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Do Drawing Stages Really Exist?
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Children's Early Mapping of Perspective

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Drawing in perspective seems to involve a prolonged development and is not usually present in children's drawings before about age 9—at least as found in previous research. In the study presented here, we built several three-dimensional spatial models to simulate the developmental stages of children's spatial drawing systems, a simple platform without spatial constraints (Stage 1), and a platform with walls and a sky lid (earth model; Stage 2). Stage 3 (orthogonal) and Stage 4 (perspective) models had explicit boundaries around the spatial field to denote areas and a matched control that controlled for the surround area outside of the boundaries. Four age groups from 7 to 10 years of age drew five non-overlapping figures. All age groups adapted the average figure size to the level of the spatial system (stage) of the models but only when explicit spatial field boundaries were available: The more advanced the spatial system, the smaller the average figure size. It was striking to note that 7- to 8-year-old children drew in perspective as often as 9- to 10-year-olds when the spatial models had a trapezoid field with converging diagonal sides. This early perspective mapping may have occurred because of the agreement between retinal image (appearance) and design (identity) of the perspective models. Hence, it would be more useful to think of the perspective drawing development as a layered rather than as a stagewise process because typically developing young children can access low-level visual information and draw in perspective instead of deploying high-level conceptual knowledge about the geometrical principles of perspective construction.

Keywords: perspective mapping, figure size, iconic objects, spatial areas, nonaccidental spatial boundaries

Researchers studying drawing development showed that the ability to draw spatial perspective is a lengthy process occurring during middle childhood. This development is supposed to involve a sequence of four distinct drawing stages (Luquet, 1927/2001; Piaget & Inhelder, 1956; Piaget, Inhelder, & Szeminska, 1960). Young children in the first stage do not draw spatial axes at all but only objects and figures. The emergence of spatial axes in the second stage begins with the construction of a horizontal spatial axis for the ground (and sky) or use of the lower edge of the drawing page to line up figures and objects. The third stage consists of the drawing of areas, often with orthogonal angles, which in the fourth stage are drawn with converging diagonals to represent perspective (Lange-Küttner, 1997, 2004).

However, the idea that development proceeds in stages may be a result of the type of measurement technique that was employed (Karmiloff-Smith, 1995; Liben, 1982; Uttal, Fisher, & Taylor, 2006). For instance, the development of drawing in perspective has been primarily assessed with drawings from long-term memory; that is, children were asked to draw a landscape picture without a model present (Kerschensteiner, 1905; Lange-Küttner, 1989, 1994, 1997). However, drawing from memory does not demonstrate their ability to draw in perspective from perceptual input; for instance, draftsmen often sit with their easel in front of a landscape so that they can look at it when composing perspective. Previous research with children showed that when a three-dimensional (3D) spatial model was used, the ability to notice which objects were invisible from a certain point of view became especially relevant for drawing in perspective (Ebersbach, Stiehler, & Asmus, 2011).

The current study goes one step further because we built wooden 3D models that simulated the drawing stages in the development of depicting perspective. We then evaluated whether young children would be able to pick up perspective cues from spatial models that were built with a trapezoid instead of a normal orthogonal (rectangular) floor plan. The front width of these spatial models was wider than the back width because of converging

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diagonal sides. In this way, the spatial models had perspective "built in" as a design and "embodied" perspective.

Why call the models with a trapezoid floor plan an embodiment of perspective? Apart from modern architecture buildings, which incorporate diagonals (e.g., the Denver Art Museum or the Graduate School of the London Metropolitan University designed by Daniel Libeskind), people rarely encounter diagonals in the environment. Rather, perspective is a result of retinal and brain processing where, for instance, the boundaries of a street, which in reality are running in parallel, are perceived as converging diagonals toward a vanishing point. In this way, drawing in perspective requires drawing a perceptual illusion, or, in other words, drawing in perspective is drawing the optical impression as perceived by the viewer (view-specific) rather than reproducing the way a street was designed and built (object-specific).

Preschool children only gradually understand the distinction between appearance and reality (Flavell, Flavell, & Green, 1983; Flavell, Green, Wahl, & Flavell, 1987). They appear to use this knowledge to produce visually realistic perspective in their drawings only from about age 9—at a time when their attention has become more attuned toward spatial boundaries (Lange-Küttner, 2006, 2009, 2013). Hence, when building models with converging diagonals as sides, we hoped to facilitate drawing in perspective for children because they could directly perceive perspective as an object-specific property. Hence, the current study investigated whether one could circumvent the necessity of a visual awareness of convergence in the perceptual input by making perspective an object-specific (design) property. We expected that this would induce children to produce view-specific, visually realistic perspective drawings at a younger age than the stage model would suggest. In the following paragraphs, studies on the stages involved in using diagonals in a drawing are reviewed. In particular, in addition to the drawing stages of perspective, the more modern approach of "drawing systems" is explained. The main difference between these two approaches is that the concept of a developmental stage stems from the research on child development whereas the concept of a drawing system originates from art psychology.

Drawing and Perceiving

Is the development of drawing in perspective so slow or not achievable for many children (Lange-Küttner, 1989, 1994, 1997) and adults (Deręgowski, 1971; Hagen, 1985) because converging diagonals are difficult to draw or because diagonals are difficult to perceive? Young children find it difficult to accurately perceive diagonal lines (Olson, 1970/1996): Only approximately one third of 4- to 5-year-olds, but 85% of 6- to 7-year-old children, visually discriminate diagonals. However, although the visual perception of diagonals is achieved at approximately 7 years, only thereafter do children begin to understand geometrical concepts such as oblique and obtuse angles and learn to compute angularity on the basis of the assumption that a circle has 360° (Piaget et al., 1960).

Children also begin to realize that they sometimes have to discard perceptual information to make proper judgments (Lange-Küttner, Averbeck, Hirsch, Wiebner, & Lamba, 2012). All of the classic conservation experiments of Jean Piaget challenged children to disregard form and appearance changes of objects so that they could come to the correct logical conclusion that the mass of objects stayed the same although the perceptual impression was transformed (conservation judgment; Piaget, 1971).

Hence, one would expect that the conservation judgment involves the consideration of the distinction between appearance and reality (AR; e.g., Flavell, 1986; Flavell et al., 1983; Thomas, Nye, & Robinson, 1994; Woolley & Wellman, 1990). Is the identity of an object really affected when changes in its appearance occur? Children can make correct AR judgments at approximately age 5. The few studies that investigated the impact of the level of perceptual judgment on conservation tasks used a training design with the hypothesis that AR training should improve the conservation judgment (e.g., Langer & Strauss, 1972; Russell & Mitchell, 1985; Slaughter, 1998). However, there was no general transfer from AR training to conservation tasks. Instead, training effects were highly specific, such that training on length illusions improved length conservation judgments but not performance in any other conservation task (Langer & Strauss, 1972). Children can be trained in perceptual tasks such as mental rotation, but they showed only item-specific learning (Kail, 1986; Kail & Park, 1990). Hence, the expectation in the study presented here was that the direct visual experience of embodied perspective in the 3D models would cue children to draw converging diagonals much earlier than would be expected from the drawing literature.

Spatial Drawing Systems

Dubery and Willats (1972) were the first to establish the notion of spatial drawing systems to explain that there is not usually a one-to-one mapping between, for instance, seeing a table and drawing a table on paper. Instead, several drawing systems for the graphic representation of space and spatial objects are gradually developing in children in a more or less sequential fashion (Lange-Küttner, 1989, 1994, 2008; Schwamborn, Mayer, Thillmann, Leopold, & Leutner, 2010; Vinter & Marot, 2007; Willats, 1995, 1997, 2005). When referring to ready-made predrawn spatial axes systems on a page designed to help young children to draw foreshortened figures, Lange-Küttner used the term "spatial systems" (Lange-Küttner, 2009).

