$. In contrast, in the boys' sample, the EFT explained a large share of 31%, and age 32% of the variance when drawing cube volume, $F(7, 48) = 3.66$, $p = .004$, $R = .62$, $R^2 = .38$.

DISCUSSION

Like in a previous longitudinal study (Lange-Küttner, 1994), depth construction via spatial axes and via occlusion were highly contingent within each participant, that is, a child drawing several sides of the cube was also highly likely to draw occlusion. This showed that both techniques to depict 3D were highly related, but what are the spatial abilities that enable a child to conceptualize depth in pictorial space?

The present study investigated the underlying spatial abilities when drawing two occluding cubes in girls and boys. The hypothesis was that girls would use an approach that capitalizes on details reflecting a more small-scale approach, while boys would focus more on the silhouette of an object and apperceive the cubes in a larger context within their spatial field (Lange-Küttner, 2011; Lange-Küttner*, et al.*, 2002). This hypothesis was clearly confirmed. Girls were more likely to embark on folding out the occluding two cubes. In contrast, boys were more likely to draw the two cubes separately, thus preserving in a 'clean' view (or good Gestalt) of the shape of each individual cube (Lange-Küttner & Reith, 1995). The differences between both genders were not deterministic, but probabilistic. There was still a considerable proportion of boys (i.e. about one third) who drew the cubes as diagrammatic fold-outs, while a similar proportion of girls drew two-face cubes.

From the human figure drawing test, we know since a long time that girls usually draw plenty of details which results in a higher score than in boys (Goodenough, 1926; Goodenough & Harris, 1950; Naglieri, 1988), but the reason for this advantage has never been explained. Also in the current study that used 'inanimate' cubes, rather than 'animate' human figures as drawing topic, boys focused on the silhouettes of each of the cubes. In contrast, girls were more inclined to draw what has been called in one of the earliest empirical studies into children's drawings a 'fold-out' or 'diagrammatic view' of the cube array (Kosslyn, *et al.*, 1980). Kosslyn *et al.* stated that diagrammatic drawings would be of the greatest interest as they would be more likely to reveal some information about the underlying mental representations of spatial concepts than conventional drawings. Kosslyn *et al.* found that 4- to 11-year-old children mostly preferred drawings in viewpoint perspective; only very few children preferred diagrammatic depictions when they had a choice. Resemblance was an explanation for this preference in 44% of the 4-year-olds, that is nearly half the sample of this young age group, but it had become the most prominent explanation for preference in 11-year-olds, with 79% of the sample stating that they preferred viewpoint perspective for this reason. However, while diagrammatic drawings were not preferred, also in Kosslyn *et al.*'s study many children were actually drawing these fold-outs, with a peak in 6- to 9-year-olds, which is exactly the age range of the present sample.

The current study also allowed to distinguish between design details (cube faces) and surface details (details within a cube face). The variable that we controlled was the amount of detail in the front face of the cube which contained exactly nine squares. To count up to nine should not be a difficult task for children of this age, and this counting could have been used to control the amount of depicted surface details on the front face of the cube. However, most of those children who picked up on the surface details were drawing them rather summarily in large quantities like a pattern. This was still the case at age 9 when the mean number of surface parts on the front face was still exceeding the correct number by seven – that is nearly the double of the correct amount. In contrast, those children who controlled the exact amount of detail, were also more likely to draw in 3D, which speaks to the importance and impact of accuracy on the depiction of dimensionality (see also Schwamborn, *et al.*, 2010). There were no gender differences in this regard.

However, there were gender differences in the impact of MRT accuracy and reaction times on drawing, that is, the ability to identify the identity of a rotated object was predictive for drawing of occlusion. Similar to the occluding cube drawing task, in the Shephard and Metzler (1971) mental rotation task children were asked to look at two objects. They then had to decide whether the shapes were identical when presented in different alignments. Boys were not faster than girls, but they tended to be more correct than girls in their decisions. Hence, boys were comparably more efficient in the MRT decision making, as they could come to more correct conclusions within the same time. In boys, these reaction times in the MRT were the only significant predictor for drawing occlusion. Figure 5B illustrated that especially the efficient boys with shorter reaction times were more likely to draw occlusion of the cubes, while in girls, time did not matter. Mental rotation reaction times were already task-specific for boys at this young age (see also Lange-Küttner, 2012), that is, boys' reaction times in the MRT did not correlate with their reaction times in the EFT. In contrast, girls seemed to work at their own steady pace, independently of the task at hand, as their reaction times were significantly correlated.

In contrast, in girls, accuracy in the MRT was the only significant predictor for drawing of occlusion. Figure 5A illustrated that those girls who were at about chance (chance = 50% correct in a choice of two) in deciding about the identity of the cube aggregates in the MRT, were also much more likely to draw separate cube shapes.

