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Children's representations of another person's spatial perspective: Different strategies for different viewpoints?

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ABSTRACT

The current study investigated development and strategy use of spatial perspective taking (i.e., the ability to represent how an object or array of objects looks from other viewpoints) in children between 8 and 12 years of age. We examined this ability with a task requiring children to navigate a route through a model city of wooden blocks from a 90° and 180° rotated perspective. We tested two hypotheses. First, we hypothesized that children's perspective-taking skills increase during this age period and that this process is related to a co-occurring increase in working memory capacity. Results indeed showed clear age effects; accuracy and speed of perspective-taking performance were higher in the older age groups. Positive associations between perspective-taking performance and working memory were observed. Second, we hypothesized that children, like adults, use a mental self-rotation strategy during spatial perspective taking. To confirm this hypothesis, children's performance should be better in the 90° condition than in the 180° condition of the task. Overall, the results did show the reversed pattern; children were less accurate, were slower, and committed more egocentric errors in the 90° condition than in the 180° condition. These findings support an alternative scenario in which children employ different strategies for different rotation angles. We propose that children mentally rotated their egocentric reference frame for 90° rotations; for the 180° rotations, they

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inverted the left–right and front–back axes without rotating their mental position.

Introduction

The focus of the current study was on children's spatial perspective taking, the ability to mentally represent how objects in space appear to another person. Developmental research has shown that children's reconstructions of another person's spatial perspective become much more accurate during the elementary school years (e.g., Coie, Costanzo, & Farnill, 1973; Frick, Mohring, & Newcombe, 2014; Phinney & Nummedal, 1979). Much less is known, however, about the strategies used by children for solving perspective-taking problems. Studies showed that adults employ a mental self-rotation strategy during spatial perspective taking. They rotate their own reference frame in order to align the own reference frame with the reference frame of the other (i.e., they put themselves in the shoes of the other) (Kessler & Thomson, 2010; Kozhevnikov & Hegarty, 2001; Michelon & Zacks, 2006). The current study tested two main hypotheses, namely that children's perspective-taking ability improves with age and is related to age-related increases in working memory capacity (Hypothesis 1) and that children, like adults, use a mental self-rotation strategy during spatial perspective taking (Hypothesis 2).

Development of spatial perspective taking

Spatial perspective taking has been assessed by a variety of tasks, beginning with Piaget's Three Mountains task (Piaget & Inhelder, 1956). This task required children to look at a model layout of three mountains and to judge the way a doll would see this layout from a specific position, either by rebuilding the layout or by choosing the correct view from a set of photographs. In general, children up to the age of 10 years frequently committed egocentric errors on this task. That is, their answers resembled their own view of the mountains. Subsequent studies used variations of this task to investigate children's difficulties with spatial perspective taking more specifically. By doing so, Flavell (1992) differentiated between two levels of perspective-taking ability developing sequentially. The relatively simple "Level 1" perspective taking (i.e., the ability to judge whether, from a different position, a given object can be seen or not) was found to emerge before the age of 4 years (e.g., Sodian, Thoermer, & Metz, 2007). More exact computations ("Level 2") of *how* a given object can be seen (e.g., right side up or upside down) and *where* it is located (e.g., in the left or right of the visual field) was found to develop after the age of 4 years (see also Newcombe, 1989).

Level 2 perspective taking involves the construction of a mental representation that equals the view of the other person. Developmental studies demonstrated that these representations become more accurate during the elementary school years in that the number of purely egocentric errors (i.e., the child's reconstruction equals the own perspective) and the number of reconstruction errors (i.e., the child's reconstruction does not equal the own perspective but contains front–back and/or left–right reversals) decrease. For example, the study of Frick and colleagues (2014) demonstrated a decrease in egocentric errors between 4 and 8 years of age. These authors presented children with scenes of toy photographers taking pictures of layouts of objects (one, two, or four) from different angles (0°, 90°, or 180°) and asked them to choose which one of four pictures could have been taken from a specific viewpoint. Results showed that scenes with one object were easier than scenes with multiple objects. The 4-year-olds performed near chance level, even in the simple layouts with only one object, whereas nearly all the 8-year-olds performed above chance level. The number of egocentric errors (i.e., selecting the picture that represented their own perspective) decreased significantly with age; a steep decline was observed between 7 years (~70% of errors egocentric in the more complex layouts) and 8 years (~40% of errors egocentric). These findings corroborate other studies showing that spatial