Children usually do not begin drawing space with perspective. Instead, they initially represent just objects in empty space. However, these graphic objects are iconic and generally convey valuable disambiguating information that shows children's knowledge about object identity and function (intellectual realism) (Luquet, 1927/2001). For instance, a cup would always be drawn with a handle even if the handle was out of sight because this is what differentiates a cup from, for instance, a vase (Davis, 1983, 1985; Ford & Rees, 2008; Lange-Küttner, 2011). Children would even agree that a change in this kind of iconic object can have an effect on the real object (Jolley, 2008), which may have been a "leftover" from an earlier time when infants actually grasped objects in pictures (DeLoache, Pierroutsakos, Uttal, Rosengren, & Gottlieb, 1998). Attention to the full view that reveals object function is one reason children are not drawing one object behind another (Bremner & Batten, 1991; Bremner, Morse, Hughes, & Andreasen, 2000; Cox, 1978; Jee, Gentner, Forbus, Sageman, & Uttal, 2009; Lange-Küttner & Ebersbach, 2013; Light & MacIntosh, 1980; Morra, Angi, & Tomat, 1996).

However, with the beginning of regular schooling, children's location memories become more organized and increase rapidly

(Lange-Küttner, 2010a, 2010b), their view of the world changes (Vosniadou & Brewer, 1992), and a preoccupation with explicit spatial axes systems emerges. Children now line up figures and objects on a horizontal groundline, often accompanied by a horizontal skyline (Lewis, 1990). This one-dimensional spatial drawing system becomes more complex when children begin to combine the horizontal with a vertical axis, creating areas and a multidimensional spatial axes system (Piaget & Inhelder, 1956). Finally, in perspective, spatial axes converge into a viewpoint, and children reduce a figure's size when further in the background (Deręgowski & Parker, 1996) or when they encounter the constraints of explicit area boundaries (Lange-Küttner, 2004, 2009).

One could argue that drawing a diagonal is not that difficult for children because they already draw diagonal lines much earlier when, for instance, drawing the roof of a house. A typical picture of a house is usually a combination of a square or rectangle for the house and a triangle for the roof. Five-year-old children already do this, and one would not have to wait until they are about 10 years old for a diagonal to appear in a drawing. The diagonal is a property and feature of the roof as an iconic "thing" that they can map onto a page. However, that children do not understand the angularity of a diagonal construction becomes apparent if they have to add a chimney to the roof, which requires the coordination of a diagonal with a vertical line. Children who drew groundline constructions are already in control of orthogonal angles, but this ability usually leads to the mistake of attaching the chimney with a 90° angle to the roof instead of using an oblique angle (Liben, 1981; Perner, Kohlmann, & Wimmer, 1984). The same "orthogonal" error occurs in overall space (the term "overall space" refers to the entire space on the page) when young children draw trees on a hillslope with a 90° angle (Liben, 1981). Hence, it is generally agreed that diagonal constructions for perspective require an understanding of oblique angles that develops after the conceptualization of orthogonal 90° angles (Lange-Küttner, 2008; Piaget et al., 1960; Tzuriel & Caspi, 1992).

Direct Mapping of Perspective

There are no studies that have shown free perspective drawings before the age of 9 years, except in savant-talented autistic children (Arnheim, 1980; Pring, Hermelin, Buhler, & Walker, 1997; Selfe, 1977, 1983, 1985). Autistic individuals are also remarkably adept in depicting in three dimensions because they seem to be better able to ignore iconic object meaning than control participants (Sheppard, Ropar, & Mitchell, 2007, 2009; Sheppard, Mitchell, & Ropar, 2008; see also Tallandini & Morassi, 2008. The discussion in the literature focuses on the questions of whether individuals with autism have privileged access to lower level, less-processed visual information (Snyder, 2009) or whether they show enhanced visual perception (Mottron, Dawson, & Soulières, 2009) and sensory hypersensitivity (Baron-Cohen, Ashwin, Ashwin, Tavassoli, & Chakrabarti, 2009). Indeed, drawing in perspective may be a result of not categorizing and extracting relevant object features (Plaisted Grant, & Davis, 2009). Snyder (2009, p. 1400) assumes that "our brains possess all of the necessary information required to draw, but we are apparently unable to consciously access it for the purpose of drawing." He could prove that when he briefly inhibited the left anterior temporal lobe with transcranial magnetic stimulation (rTMS), participants could draw more visually realistic. Although temporal lobe atrophy (semantic dementia) causes a loss of awareness of object identity, function, and shape that appears when drawing from memory, the correct copying from a model was still preserved (Patterson & Erzinclioglu, 2009).

What is perspective? Perspective is an illusion created by the anatomy of our eyes (Gregory, 1966/1990). "*When an artist employs geometrical perspective, he does not draw what he sees—he represents his retinal image*" is how Gregory (1966/1990, p. 174, italics in the original) summarizes the process of perspective construction. Historically, viewpoint perspective in drawings was invented during the Renaissance in the 15th century in Northern Italy. There were several approaches to the depiction of perspective in pictorial space such as the introduction of a human scale by the Italian artist Alberti. He suggested to locate first one viewpoint on a page on the basis of the height of a human figure (Abels, 1985). Cross-sectioning axes from a second, sideways viewpoint then created perspective trapezoid areas on which figures could be placed. A shortcut to obtain the cross section with a technical apparatus was used by Da Vinci (Gregory, 1966/1990, p. 166) and by Dürer, who had visited the North Italian artist several times (Abels, 1985, p. 173). A transparent panel with a grid placed between the draftsman and the scene provided the cross section and allowed the direct mapping of perspective.

This direct mapping of perspective with the screen method also helps 5-year-old children to refer to the overall spatial framework when depicting overlapping objects and oblique constructions (Reith & Dominin, 1997; Reith, Steffen, & Gillièron, 1994) so that they could already draw similar to 9-year-old children. Hence, it seems not absolutely necessary that children acquire the geometrical and mathematical knowledge about vector space to be able to draw in three dimensions on a two-dimensional surface. Does this reduce their achievements? Children want to draw in perspective even if they are not yet able to do so (Kosslyn, Heldmeyer, & Locklear, 1977), but they only gradually conceptualize their visual impressions (Flavell, Green, Herrera, & Flavell, 1991). Hence, if children use similar technical devices and cues as the early artists and succeed, it would show that they may not have understood the mathematical equations for producing exacting architectural perspective drawings, but neither do many artists who paint landscapes in perspective.

Size Adaptation

By now it should be clear that in a perspective drawing only the spatial axes are needed to control the projective figure size. However, in children this is only the case if spatial fields are explicitly constructed on the page, and that is usually only the case in a few children and adolescents (Lange-Küttner, 1994, 1997). In drawings of younger children, figure size is not only controlled by a less constrained spatial system such as a groundline but (also) by the number of figures that share the pictorial space (Lange-Küttner, 1997, 2004). The fewer shapes are drawn on a page, the larger they can be (Freeman, 1980; Thomas, 1995). Hence, in younger children, figure size is a function of the number of figures rather than of the spatial system itself.

Is this the case because young children do not think about space or because they are more focused on objects? Young children see space differently than their mothers do (Smith, Yu, & Pereira, 2011). Smith et al. (2011) used head-mounted field cameras to reveal that although mothers surveyed the entire spatial array, their 2-year-old offsprings focused on one particular object at a time. Infants hold one object very close so that it becomes so large in size that it filled their entire view. This proximity made attention focusing and naming of this one object easier because it excluded all other distracting objects in the visual field (Yu, Smith, Shen, Pereira, & Smith, 2009).

Hence, what children would need to learn thereafter is to allow additional objects into the visual field in a controlled fashion until they are able to survey many small objects in the entire spatial field similar to adults. This is exactly what happens in the drawings of young children. In pictorial space, young children initially draw only a few objects, and their size stays relatively unregulated by spatial context (Lange-Küttner, 1997, 2004, 2009; Lewis, 1990). For instance, a dog can be drawn as tall as his owner or the owner of a house as tall as her building (Silk & Thomas, 1988). On the other hand, younger children are also able to make subtle size adaptations when a model is present (Nicholls, 1995).