The Neo-Piagetian developmental psychologists Pascual-Leone (1989) and Morra (2002, 2005, 2007; Morra, S., 2008) claimed that control of a perceptual field factor would be important for children's drawing of occlusion, especially if the two objects had similar shapes (Morra, S., 2008; 2008; Morra*, et al.*, 1996). However, the current study showed that for occlusion drawing, for both genders, the MRT - where children judged object identity and similarity - was more important than the EFT where children had to detect the contour of a shape hidden within a spatial context (the spatial field).

The spatial context task EFT, however, was important in boys' drawing of cube 3D volume. The higher the boys scored in the EFT, the more likely they were to draw an advanced drawing system. This confirmed our initial hypothesis that the EFT would be more important for boys than for girls. In this task, children had to trace the contour of a shape with a finger and ignore the noisy spatial context in which it was embedded. Tracing a contour seems to be a process that facilitates long-term memory of visual shapes in young children (Ross, 2008). For girls, however, the EFT was not predictive for drawing 3D volume. Instead, like in the prediction of occlusion, MRT accuracy best predicted the level of cube volume. Those girls who were at chance in judging the identity of rotated cube aggregates were also more likely to draw separate orthographic one-face cubes. This result confirmed our initial hypothesis that a female disadvantage in mental rotation would have an impact on their spatial drawing.

Hence, the current study confirmed our assumption that spatial abilities would be differentially predictive for spatial drawings of boys and girls. Furthermore, the drawing task allowed to make an important distinction between surface details and design details. When the surface details were depicted, they were more likely to be treated as texture rather than as a design detail of the cube itself. The girls' focus on detail emerged only for design detail – similar to the human figure drawing where one could argue that the differentiation of nameable body parts specifies the design and the anatomy of the human body (Cox, 1993; Lange-Küttner, 2011). When drawing a diagrammatic cube layout, one could name the sides of the cubes as top and bottom, left and right, front and back. The current differentiation of *texture detail* vs. *cube detail* thus showed that the girls were not just exercising their fine motor skills (Lange-Küttner, 1998; Toomela, 2002) and relatively smaller fingers (Peters, Servos, & Day, 1990). Girls were interested in the cube construction rather than just in the more decorative surface details. Future studies should show whether this will hold true when the surface details of the Rubik's cubes are not coated in paint, but remain functional, moveable object parts.

In contrast, boys seemed more adept in an efficient identification of visual shapes, and they used this ability in their drawings. This conformed with the most accepted theory in the drawing literature that suggested that visual realism is the most advanced stage of drawing where children aim to map their optical impression of reality on to the drawing page (Luquet, 1927). Hence, boys used quite a different ability for drawing than girls. In a recent review paper, Rittschof (2010) writes: "Cognitive styles should emphasize the *manner or propensity (italics in the original text)* of students in organizing and gathering information whereby one style is different but not necessarily superior to the other" (p. 102). Rittschof presumed that field independence – as measured by the EFT - was not correlated with thinking styles

(Zhang, 2004), but would be a perceptual ability that would be 'tantamount' (Sternberg, 1997) and nearly indistinguishable (MacLeod, Jackson, & Palmer, 1986) from spatial ability.

However, Minsky and Papert (1972) presumed that the underlying representation of drawing is a structural description of object features and their relations, not unlike a *graphic syntax* (Goodnow & Levine, 1973; Van Sommers, 1984, 1989; Vinter, Picard, & Fernandes, 2008). This approach would aptly describe the girls' drawing strategy in this study. In contrast, Kosslyn et al. (1977) showed that children did not intend to base their drawings on the most detailed and explicit description of an object (the diagrammatic layout), but on a perceptually correct resemblance that maps their optical viewpoint in a visually realistic way. This is a perceptual approach that was favoured by the majority of boys in this study. Girls appeared to use drawing as a technical language (Tzuriel & Egozi, 2007) and some struggled more with the perceptual aspects, while boys seemed to use drawing as a translation of their vision, but few showed unfolding of the different cube aspects. Hence, these gender-specific pathways to 3D depth depiction showed that both the structural graphic syntax and the perceptual resemblance theory were justified by empirical evidence – even though visual realism appeared to be the ultimate aim of both genders.

In terms of psychological theory of visual cognition, our suggestion is that at a time when children discover the appearance-reality distinction and the dual nature of pictures (Flavell, Green, & Flavell, 1986; Jolley, 2008; Robinson, Nye, & Thomas, 1994) as well as the rules of visual projection (Flavell, Green, Herrera, & Flavell, 1991), boys were more likely to attend to the projective appearance of the cubes (the visual object), while girls were more likely to graphically explore aspects of the identity of the cubes (the real object). These gender-specific profiles would allow to make predictions for gender-specific challenges that could be investigated in future research. For instance, if girls prove to be more interested in the construction and design details, they would need to invest more effort into information integration of these details (Anderson, 1981; Wilkening, 1979) if a concise outline is required. In contrast, if boys turn out to be more interested in holistic visual resemblances (Wilkening & Lange, 1989), it could be predicted that they will find that they have to dedicate more time to locate a detail where a construction plan or script has become dysfunctional. In this way, gender research in spatial abilities shifts away from differences in performance level, and towards differences in spatial reasoning styles.