perspective taking is certainly not fully free of egocentric errors in children at around 8 years of age (e.g., Gzesh & Surber, 1985; Rigal, 1996).

Reconstruction errors involve problems in determining the exact positions and orientations of objects in the layout. When viewed from the opposite, two figures behind each other reverse their front–back position and two figures side by side reverse their left–right position. Similarly, a figure seen from the front is seen from the back, and a figure looking to the left is looking to the right. Studies investigating developmental patterns in reconstruction errors argued for a stepwise decrease in front–back and left–right reversals. That is, children are hypothesized to master the different spatial transformations (e.g., front–back and left–right reversals) one by one. Coie and colleagues (1973) demonstrated, on the basis of a study with a perspective-taking task comparable to Piaget's Three Mountains task, that perspective-taking development proceeds across three phases. First, children acquired ability in understanding before–behind relationships, which is comparable to Level 1 perspective taking (i.e., deciding whether objects are visible to the other person [i.e., in front of that person] or not [i.e., behind that person]). Second, they learned to reconstruct changes in the shape and orientation of objects when seen from another view (e.g., inferring whether the other person would have a frontal or side view of the objects), and finally they were able to reconstruct the left–right relationships among objects. The finding that the understanding of left–right position reversals is the most difficult for children and the last to be mastered is supported by other studies (e.g., Phinney & Nummedal, 1979; Rigal, 1996).

Taken together, children's ability to reconstruct the other person's perspective improves with age, as shown by a steep decrease in purely egocentric errors. However, difficulties in inhibiting the interference of the own perspective are persistent, especially in tasks that require the determination of the relative positions of multiple objects. To understand these developmental patterns, insight in underlying processes and strategies is needed.

Perspective-taking strategies

The strategies children use to reconstruct the spatial perspective of another person are hardly investigated. Studies with adults showed differences in underlying strategies between Level 1 and Level 2 perspective taking. Level 1 perspective taking (i.e., deciding whether objects are visible to another person or not or whether objects are in front of or behind each other) does not require a person to mentally rotate into the position of the other person. The problem can be solved from the own position by tracing the line of sight of the other person. In contrast, Level 2 perspective taking is subserved by a mental self-rotation strategy (Surtees, Apperly, & Samson, 2013a, 2013b). That is, adults align one's own perspective with that of another by mentally rotating their own egocentric reference frame (Kessler & Thomson, 2010; Kozhevnikov & Hegarty, 2001; Michelon & Zacks, 2006).

The use of mental self-rotations cannot be observed directly but instead needs to be inferred from error patterns and response times. When making mental self-rotations, error rates and response times typically increase linearly with increasing angular difference (e.g., Kessler & Thomson, 2010; Michelon & Zacks, 2006; Surtees et al., 2013b). In other words, the larger the distance between the own perspective and the other perspective, the more error prone and time-consuming the mental self-rotation process is. According to this view, 180° self-rotations are the most difficult because they require the largest distance to "travel" from the own mental position to the target position (Newcombe, 1989). Additional evidence for a mental rotation strategy in adults comes from studies with thinking aloud protocols, in which adults indicated to mentally take the position of the other person (Gronholm, Flynn, Edmonds, & Gardner, 2012). Notably, adults do not always employ the mental self-rotation strategy in tasks requiring them to make left–right decisions. One commonly used alternative strategy is the object-rotation strategy, in which individuals rotate the object(s) in mind without mentally rotating their own viewpoint. For example, in the study of Gronholm and colleagues (2012), in which participants needed to make speeded judgments about the hand in which a front-view schematic figure held a ball, approximately half of the participants reported to invert left and right without adopting the perspective of the other person.