When children enter school, a twofold process occurs (Lange-Küttner, 1997). First, young children draw increasingly more objects. The more objects, the smaller they have to be because the space on the drawing sheet becomes limited (object-driven size reduction). Second, the drawing systems become increasingly complex, and their spatial constraints also limit figure size (axes-driven size reduction). Only from age 9 do children become aware of the constraints of spatial boundaries (Lange-Küttner, 2004, 2009). At this age, they are also more likely to allocate figures and objects to regions and areas rather than to individual places (Lange-Küttner, 2006). Because regions are more integrated units, this less piecemeal approach greatly facilitates spatial memory (Lange-Küttner, 2010a, 2010b, 2013).

The powerful interaction of space with figure size was also revealed when a 3D life-sized room with a modified floor plan was used, the Ames room (Ittleson, 1952). In the original Ames room, three sides of the rectangular room were normal, but the back of the room toward which the viewer was looking was diagonal. This floor plan created a shorter looking distance on the right side (with an obtuse angle) and a longer looking distance on the left side (with an acute angle). The unusual floor plan of the Ames room was not known to the viewers who could only deploy monocular vision and look into the room via a peephole. Although the room seemed "normal" to viewers, adult persons inside of the room appeared extremely large on the right side and child-sized on the left side of the room. The unanimous conclusion was that we are used to seeing a room as rectangular and do not expect any perspective built into the floor plan of a room. Hence, the naïve participants actually saw the Ames room as a normal room with the usual orthogonal corners, but as a result experienced an extreme figure size illusion in which a person could appear as tall as the height of the room. A manipulation of the floor plan similar to that of the Ames room was also used in the current study because the perspective model was built with a trapezoid floor plan.

The Current Study

Three-dimensional spatial models were previously used to investigate the development of understanding and remembering of spatial relations in children (DeLoache, 1989; DeLoache, Miller, & Rosengren, 1997; DeLoache & Sharon, 2005; Ebersbach et al., 2011; Hund & Plumert, 2002; Piaget & Inhelder, 1956; Troseth, Pickard, & DeLoache, 2007) Young children as young as 1.5 years of age are sensitive to spatial cues when the dimensions of a room are small (Learmonth, Newcombe, Sheridan, & Jones, 2008). In the current study, a series of 3D spatial models simulated the developmental acquisition sequence of drawing systems. Would children also adjust their figure size to the level of the spatial system when it was not directly drawn on their drawing page (Hargreaves, Jones, & Martin, 1981; Lange-Küttner, 2004, 2009) but rather in front of them embodied in a spatial model? It was predicted that just the orthogonal and diagonal 3D models should lead to a striking figure size reduction. The spatial models were populated with five same-sized figures that were standing in a staggered fashion without any overlap. This was different from previous studies (Lange-Küttner, 1997, 2004, 2009) in which children drew figures from memory and not from model figures. However, the visibility of the figures should have a conservative effect on figure size modification (object size constancy).

Throughout the text, the term "spatial model" will be used when referring to (the effects of) the 3D models and the term "drawing system" for the spatial axes systems that children drew on the page. Although the spatial models were presented to children in random order, here they are described in the developmental acquisition sequence. Because children initially just draw objects distributed on a page, the first model was just a green platform. The second model also had a green floor plus a blue sky lid that was supported by walls, which was equivalent to the stripy groundline drawings with earth and sky. The third model was a platform with an orthogonal spatial field on the ground, similar to a sports playing field, and walls as before, but without the sky lid, simulating the more sophisticated areas that children begin to draw. Finally, the fourth model was the same as the third model, but with a trapezoid shaped field, equivalent to a playing field in perspective. The third and fourth models will be called "advanced" because they appear late in children's drawing development (Cox, 2005; Jolley, 2009).

Furthermore, it was controlled whether the area surrounding the spatial boundaries of the playing field would have an effect on figure size. Hence, in each of the two advanced spatial models (orthogonal and diagonal), children were presented with a control model that had the same-sized playing field but no explicit spatial boundaries and no surrounding area. For the perspective model only, this omission of the surrounding area had the added effect that the floor plan no longer had an orthogonal shape. Instead, similar to the Ames room, the floor plan itself had diagonals in the form of a trapezoid shape. This was new, and it was not exactly predictable how children would react toward this specific model, but it was expected that the built-in perspective would cue an advanced drawing system. An initially strong discrepancy between the spatial model and the children's spatial drawing system on the page is the hallmark of the theory that there is a qualitative, stagewise change in the development toward perspective drawing (Luquet, 1927/2001; Piaget & Inhelder, 1956). If the youngest age

Table 1
Age Groups (Years; Months)

Age in Years	*n*	Gender (Boys/Girls)	*M*[a]	Min[a]	Max[a]
7	13	7/6	7;9	7;5	7;11
8	17	9/8	8;4	8;1	8;10
9	12	5/7	9;8	9;1	9;11
10	17	9/8	10;3	10;0	10;7

Note. $N = 59$.
[a] Data presented as years; months.

group would be able to draw in perspective, then this result would challenge this long-standing theory.

Method

Participants

The sample consisted of 67 participants from age 7 to age 10. The children attended a primary school in Buckinghamshire, England. The drawing series of one 9-year-old child was excluded because of drawing fewer than the prescribed five figures in some of the pictures. Two further data sets of 9-year-olds and five data sets of 10-year-olds were excluded because they used the drawing booklets in a portrait rather than a landscape format. For the resulting sample of 59 children, age group means and age range, as well as the number of boys and girls, are noted in Table 1. T1

Apparatuses and Material

The following spatial models were used in one session for a within-subject measurement:

Surface space. Of course, it is not possible to exactly build "empty space" where children's figures drift across the model. Thus, the surface spatial model only resembled to some extent the early empty space of children's drawings where spatial relationships are still implicit (Bremner, 1985; Light & Humphreys, 1981; Light & MacIntosh, 1980). The surface platform had the same size in centimeters as an A4 drawing sheet (see measurements in Figure 1). There were no walls or delineated fields that would have acted as spatial constraints. F1

In this empty space, only the amount of figures on the page could constrain figure size. Five figures were previously shown to be the optimal number of figures to make space scarce enough so that it would have an effect on figure size (Lange-Küttner, 1997, 2004, 2009).

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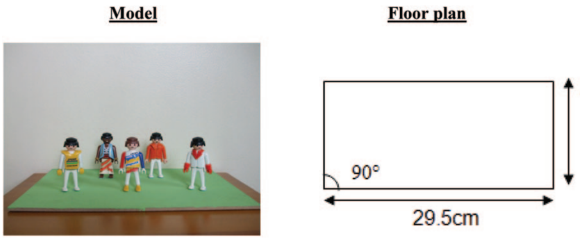

Figure 1. Surface space. The spatial model resembled the empty space of young children's drawings. The measurements of the platform were the same as those of an A4 sheet. No walls or delineated fields would constrain the drawing of figure size.

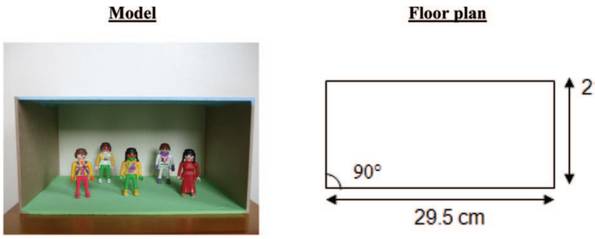

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Figure 2. Earth space. This space model emulates the stripy drawings of children who draw groundline and skyline pictures. Children denote with these stripes two properties of our earth (i.e., they can walk on the ground due to gravity and there is a heaven above us). Again, the floor plan measurements match that of an A4 drawing sheet. The walls on either side were 15 cm high and the sky lid had the same measurements as the ground.