In the current study, we used various spatial tasks to explore the background of gender-specific pathways to the three-dimensional visual realism in the drawing of two overlapping cubes. A limitation was that the amount of detail and the regularity of the outline was not directly manipulated by using different drawing models. This more direct test is underway with different sorts of cube models using a within-subject measurement. Because cognitive style is also culturally determined, future research may reveal interesting cross-cultural differences.

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Table 1

Descriptive Statistics of Age (years; months) and Gender per Age group

Age Group	Gender	*n*	*M*	*Min*	*Max*	*SD (months)*
6 years	total	18	6;7	6;2	6;11	3
	boys	8	6;7	6;2	6;11	3
	girls	10	6;6	6;2	6;11	4
7 years	total	23	7;4	7;0	7;11	4
	boys	11	7;4	7;1	7;11	4
	girls	12	7;4	7;0	7;11	5
8 years	total	37	8;7	8;1	8;11	3
	boys	20	8;6	8;1	8;11	3
	girls	17	8;7	8;1	8;11	3
9 years	total	19	9;6	9;0	10;8	6
	boys	10	9;6	9;0	10;1	5
	girls	9	9;7	9;0	10;8	8
Total sample		*N* = 97 (49 boys, 48 girls)				

Table 2

Categorization of the drawings: cube volume and occlusion

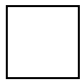
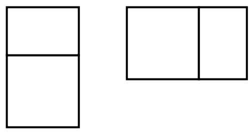
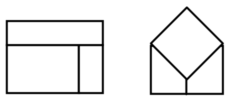
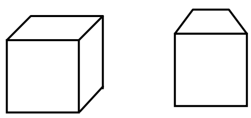
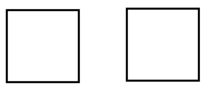
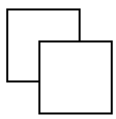
Cube volume	*Description*	*Score*	*Examples*
(1) Orthographic	One-Face Cube: All sides implicit	1	
(2) Vertical or horizontal	Two-Face Cube: Front face plus top or side face unfolded	2	
(3) Diagrammatic, Fold-out	Front face plus top and side faces unfolded (same ground line)	3	
(4) Oblique / viewpoint perspective	Oblique angles, parallel lines or common vanishing point	4	
Occlusion			
None		0	
Occlusion		1	

Table 3A

Children's Sensitivity to the Surface Parts of the Front Cube Face

		Age Group				
		6 Years	7 Years	8 Years	9 Years	Total
No Surface Parts Depicted	Observed *n*	5	13	27	8	53
	Expected *n*	9.8	12.6	20.2	10.4	53
	Percent *n*	9.4%	24.5%	50.9%	15.1%	100%
	% per age group	27.8%	56.5%	73.0%	42.1%	54.6%
Surface Parts Depicted	Observed *n*	13	10	10	11	44
	Expected *n*	8.2	10.4	16.8	8.6	44
	Percent *n*	29.5%	22.7%	22.7%	25.0%	100%
	% per age group	72.2%	43.5%	27.0%	57.9%	45.4%
Binomial *p* (one-tailed)		.048*	.339	.001**	.324	

Note. $^{**}p < .01$, $^{*}p < .05$.

Table 3B

Accuracy of the Number of Surface Parts on the Front Cube Face and Level of the Cube Drawing

		Space System				
		1	2	3	4	Total
No surface parts	Observed *n*	23	9	14	7	53
	Expected *n*	19.7	10.9	14.8	7.6	53
Inaccurate surface parts	Observed *n*	11	9	12	2	34
	Expected *n*	12.6	7.0	9.5	4.9	34
Accurate surface parts (9 squares)	Observed *n*	2	2	1	5	10
	Expected *n*	3.7	2.1	2.8	1.4	10
Total *N*		36	20	27	14	97

Table 4

Age Development of the Scores of the Spatial Tests (Mean % correct and Reaction Times with SD in brackets)