Preliminary evidence indicates the use of the mental self-rotation strategy in children. Roberts and Aman (1993) administered 6- to 8-year-old children a computerized reaction time task, in which they

needed to judge the position of a dot that was either to the left or to the right of a picture of a triangle. The triangle was displayed at 1 of 16 rotations, at 0° (facing straight up) and at rotation positions of 22.5° increments. Only the children who correctly identified left–right directions made a mental self-rotation (i.e., they had linear increases in reaction time). Children making errors in identifying left and right were supposed to use a stationary self as a reference frame. The children who were supposed to use a mental self-rotation strategy were significantly older (i.e., 7 years 10 months) than the children not using this strategy (i.e., 6 years 9 months). Crescentini, Fabbro, and Urgesi (2014) also showed that the mental self-rotation strategy becomes available in children at around 8 years of age. They observed different developmental trajectories for children's performance on object-based and perspective-based transformation tasks. Whereas object-based transformations were observed in 7-year-olds, perspective-based transformations emerged 1 year later, from 8 years of age. In line with these findings, the factor-analytic study of Vander Heyden, Huizinga, Kan, and Jolles (2016) showed an increasing dissociation between object-based and perspective-based transformations in children between 8 and 12 years of age. Together, these findings indicate that children under the age of 8 years predominantly use an object-rotation strategy. They rotate the objects in their mind without mentally rotating their own position. From around 8 years of age, children continue to use this object-rotation strategy, but they also learn to employ a self-rotation strategy.

The role of working memory

The major challenge during mental self-rotation is to control the conflict between the actual ego-centric view (i.e., what you see right here right now) and the mental representation of the other person's view. The actual view needs to be inhibited in order to make space for the imagined view, but at the same time it should remain available in working memory for computational processes (Epley, Keysar, Van Boven, & Gilovich, 2004). Adults generally succeed in controlling this interference because they have sufficient cognitive resources available (Epley, Morewedge, & Keysar, 2004; Surtees, Butterfill, & Apperly, 2012). Nevertheless, their perspective-taking performance is slower and less accurate when they simultaneously need to perform on a task taxing their inhibition or working memory (Epley, Keysar, et al., 2004; Lin, Keysar, & Epley, 2010; Qureshi, Apperly, & Samson, 2010). It may be suggested that children's errors in perspective taking reflect an inability to completely control the egocentric interference during the mental self-rotation process because their inhibitory and working memory functions are still developing (e.g., Best & Miller, 2010; Gathercole, Pickering, Ambridge, & Wearing, 2004; Huizinga, Dolan, & van der Molen, 2006; Lin et al., 2010).

Based on previous findings, we hypothesized that children from 8 years of age, like adults, employ a mental rotation of their own reference frame under different rotation angles of spatial perspective taking. Because this ability of mental self-rotation is a demanding task, we expected that perspective-taking performance would be specifically related to age-related increases in working memory capacity.

The current study

The main goal of the current study was to understand developmental changes in spatial perspective taking by investigating 8- to 12-year-old children's performance and strategy use on a Level 2 spatial perspective-taking task. The developmental literature has focused mainly on the early development of perspective taking during infancy and early childhood but has failed to provide an account of the developmental processes and strategies that contribute to spatial perspective-taking skills in older children. Based on the indications that the mental self-rotation strategy emerges from 8 years of age (e.g., Crescentini et al., 2014; Roberts & Aman, 1993; Vander Heyden et al., 2016), the current study focused on children between 8 and 12 years of age.