Earth space. The earth spatial model resembled the horizontal axes system that children create when they become aware of the physical properties of the earth; that is, they draw the ground that we are walking on and the heaven above us (the blue strip of sky that is usually depicted with a sun) (Hargreaves et al., 1981; Lange-Küttner, 2008). This model with a sky lid (see Figure 2) constrains figure size more than the surface space system, but if figures are drawn based on the lower edge of the sheet of paper, then they can still loom large when depicted with their heads in the clouds. Hence, although this horizontal axes system constrains figure size, it may not do this as much as the next two systems because a figure line-up on the ground enables even more size expansion toward the upper edge of the paper. F2

Walls were another constraint of the earth model (see also Lee & Spelke, 2008; Nardini, Atkinson, & Burgess, 2008) because they were needed to support the sky lid. These walls were also kept as spatial constraints in the following spatial models.

Orthogonal space. Like in the paper drawing sheets (Lange-Küttner, 2004, 2009), an orthogonal playing field was inserted into the 3D spatial model (see Figure 3A). The orthogonal space model represented a transition to projective space because, for the first time, spatial boundaries of an area constrained figure size. The lid that represented the horizontal skyline denoting heaven in the earth model was omitted because projective systems are composed of areas rather than single lines. F3

In a second orthogonal control model (see Figure 3B), the five figures stand within an absolutely identical, same-sized playing field, but this time it constituted the entire ground surface. The difference was that there were no explicit spatial boundaries around the playing field and no surrounding strip of land. Instead, just the walls were the delimiters of the playing field.

It was predicted that the spatial model with the explicit meaningful playing field boundaries would constrain figure size more than the model without boundaries despite having exactly the same area in square centimeters.

Perspective space. The perspective spatial model and its control model were built in the same way as the two orthogonal models. However, the layout of the playing field and the floor plan of the perspective model without the surround violated what is known about playing fields (i.e., that they are usually rectangular).

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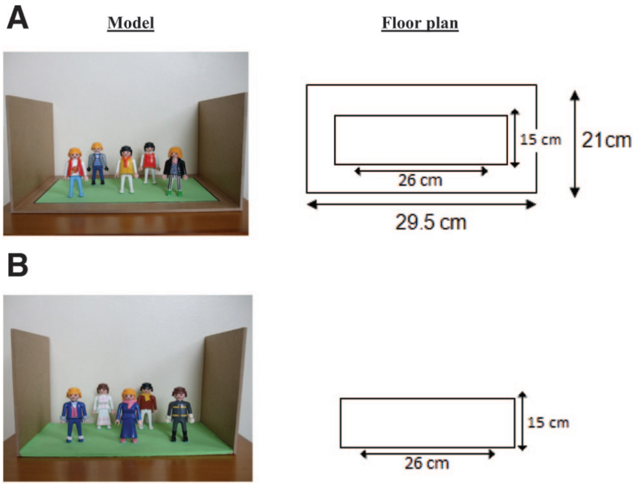

Figure 3. Orthogonal space. This model represents an extended version of the earth model, but it is already a transition to projective space. The extension into infinity of overall space is now reinstated by omitting the blue heaven, which constrained figure size upward. Instead, the sky is open to space as it is in reality. However, new constraints were introduced by inserting an orthogonal playing field with explicit boundaries. Model 6A has again the same measurement as an A4 drawing sheet. Model 6B is a control display in which the playing field was of the very same size as in Figure 6A, but without a surrounding area. (A) Ground with walls and playing field with explicit borders. (B) Ground with walls as borders of the playing field.

F4

A trapezoid floor plan with oblique angles was used (see Figure 4, A and B) that was similar to the Ames room which violated assumptions about orthogonally constructed rooms (Gerace & Caldwell, 1971). One could say that in these two diagonal models, perspective was directly perceptible (Gibson, 1979) because perspective was a property of the model itself.

A4 booklets that contained six blank pages of plain white A4 paper were used with two sheets of colored paper for the front and back covers. The booklet was given in landscape format and stapled twice on the short left-hand side. The spatial models (visual appearance and floor plan measurements, see Figures 1–4) were populated with five figures each randomly drawn from a pool of 30 playmobil figures with varying sex, ethnicity, and dress. Hats and other head items were removed from all figures to achieve consistency. They were always placed on the same five locations in each spatial model with the figures facing the viewer. There were three figures in the front and two in the back row placed in a staggered fashion so that each figure was clearly visible, without overlap. All children drew with a pencil.

Procedure

Children were given each spatial model in a randomized sequence. Six tables, each with one spatial model and figures setup, were placed in the corners and along the wall of a room in a way that children could not see each other. This arrangement made it possible that six children were each drawing one model at the same time and then rotated places at random, taking their drawing booklets with them. The experimenter marked the spatial model and sequence on each drawing. This was repeated until all six drawings were completed.

Children were informed that they would have 10 min for each drawing. They were told when 5 min had passed so that they knew half of the allocated time had gone. They were instructed to look carefully at the scene in front of them, and they were informed that the green area always represented a playing field and that the blue lid on one of the boxes represented the sky.

Scoring. To calculate figure size, a line was drawn underneath the two feet of each figure and another line over the head. A vertical line was then drawn that connected the two horizontal axes running through the split of the two legs. To calculate figure height, the length of the vertical axes was measured in centimeters and millimeters using a ruler. Hats and hair style added by the children were included in the measurement.

The figure sizes of the entire sample (6 spatial models with 5 figures each = 30 figures per participant × 59 = 1,770 figures) were measured by two raters. For the average size scores, interrater reliability values were as follows: surface model $r = .997$; earth model, $r = .999$; orthogonal model, $r = 1.0$; perspective model, $r = .999$; model with the orthogonal playing field with boundaries, $r = .997$; and the perspective playing field with boundaries, $r = .990$, respectively, all $ps < .001$ (Pearson correlations, two-tailed). The size in centimeters of the five figures per model that each child drew were averaged with SPSS, with the mean as the average figure size and the standard deviation as the average difference between the five figures.

Furthermore, the drawing systems were classified as no spatial system (1), groundline (2), orthogonal (3), and diagonal (4) (see Figure 5). However, because the current 3D models had walls, the

F5

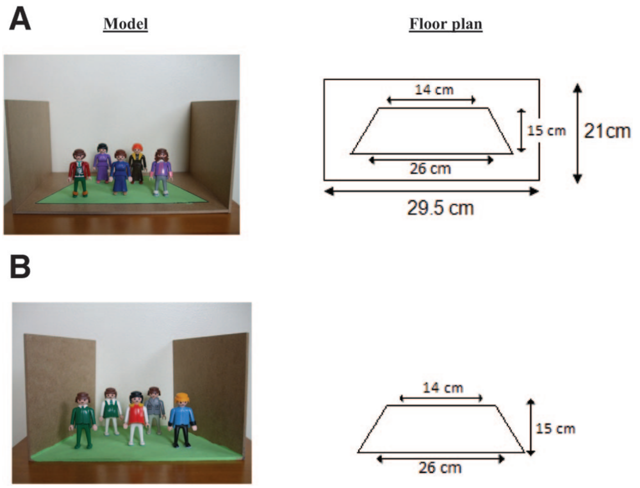

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Figure 4. Perspective system. This spatial model is the same as the orthogonal model except that the angles of the playing field are 70° and 110° rather than 90°. In this way, the diagonals of the perspective models were strongly converging and directly perceptible (Gibson, 1979) because they were properties of the array. In Model 7A, the model had the measurements of an A4 sheet with a trapezoid playing field inserted. In Model 7B, this very playing field had the identical extensions, covered the entire surface, and had no surrounding area. (A) Ground with walls and diagonally converging playing field with explicit borders. (B) Ground with diagonally converging walls as borders of the playing field.