Variable	6 Years	7 Years	8 Years	9 Years	Age *(F)*	Gender *(F)*	Age by Gender *(F)*
Mental Rotation Test (MRT)	.60 (.17)	.59 (.14)	.68 (.19)	.78 (.15)	5.37 **	3.43 (*)	0.50
Boys	.63 (.18)	.65 (.13)	.73 (.16)	.79 (.12)	2.52 (*)		
Girls	.59 (.18)	.54 (.12)	.62 (.21)	.78 (.19)	3.12 *		
rt MRT in seconds	8.9 (6.9)	10.0 (8.6)	9.3 (5.7)	8.8 (6.4)	0.14	0.02	0.10
Boys	8.9 (7.1)	9.4 (10.3)	9.1 (5.2)	9.3 (8.1)	0.00		
Girls	8.9 (7.1)	10.7 (6.9)	9.6 (6.4)	8.3 (4.3)	0.27		
Embedded Figures Test (EFT)	.63 (.19)	.65 (.17)	.75 (.15)	.75 (.13)	3.93 *	1.26	0.53
Boys	.64 (.18)	.63 (.19)	.73 (.17)	.70 (.14)	1.12		
Girls	.61 (.21)	.67 (.15)	.77 (.12)	.81 (.09)	3.96 *		
rt EFT in seconds	12.2 (5.4)	9.9 (3.2)	9.1 (3.6)	7.4 (3.4)	5.21 **	2.35	0.98
Boys	13.2 (7.8)	9.9 (3.3)	9.1 (3.5)	9.0 (3.8)	1.80		
Girls	11.3 (2.5)	10.0 (3.3)	9.1 (3.9)	5.7 (1.7)	5.43 **		
Water Level Test (WLT)	.29 (.28)	.34 (.20)	.47 (.19)	.56 (.25)	5.66 **	0.08	1.05
Boys	.35 (.38)	.35 (.24)	.44 (.20)	.50 (.23)	0.83		
Girls	.24 (.19)	.34 (.20)	.49 (.19)	.63 (.27)	7.28 **		

Note. $^{**}p < .01$, $^{*}p < .05$, 3 *df* for Age, 1 *df* for Gender and 3 *df* for Age by Gender

Table 5

Correlations (Spearman's Rho) between drawing scores, spatial scores, and age in months, separately for each gender

Variable	Volume	Occlusion	Details	EFT	*rt* EFT	MRT	*rt* MRT	WLT	Age
Cube volume		.72**	.01	.32*	-.36*	.40**	.01	.21	.42**
Occlusion	.32*		-.12	.38**	-.38**	.45**	.02	.32*	.42**
Details	.10	-.19		-.12	.02	-.10	-.22	-.16	-.36*
Embedded Figures Test (EFT)	.49**	.01	-.04		-.26	.35*	.17	.60**	.47**
Reaction time *rt* EFT	.01	.02	-.02	-.21		-.03	.41**	-.44**	-.51**
Mental Rotation Test (MRT)	.26	.04	-.04	.38**	-.22		.24	.37*	.35*
Reaction time *rt* MRT	-.07	-.31*	.36*	-.01	.06	.08		.07	.05
Water Level Test (WLT)	.35*	.08	-.03	.26	.05	.15	-.05		.53**
Age	.41**	.04	.04	.22	-.13	.34*	.10	.24	

Note. ***p* < .01, **p* < .05. Correlations for girls are listed above the diagonal, correlations for boys below the diagonal

Table 6

Best Predictors for Drawing Occlusion in Girls and Boys (Multiple regression)

Predictor for Occlusion	*Beta*	*t*	*p*
Total Sample (*N* = 96)			
Embedded Figures Test (EFT)	.11	.95	.344
rt EFT	-.02	-.18	.860
Mental Rotation Test (MRT)	.15	1.34	.184
rt MRT	-.17	-1.64	.106
Water Level Test (WLT)	.10	.83	.410
Details Cube Front Face	-.11	-1.10	.276
Age in months	.04	.32	.753
Girls (*n* = 47)			
Embedded Figures Test (EFT)	.216	1.334	.190
rt EFT	-.286	-1.646	.108
Mental Rotation Test (MRT)	**.395**	**2.743**	**.009**
rt MRT	-.033	-.217	.830
Water Level Test (WLT)	-.119	-.658	.514
Details Cube Front Face	-.092	-.663	.511
Age in months	.086	.484	.631
Boys (*n* = 48)			
Embedded Figures Test (EFT)	-.015	-.094	.926
rt EFT	.110	.713	.480
Mental Rotation Test (MRT)	.034	.204	.839
***rt* MRT**	**-.311**	**-2.089**	**.043**
Water Level Test (WLT)	.083	.511	.612
Details Cube Front Face	-.162	-1.039	.305
Age in months	-.038	-.229	.820

Note. Significant factors are printed in bold font

Table 7

Best Predictors for Drawing Cube Volume in Girls and Boys (Multiple regression)

Predictor for Cube volume	*Beta*	*t*	*p*
Total Sample (*N* = 97)			
Embedded Figures Test (EFT)	**.251**	**2.405**	**.018**
rt EFT	.017	.162	.872
Mental Rotation Test (MRT)	.103	1.029	.306
rt MRT	-.077	-.818	.415
Water Level Test (WLT)	.062	.583	.561
Details Cube Front Face	.140	1.471	.145
Age in months	**.306**	**2.699**	**.008**
Girls (*n* = 48)			
Embedded Figures Test (EFT)	.164	.978	.334
rt EFT	-.300	-1.665	.104
Mental Rotation Test (MRT)	**.310**	**2.077**	**.044**
rt MRT	.015	.092	.927
Water Level Test (WLT)	-.288	-1.540	.131
Details Cube Front Face	.089	.616	.541
Age in months	.306	1.661	.105
Boys (*n* = 49)			
Embedded Figures Test (EFT)	**.350**	**2.522**	**.016**
rt EFT	.146	1.120	.269
Mental Rotation Test (MRT)	.000	.001	.999
rt MRT	-.065	-.518	.607
Water Level Test (WLT)	.237	1.723	.093
Details Cube Front Face	.057	.483	.664
Age in months	**.322**	**2.271**	**.028**

Note. Significant factors are printed in bold font

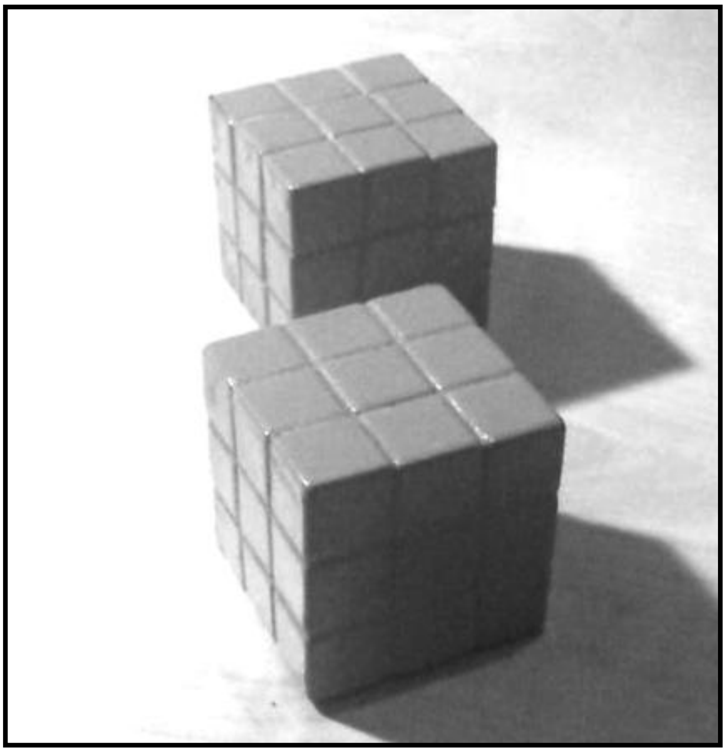


Figure 1 Cubes as presented in the drawing task.

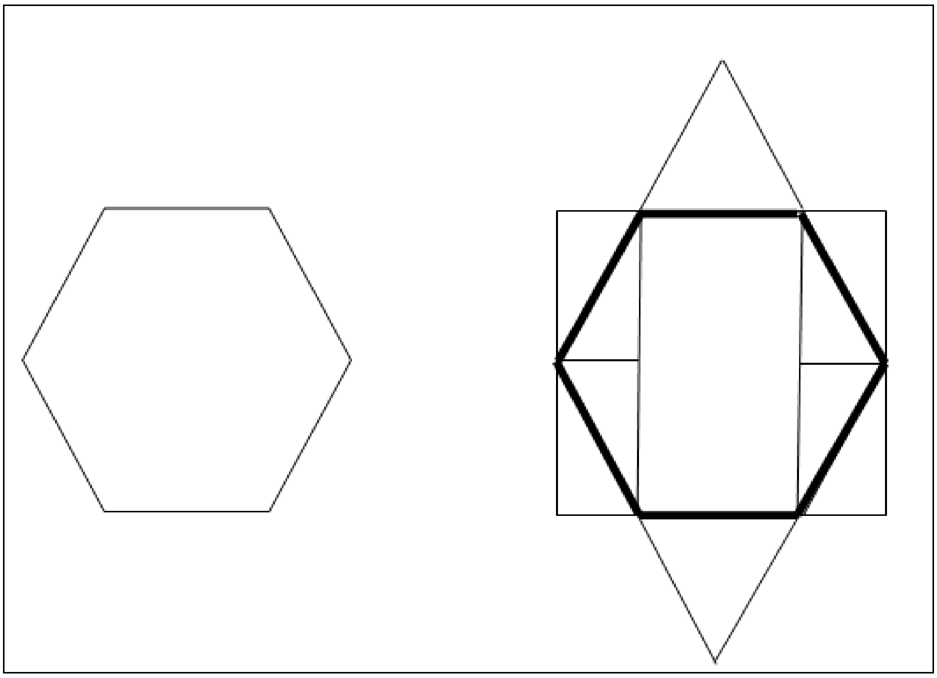


Figure 2 Example item of the Embedded Figures Test (EFT) (adapted from Witkin et al., 1971). *Note.* The bold line is not marked in the original test, but shows the correct solution.