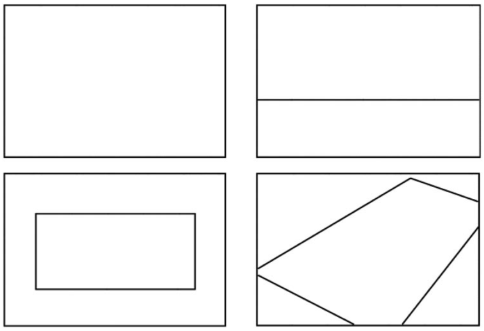

Figure 5. Drawing systems. Pictograms used to score the drawing systems on the page (from Lange-Küttner, 2004, with permission from AQ: 8 Elsevier publishers). Upper left, empty space; upper right, groundline; lower left, orthogonal field; lower right, perspective.

scoring rules were extended to satisfy the following cases. When children were drawing a groundline, but with the left and right walls as lines making a U-shape, this was still scored as 2 = groundline and not as 3 = orthogonal unless the ground was an area in which figures were located with their feet. If figures were standing on the upper edge of an area, then this was also scored as groundline. When the walls were the boundaries of the playing field and drawn with diagonals, whereas the floor plan was drawn orthogonally, this was evaluated as a 4 = perspective drawing. Two raters scored all drawings (59 × 6 = 354 drawing systems); inter-rater reliability was $r = .917$, $p < .001$. The remaining disagreements were discussed, and the agreed scores were used for the analyses.

Results

First, the development of the drawing systems is reported. It was expected that age differences should appear for the more advanced spatial models, in particular for the perspective models, which only the older children should be able to draw in a visually correct T2 manner. Frequencies are listed in Table 2 and were tested with χ^2 per model and with a dummy variable in the analysis of variance across models. Second, the adaptation of the figure size was tested with analyses of variance. The hypothesis was that average figure size should be increasingly reduced in the more constrained spatial models. Third, the average difference between figures was tested with analysis of variance. The hypothesis was that differences in figure sizes should be increasingly reduced the more advanced the spatial model. In short, figure size would not only get smaller but (also) become more uniform.

1. The Development of the Drawing Systems

The drawing systems that children constructed on the page are listed in Table 2. Frequencies were analyzed using χ^2 analysis per 3D model. The 7- and 8-year-old children ($n = 30$) and the 9- and 10-year-old children ($n = 29$) were merged into one group each, respectively, to increase cell frequency. Means for the two age T3 groups are listed in Table 3. The frequencies in the two columns for age groups were compared with Bonferroni-corrected z tests. Percentages refer to the n of each age group.

Surface model. The development of drawing systems with age was significant, with 7- to 8-year-old children (43.3%) drawing groundline systems more often than 9- to 10-year-old children (13.8%), $\chi^2(3, 59) = 9.97$, $p = .019$, $\phi = .41$. Of all 59 drawings, 8.5% were in perspective.

Earth model. The development of drawing systems with age was significant, with 80% of the 7- to 8-year-old children drawing orthogonal areas but only 44.8% of the 9- to 10-year-old children, $\chi^2(3, 59) = 7.86$, $p = .049$, $\phi = .37$. Of all 59 drawings, 13.6% were in perspective.

Orthogonal playing field model with explicit spatial boundaries. The development of drawing systems with age was highly significant, $\chi^2(3, 59) = 11.55$, $p = .009$, $\phi = .44$. Again, a large proportion of the 7- to 8-year-old children (53.3%) drew orthogonal areas significantly more often than 9- to 10-year-old children (27.6%). Instead, 9- to 10-year-old children were more likely to ignore the spatial context (31%) in comparison to 7- to 8-year-old children (6.7%). Of all 59 drawings, 15.3% were in perspective.

Orthogonal playing field model (no playing field surround). The development of drawing systems with age did not reach significance, $\chi^2(3, 59) = 7.17$, $p = .067$, $\phi = .35$. Differences went into the same direction as in the other orthogonal model, but

Table 2
Frequencies (in %) of Children's Drawing Systems per 3D Model

3D Model	7 Years	8 Years	9 Years	10 Years
Surface				
Empty space	7.7	17.6	33.3	29.4
Groundline	46.3	41.2	8.3	17.6
Orthogonal field	38.5	23.5	58.3	47.1
Perspective	7.7	17.6	0.0	5.9
Earth				
Empty space	0.0	17.6	33.3	23.5
Groundline	7.7	0.0	0.0	11.8
Orthogonal field	92.3	70.6	41.7	47.1
Perspective	0.0	11.8	25.0	17.6
Orthogonal with boundaries				
Empty space	0.0	11.8	33.3	29.4
Groundline	53.8	17.6	16.7	17.6
Orthogonal field	46.2	58.8	25.0	29.4
Perspective	0.0	11.8	25.0	23.5
Orthogonal				
Empty space	15.4	23.5	33.3	41.2
Groundline	53.8	23.5	8.3	23.5
Orthogonal field	30.8	47.1	25.0	29.4
Perspective	0.0	5.9	33.3	5.9
Perspective with boundaries				
Empty space	7.7	17.6	33.3	35.3
Groundline	23.1	29.4	8.3	11.8
Orthogonal field	7.7	17.6	16.7	23.5
Perspective	61.5	35.3	41.7	29.4
Perspective				
Empty space	7.7	5.9	25.0	35.3
Groundline	30.8	17.6	8.3	11.8
Orthogonal field	7.7	5.9	8.3	11.8
Perspective	53.8	70.6	58.3	41.2

Note. Percentages add up to 100% per age group per model. Small deviations above or below 100% are caused by SPSS rounding of decimals.

Table 3

χ^2 Tests of Frequencies (in %) of Children's Drawing Systems per 3D Model

3D Model	7–8 years	9–10 years	n	χ^2
Surface				
Empty space	13.3	31.0	13	9.97*
Groundline	43.3	13.8	17	
Orthogonal field	30.0	51.7	24	
Perspective	13.3	3.4	5	
Earth				
Empty space	10.0	27.6	11	7.86*
Groundline	3.3	6.9	3	
Orthogonal field	80.0	44.8	37	
Perspective	6.7	20.7	8	
Orthogonal with boundaries				
Empty space	6.7	31.0	11	11.55**
Groundline	33.3	17.2	15	
Orthogonal field	53.3	27.6	24	
Perspective	6.7	24.1	9	
Orthogonal				
Empty space	20.0	37.9	17	7.17
Groundline	36.7	17.2	16	
Orthogonal field	40.0	27.6	20	
Perspective	3.3	17.2	6	
Perspective with boundaries				
Empty space	13.3	34.5	14	5.90
Groundline	26.7	10.3	11	
Orthogonal field	13.3	20.7	10	
Perspective	46.7	34.5	24	
Perspective				
Empty space	6.7	31.0	11	6.70 $(^*)$
Groundline	23.3	10.3	10	
Orthogonal field	6.7	10.3	5	
Perspective	63.3	48.3	33	

Note. Percentages add up to 100% per age group per model. Small deviations above or below 100% are caused by SPSS rounding of decimals. $(^*)\ p < .10$. $^*\ p < .05$. $^{**}\ p < .01$.

age differences were not as pronounced. Of all 59 drawings, 10.2% were in perspective.

Diagonal playing field model with explicit spatial boundaries. Children's drawing systems on the page did not follow an age trend, $\chi^2(3, 59) = 5.90$, $p = .117$, $\phi = .32$. There were a high number of perspective drawings in total (40.7% of all 59 drawings). It was impressive that nearly half of the 7- to 8-year-old children (46.7%) engaged in drawing in perspective
AQ: 3 (see examples in Figure 8, left column) and approximately one third of the 9- to 10-year-old children (34.5%).