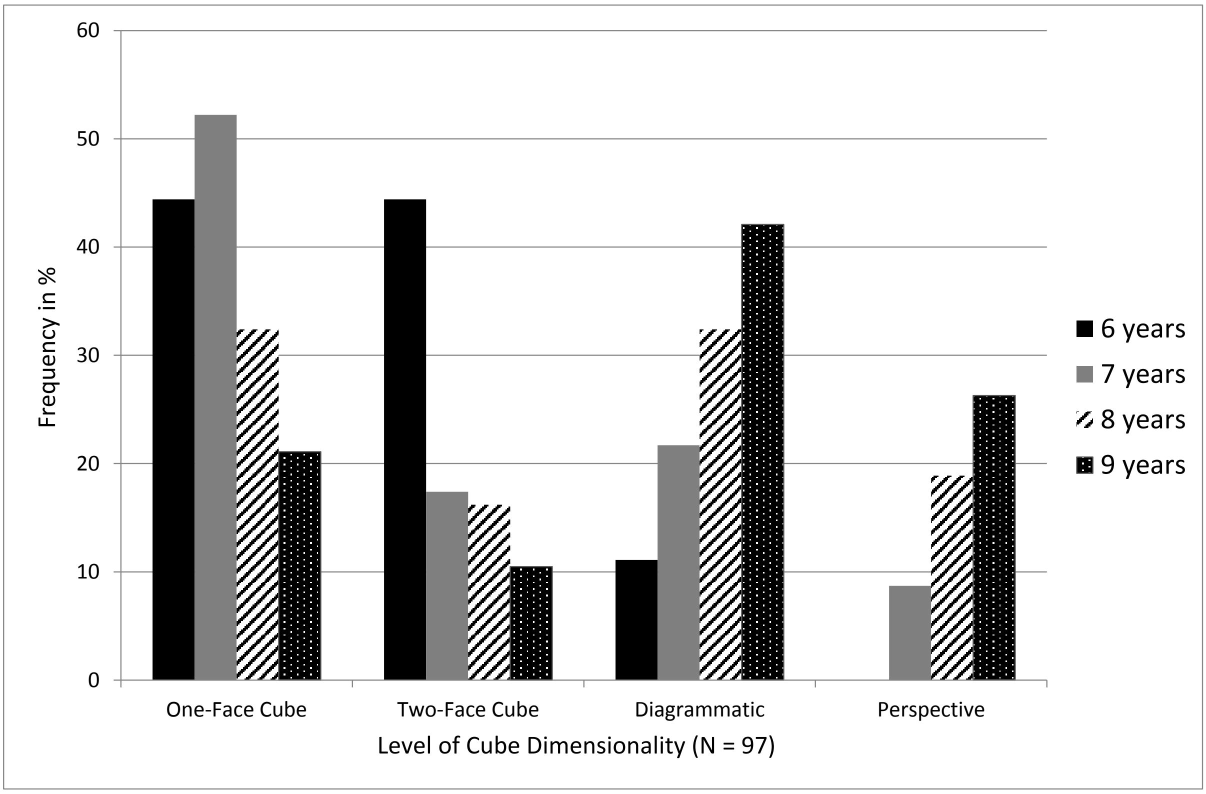


Figure 3A Frequency distribution of the levels of the cube drawing by age.