Diagonal playing field model (no playing field surround). Again, the age trend did not reach significance, $\chi^2(3, 59) = 7.00$, $p = .072$, $\phi = .34$. There was an even higher number of perspective drawings in total (55.9% of all 59 drawings). With the Ames-like trapezoid floor plan, nearly two thirds of the 7- to 8-year-old children drew in perspective (63.3%; see drawing examples in Figure 10, right column) and approximately half of the 9- to 10-year-old children (48.3%).

Drawing in perspective was then compared across the 3D models with analysis of variance, testing the percentages of children drawing in perspective against those who did not. When the Mauchley test of sphericity was significant, the degrees of freedom were adjusted according to Huynh-Feldt. Distribution of the group
F6 means for perspective drawing systems are plotted in Figure 6. A 2 (age groups) by 4 (spatial models) multivariate analysis of variance (MANOVA; Models 1, 2, 3B, and 4B) with drawn spatial boundaries and surrounds around the playing fields showed a significant main effect of the spatial model, $F(2.56, 59) = 11.71$, $p < .001$, $\eta^2 = .17$. With each advance in complexity, the models were yielding increasingly more perspective drawing systems (surface $M = 8\%$, earth $M = 13.7\%$, orthogonal $M = 15.4\%$, diagonal field $M = 40.6\%$). This effect interacted with age, $F(2.56, 59) = 3.44$, $p = .024$, $\eta^2 = .06$, because this was true only for the 9- to 10-year-old children. In contrast, the 7- to 8-year-old children mostly drew in perspective in response to the model with trapezoid field boundaries (see Figure 6).

The same MANOVA for the spatial Models 1, 2, 3A, and 4A, without explicit spatial boundaries around the playing fields, showed a significant main effect of the spatial model, $F(2.45, 59) = 29.77$, $p < .001$, $\eta^2 = .34$, with each model yielding increasingly more perspective drawing systems (surface $M = 8\%$, earth $M = 13.7\%$, orthogonal $M = 10.3\%$, diagonal $M = 55.8\%$), and this effect again interacted with age, $F(2.45, 59) = 3.45$, $p = .026$, $\eta^2 = .06$. That perspective drawings increased the more advanced the spatial model was again only true only for the 9- to 10-year-old children. In contrast, the 7- to 8-year-old children mostly drew in perspective in response to the model with a trapezoid floor plan (see Figure 6, on the right side).

2. Average Size Adaptation

To analyze figure size adaptation, two 4 (age groups) by 4 (spatial models) MANOVAs were run with age as the between-subject factor and repeated measures of average figure size in centimeters in the four spatial models. Group means for figure size per spatial model and age group are listed in the upper half of Table 4. T4

The MANOVA (Models 1, 2, 3B and 4B) with average figure size scores of the four surface-earth-orthogonal-perspective models as dependent variables, without spatial boundaries in the two advanced spatial models, yielded no significant results, $ps > .08$. Nevertheless, the MANOVA (Models 1, 2, 3A, and 4A) with the third and fourth dependent variables being the average figure size scores in the spatial models with explicit boundaries around the playing field yielded a significant main effect of spatial model, $F(2.91, 59) = 3.66$, $p = .015$, $\eta^2 = .06$. Children drew smaller figures in the advanced spatial models (surface $M = 5.47$ cm, earth $M = 5.69$ cm, orthogonal $M = 5.17$ cm, diagonal $M = 5.21$ cm).

This main effect was further specified by the two-way interaction of the spatial models with age, $F(8.72, 59) = 2.35$, $p = .017$,
$\eta^2 = .11$ (see Figure 7). To further explore this two-way interac- F7
tion, the analysis of variance was run again with a split sample of 7- to 8-year-old and 9- to 10-year-old children. The 7- to 8-year-old children, $F(2.52, 30) = 3.12$, $p < .05$, $\eta^2 = .10$, and the 9- to 10-year-old children, $F(3, 29) = 2.72$, $p < .05$, $\eta^2 = .09$, significantly reduced figure size with increasing complexity of the spatial models.

Hence, the curvefits of the size reduction were analyzed per age group. These size reduction curvefits (polynomial) showed high effect sizes. In the 7-year-olds, size reduction was linear, $F(1, 13) = 7.31$, $p = .019$, $\eta^2 = .38$; the more advanced the spatial model, the smaller was the average figure size. In the 8-year-olds, size reduction followed a quadratic trend, $F(1, 16) = 6.29$, $p =$

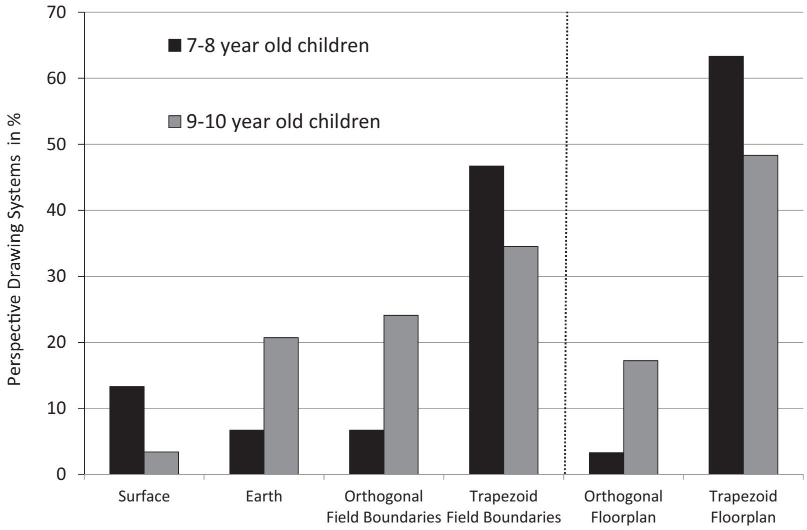

Figure 6. Percentage of perspective drawing systems when using six different 3D spatial models.

.023, $\eta^2 = .28$, as they drew larger figures in the earth model. Nine-year-olds showed again a linear size reduction, $F(1, 12) = 5.04$, $p = .046$, $\eta^2 = .31$. However, although 10-year-old children reduced size in a very similar way to the 9-year-olds, they did increase figure size in the perspective model again and this yielded a quadratic trend, $F(1, 17) = 6.83$, $p = .019$, $\eta^2 = .30$. This may have occurred because they were drawing foreground figures bigger. Differences between figure sizes within one drawing are analyzed in the next section.

3. Average Size Differences

The same set of analyses was run for average figure size differences between the figures drawn on each page. Group means for figure size per spatial model and age group are listed in the lower half of Table 4.

The MANOVA (Models 1, 2, 3B, and 4B) with scores of the average figure size difference for the four surface-earth-orthogonal-perspective models without spatial context around the playing fields yielded a significant main effect of spatial model, $F(3, 59) = 3.68$, $p = .013$, $\eta^2 = .06$. Children drew the most uniformly sized figures in the perspective system (surface $M = 0.81$ cm, earth $M = 0.89$ cm, orthogonal $M = 0.87$ cm, diagonal $M = 0.64$ cm). This was independent of age, as indicated by the main effect and the interaction with age, *p*s $> .45$.

The MANOVA (Models 1, 2, 3A, and 4A) with scores of the average figure size difference for the four surface-earth-orthogonal-perspective models with explicit boundaries also yielded a significant main effect of spatial model, $F(3, 59) = 2.79$, $p = .043$, $\eta^2 = .05$. However, when boundaries were present, children drew the most uniformly sized figures in response to the orthogonal model

Table 4
Means for Average Figure Size (cm) and Average Figure Size Difference per Spatial System (cm) per Age Group

Spatial model	7 Years	8 Years	9 Years	10 Years
(1) Average figure size				
Surface	4.84 (2.26)	4.50 (1.97)	6.13 (1.66)	6.40 (1.96)
Earth	4.92 (1.73)	5.58 (2.48)	6.21 (1.75)	6.02 (1.64)
Orthogonal with boundaries	4.41 (2.08)	4.98 (1.98)	5.67 (1.78)	5.62 (1.53)
Orthogonal	4.58 (2.37)	5.17 (2.27)	5.79 (1.90)	6.38 (1.74)
Perspective with boundaries	3.89 (1.27)	5.04 (2.17)	5.63 (1.52)	6.29 (1.73)
Perspective	4.40 (2.63)	4.47 (1.99)	5.43 (1.68)	6.31 (2.40)
(2) Average figure size difference				
Surface	1.04 (0.99)	0.66 (0.49)	0.89 (0.61)	0.72 (0.39)
Earth	0.95 (0.56)	0.78 (0.52)	0.99 (0.64)	0.89 (0.81)
Orthogonal with boundaries	0.81 (0.57)	0.62 (0.41)	0.62 (0.44)	0.72 (0.48)
Orthogonal	0.95 (0.82)	0.68 (0.54)	0.77 (0.30)	1.07 (0.90)
Perspective with boundaries	0.81 (0.64)	0.70 (0.50)	0.75 (0.39)	0.91 (0.62)
Perspective	0.65 (0.47)	0.64 (0.33)	0.70 (0.39)	0.59 (0.24)

Note. Average figure size is the mean across the five figure scores per picture. Average figure size difference is the mean difference between the five figure scores on one page.

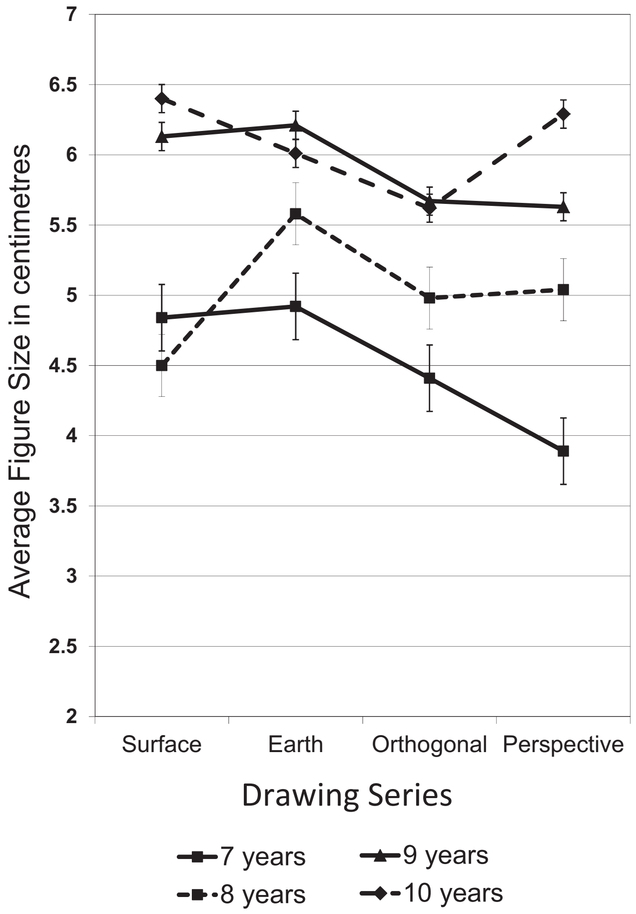

Figure 7. Average figure size in each of four different spatial models. The orthogonal and the perspective models had playing fields with explicit boundaries.

(surface $M = 0.81$ cm, earth $M = 0.89$ cm, orthogonal $M = 0.69$ cm, diagonal $M = 0.79$ cm). Again this occurred independently of age, $ps > .67$.

Discussion

For the current study, 3D spatial models were built according to the developmental sequence of drawing systems leading to perspective, from no axis to horizontal, orthogonal, and diagonal axes systems (Lange-Küttner, 1997, 2004, 2009; Willats, 1985, 1995). It was investigated whether the 3D spatial models had an effect on the drawing systems that children constructed and whether children would reduce the average figure size according to the spatial constraints of the 3D spatial models like they do when drawing figures into ready-made spatial systems on a drawing page (Lange-Küttner, 2004, 2009). The hypothesis that children would reduce figure size when looking at the most advanced spatial models was confirmed; however, this was only the case when explicit boundaries were present around the playing fields.

Furthermore, approximately one half of the 7- to 8-year-old children drew diagonal perspective when seated in front of the perspective model with the trapezoid playing field, and nearly two thirds of the 7- to 8-year-old children drew perspective when seated in front of the perspective model with the trapezoid floor plan. This result challenges our notion of the sequential development of drawing systems and ultimately the theory of the stagewise development of drawing perspective.

In a previous drawing study using a 3D spatial model with a rural scene, most children (90.9%) ignored the spatial context (Ebersbach et al., 2011) and were only drawing the building and animals. However, in the study presented here, most children drew an explicit drawing system. The somewhat more frequent omission of spatial context in the older children may reflect a true developmental trend of increasing selective attention toward figures rather than spatial context because adults also show a strong focus on figures when they observe scenes (Boloix, 2007; Evans, Rotello, Li, & Rayner, 2009). This object focus may in fact explain why so many adults do not know how to construct perspective in a drawing (Hagen, 1985; Jee et al., 2009).

Perspective as a Property

Children can shortcut the translation of 3D reality onto two-dimensional drawing paper by copying from model drawings (drawing from a drawing; 2D-2D mapping), which provide them with a direct line-to-line matching for their own drawing (Bremner et al., 2000; Chen & Cook, 1984; Wilson & Wilson, 1977). However, that between one half and two thirds of the 7- to 8-year-old children already drew in perspective from 3D models was a truly astonishing finding because it required 3D-2D translation.

Figures 1–4 show the actual photographic views, which correspond closely to what the children actually saw, and the floor plans, which show the design details. In Figures 1–3, the angularity of the photographic views and the floor plans are clearly at variance with one another, with the view in perspective but the floor plan orthogonal. However, in Figure 4, the photographic views and the floor plans were in agreement because they were both in perspective. With or without surround, the perspective models yielded comparably more perspective drawings than the other models in 7- to 8-year-old as in 9- to 10-year-old children. This result showed that even at 7 years of age, children can construct perspective systems when supported by a model that had perspective as a property and thus conformed to their visual perception.

The perspective model with the trapezoid floor plan was constructed in a similar fashion as the Ames room (Gerace & Caldwell, 1971). In the Ames room, participants were not allowed an insight into the unexpected construction principle of the space. They watched figures through a peephole, and as a result they perceived pronounced figure size distortions instead of a room distortion, demonstrating the contingent relationship between figure size and space system. In contrast, in this study participants had open visual access toward the perspective models so that the perceptual input could have a direct effect, and an early perspective mapping occurred.

This is a new and surprising finding given that in all other previous research to date, 7-year-old children are supposed to be lacking the ability to draw in perspective. What was the difference from previous research? In most previous studies, children drew scenes in perspective from memory, unless this was given as a ready-made drawing system on the page (Lange-Küttner, 2004, 2009). Hence, one could conclude that the only ability that young children are lacking for their construction of perspective is the long-term memory for correct perspective constructions. In a study by Liben (1981), first-, second- and third-graders who constructed the typical orthogonal errors (attaching trees at 90° at a hillslope) correctly drew the trees with oblique angles 5 months later. Why would they have done this? In the first phase of the experiment, they saw the correct way to depict the trees with an oblique angle. Hence, Liben suspected that the children seeing the correct way to draw transformed this experience into a lasting long-term memory representation. Likewise, in other studies, seeing a metrical grid helped children later on in a second session to remember places in an unstructured array, which amounts to visual array priming (Hund & Plumert, 2005; Lange-Küttner, 2010b; see also Vinter & Marot, 2007).