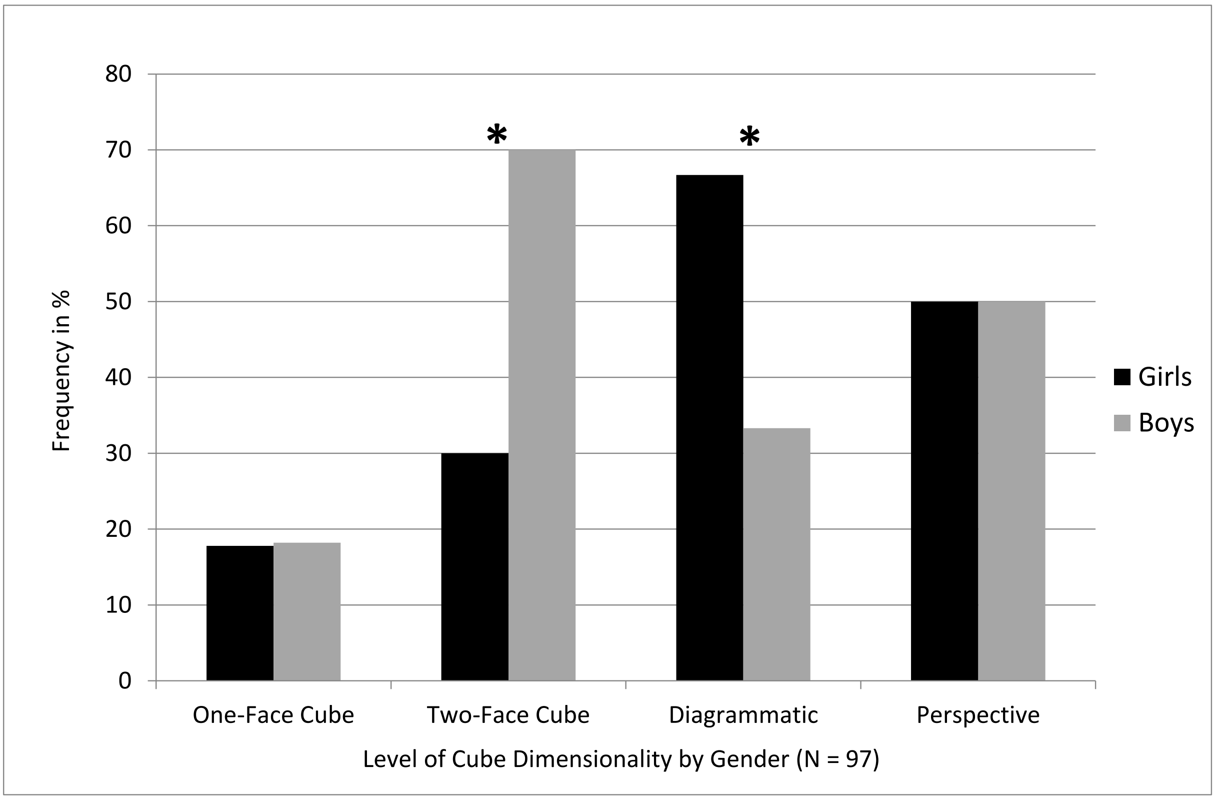


Figure 3B Frequency distribution of the levels of the cube drawing by gender.

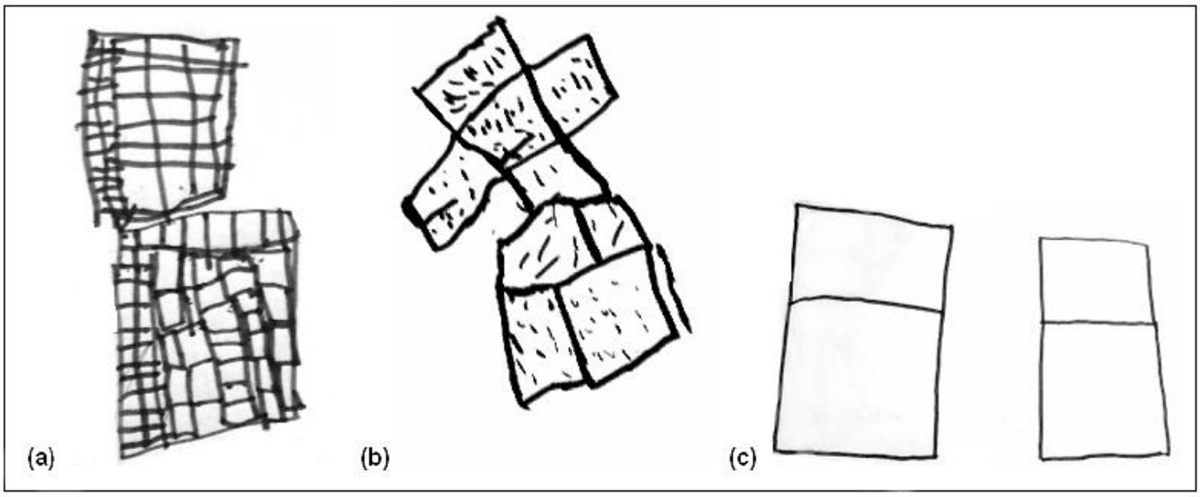


Figure 4 Examples of differentiated shapes for the occluding cubes. (a) girl drawing the surface structure of the two cubes with sides attached top and left, (b) girl drawing a diagrammatic cube with some indication of surface structure but more clearly reinforced edges, (c) boy's drawing is showing shape constancy when drawing the two cubes separately.