The current study showed that well-designed spatial models with trapezoid-shaped areas can enable children to draw in perspective years earlier than they would be able to explain the underlying mathematical, physical, and geometrical laws. In theory, a good framework for this result would be the representational AQ: 4 redescription (RR) model of Karmiloff-Smith (1995): Early perspective mapping would be available to children as input (I-level) for more elaborate conceptual re-representations later in development (R-levels). Please note that these re-representations would not only need to refer to geometrical angularity and the understanding of physical infinity but (also) to the correction of the mapped perspective itself because many of the early mappings were still approximations to a perfect and systematic depiction in perspective (see Figure 8). F8

Development of Size Modification and Spatial Boundaries

This leads to the second result. Children were drawing smaller figures the more advanced the spatial model was in front of them. Similar to the studies using predrawn systems (Lange-Küttner, 2004, 2009), size reduction was significant, but only when there were explicit spatial boundaries around the playing fields. We know that 8- to 10-year-old children are increasingly able to depict national boundaries of neighboring states in a correct manner (Axia, Bremner, Deluca, & Andreasen, 1998), but these are mostly arbitrary spatial boundaries. It is suggested here that an orthogonal field with explicit spatial boundaries is the iconic template for

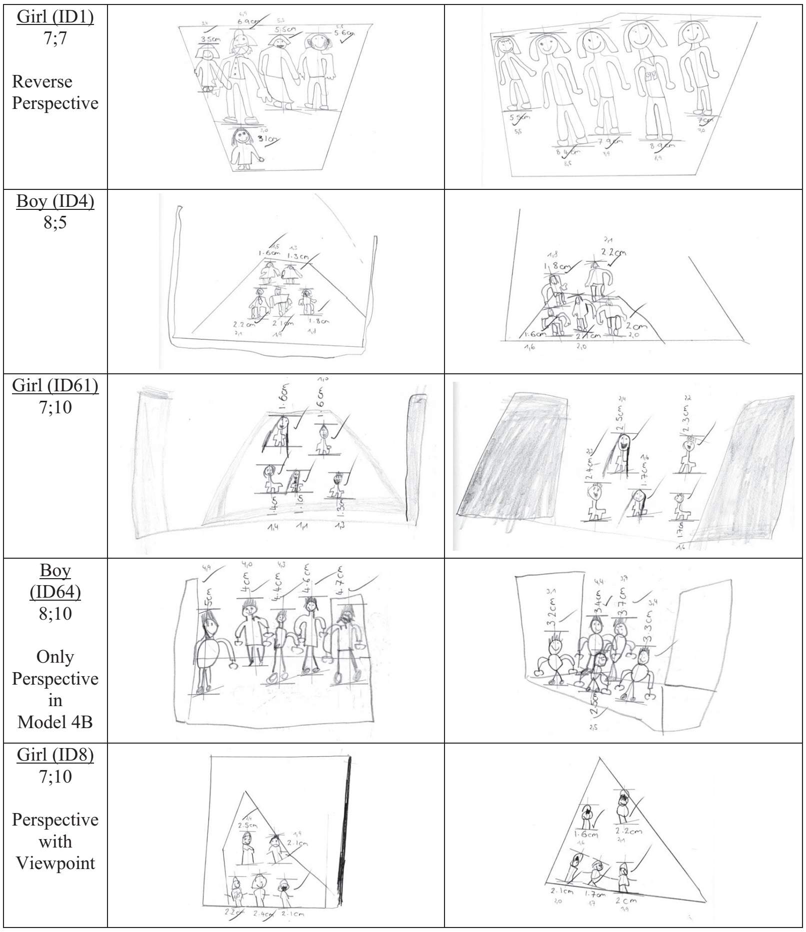

Figure 8. Drawing of diagonal spatial drawing systems in 7- to 8-year-old children. The left column contains drawings of Model 4A (perspective playing field with explicit spatial boundaries); the right column contains drawings of Model 4B (same area in perspective without surround), both drawn by the same child.

sports playing fields. Its playing field boundaries are neither accidental nor arbitrary, but they have strong connotations with rules and constraints. One may term this sort of spatial boundaries "nonaccidental boundaries," similar to the expression "nonaccidental" that Biederman (1987) used for the contours of the typical design features of objects, in contrast to changing, accidental, view-specific object contours.

This conclusion is further supported by the analyses of the uniformity of the figure size in each picture (i.e., the average difference between figures). A small difference indicated more same-sized figures and high uniformity whereas a large difference indicated small and large figures within one picture. Figure size uniformity was entirely determined by the spatial model and not by the age of the children. Figures were the most uniform in the orthogonal playing field with iconic field boundaries and in the perspective playing field that corresponded to the retinal image. Hence, it seems that we do not only have iconic objects and landmarks but (also) iconic spatial areas. A prototypical, iconic playing field should be as easily identifiable as an object icon; for example, stripy horizontal axes in a rectangular area filled with blue color would be easily identifiable as an icon for a swimming pool, at least as soon as the figures are added to the lanes.

Do Drawing Stages Really Exist?

In the current study, the perspective models with the least discrepancy between retinal input (appearance) and design (identity) yielded the highest proportion of perspective drawings at a much earlier age than predicted by stage theories. This raises the question of whether drawing stages of the spatial systems according to Piaget and Inhelder (1956) really exist. The common explanation about the development from the intellectual realism of iconic objects in empty space to the visual realism of perspective is that young children initially draw what they know and not what they see (Luquet, 1927). Hence, young children would not know that their vision distorts the angularity of rectangular constructions like a camera. Insofar, drawing development would rather consist of levels of awareness about visual functioning (Bremner & Moore, 1984).

In drawing research, Costall (1995) reported that for a long time, the rival developmental theory to the stagewise development of drawing was the repression theory. In this theory, it was assumed that children have lost access to a sensory core because of the newly emerging semantic, language-formatted concepts that begin to dominate the memory of the child (Bühler, 1930). Likewise, Frith (2003) suggested that young autistic savant children are able to map perspectives of entire scenes and landscapes in a raw format without going through a phase of schematic drawings.

The current results clearly suggest that a revision of the stage concept is necessary for drawing development. "Fast mapping" is a developmental concept for word acquisition in which 2-year-old children enlarge their vocabulary at an amazing rate surpassing any other species (Carey & Bartlett, 1978; Clark, 2007) as well as when learning to read and remember novel words in written language (Lange-Küttner & Krappmann, 2011; Rack, Hulme, Snowling, & Wightman, 1994). Likewise, the perspective mappings in the study presented here were 10-min sketches that can put some children under pressure to perform (Lange-Küttner, 1998, 2012; Lange-Küttner & Green, 2007; Lange-Küttner, Küttner, & Chromekova, 2013; Lange-Küttner & Vinter, 2008). Indeed, functional magnetic resonance imaging scans of adults' selective sketches in comparison to faithful copying needed additional brain resources in the frontal and temporal areas as well as in the cerebellum and the supplementary motor area (Schaer, Jahn, & Lotze, 2012).

Thus far, it was always assumed that young children would draw in a constructivist fashion whereas only older children could sketch (Shamir, Tzuriel, & Guy, 2007). However, these perspective drawings, created within a limited, short time period, indicated that 7- to 8-year-old children do not only prefer to draw in perspective if they could (Kosslyn et al., 1977, but they actually can, and excel in perspective drawing, if the real spatial model matches their retinal image. Hence, it may be useful to think of the development of drawing in perspective as a layered rather than a stagewise model because typically developing young children can access low-level visual information and draw in perspective instead of deploying high-level conceptual knowledge about the geometrical principles of perspective construction.

In future work, a "think aloud" protocol could help to test whether the 7- to 8-year-old children can actually explain the principles of their graphic constructions (Jee et al., 2009) and how they judge the adequacy of their depictions of perspective. Accuracy in technical drawings predicted learning and memory in Science, Technology, Engineering and Mathematics (STEM) science subjects (Schwamborn et al., 2010). Hence, it would be interesting to see in future research whether getting children to sketch in perspective could also actually accelerate their understanding of the underlying mathematical and geometrical principles. AQ: 5

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