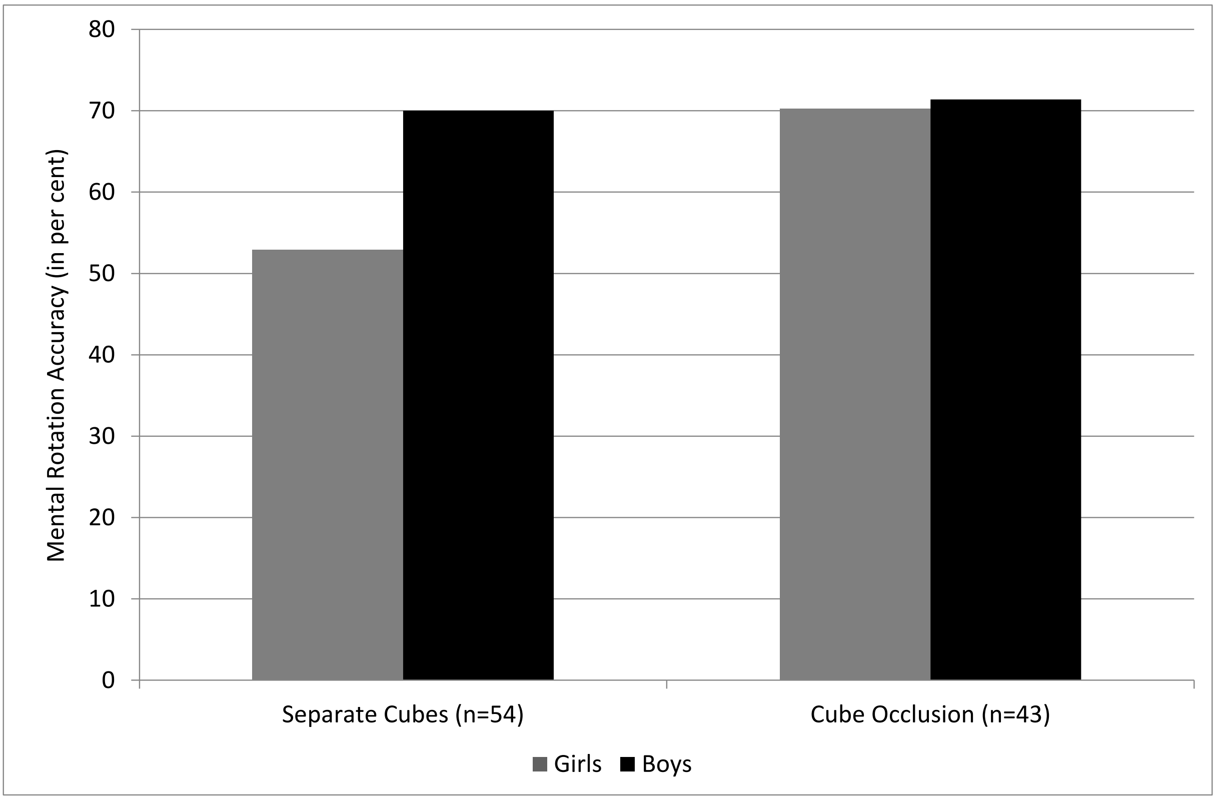


Figure 5A Drawing of Occlusion and Mental Rotation *Accuracy* by Gender

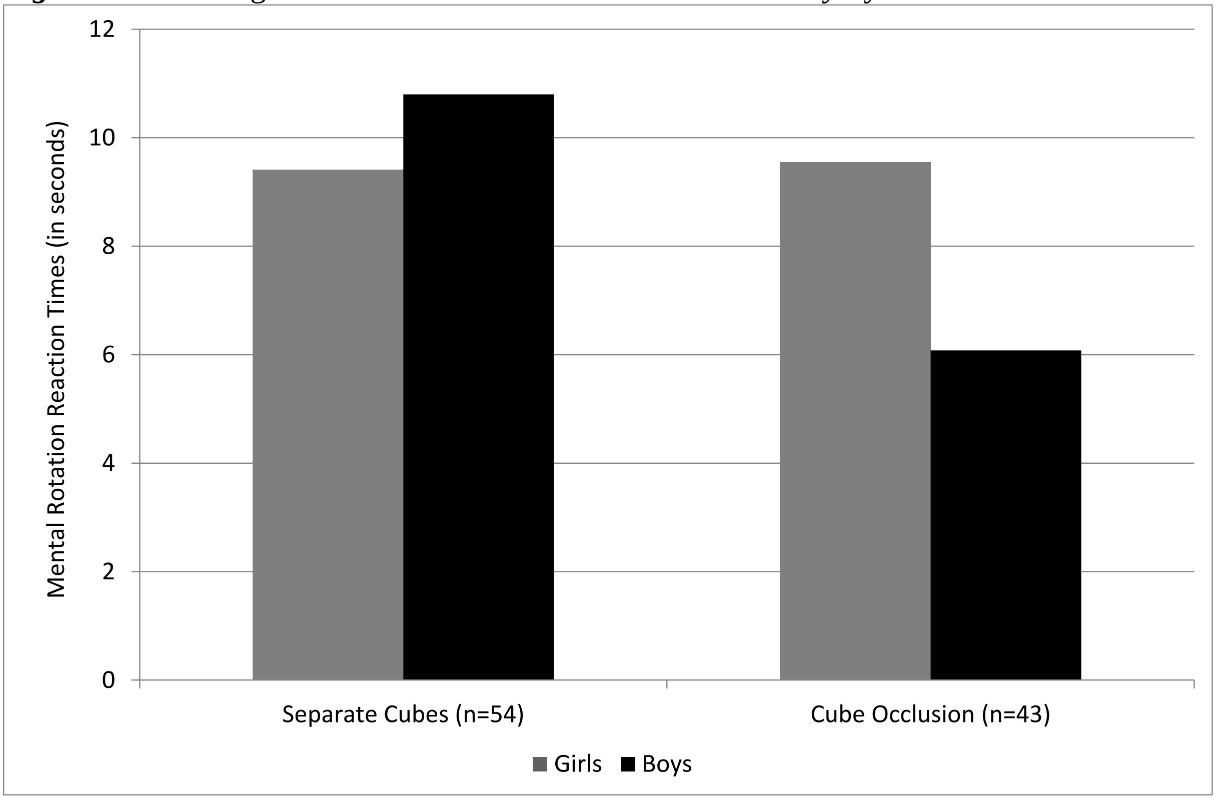


Figure 5B Drawing of Occlusion and Mental Rotation *Reaction Times* by Gender