We developed a perspective-taking task requiring children to "walk" a route (i.e., make front–back and left–right judgments) for another person (i.e., a little "doll") through a model city of wooden blocks while using a map. The task consisted of three conditions: a control condition (0°), in which there was no change of perspective, and 90° and 180° conditions, in which the start position of the doll was 90° and 180° rotated to the children's actual perspective, respectively. We examined the

accuracy and speed of perspective-taking performance in the three different conditions of the task (0°, 90°, and 180°). In addition, we investigated the points at which children started the route and differentiated between egocentric errors (routes started at the own side, no rotation to 90° or 180° perspective) and non-egocentric errors (routes started at another side).

We tested two hypotheses. The first hypothesis concerned developmental progress on the perspective-taking task. More specifically, we hypothesized age effects in accuracy and speed of perspective-taking performance, with older children having higher accuracy and speed of perspective taking and committing fewer egocentric errors than younger children. Moreover, we hypothesized the accuracy for the effortful conditions (90° and 180°) to be specifically related to working memory. The second hypothesis concerned strategy use on the perspective-taking task. We hypothesized that children, like adults, use a mental self-rotation strategy during perspective taking. If children use a mental self-rotation strategy, better performance (i.e., higher accuracy, faster speed, fewer egocentric errors) would be expected for trials in the 90° condition than in the 180° condition (i.e., rotation effects). To further examine this hypothesis on the use of the mental self-rotation strategy, we investigated accuracy and speed differences between the 90° and 180° conditions for "high-performance" trials (i.e., for trials started at the correct point and for trials with the maximum score). We expected to find indications for a mental self-rotation strategy (i.e., better performance in the 90° condition than in the 180° condition) in these subsets of trials.

Method

Participants

A total of 245 typically developing children participated in this study (117 boys [48%] and 128 girls [52%]). They were recruited from seven regular elementary schools in The Netherlands. The children were between 7.75 and 12.58 years of age (M = 9.95 years, SD = 1.20) and were from Grades 3 to 6. We divided the children into four groups based on their age: (a) 8-year-olds (n = 65 [29 boys and 36 girls], M_{age} = 8.51 years, range = 7.75–8.92), (b) 9-year-olds (n = 69 [33 boys and 36 girls], M_{age} = 9.49 years, range = 9.00–9.92), (c) 10-year-olds (n = 47 [24 boys and 23 girls], M_{age} = 10.41 years, range = 10.00–10.92), and (d) 11-year-olds (n = 64 [31 boys and 33 girls], M_{age} = 11.53 years, range = 11.00–12.58). A Pearson's chi-square test revealed that the distribution of boys and girls was the same across age groups, $\chi^2(3)$ = 0.48, p = .924. Parents gave written informed consent. Children, families, and schools did not receive any compensation for their participation in the study. The ethical committee of the Faculty of Behavioral and Movement Sciences at Vrije Universiteit Amsterdam approved the research protocol.

Materials

Perspective-taking task

The City Walk task required children to "walk" routes with a token through a three-dimensional model city. The city consisted of six wooden blocks of different shapes, sizes and colors (i.e., the buildings) placed on a board with a grid of six by six squares. The routes passed these buildings and were represented on a map with the same gridline. The routes consisted of 12 steps (i.e., with each square being a step) and had clear start and finish signs on the map (see Fig. 1).

The task comprised three conditions, each with two trials: a 0° condition, in which we checked the basic ability to perform the task and no perspective taking was required, and 90° and 180° conditions, in which we examined children's ability to represent rotated perspectives. The city on the map was rotated either a quarter turn (90°) or a half turn (180°) to the layout of blocks. The layout of blocks stayed in the same position during testing, and children were not allowed to turn their heads, meaning that they needed to mentally rotate their perspective a quarter turn or a half turn to walk the route.

To reduce the impact of task comprehension differences and to improve the reliability of performance, each condition started with a demonstration trial completed by the researcher and a practice trial completed by the child. During the demonstration trials, the researcher told the children that the

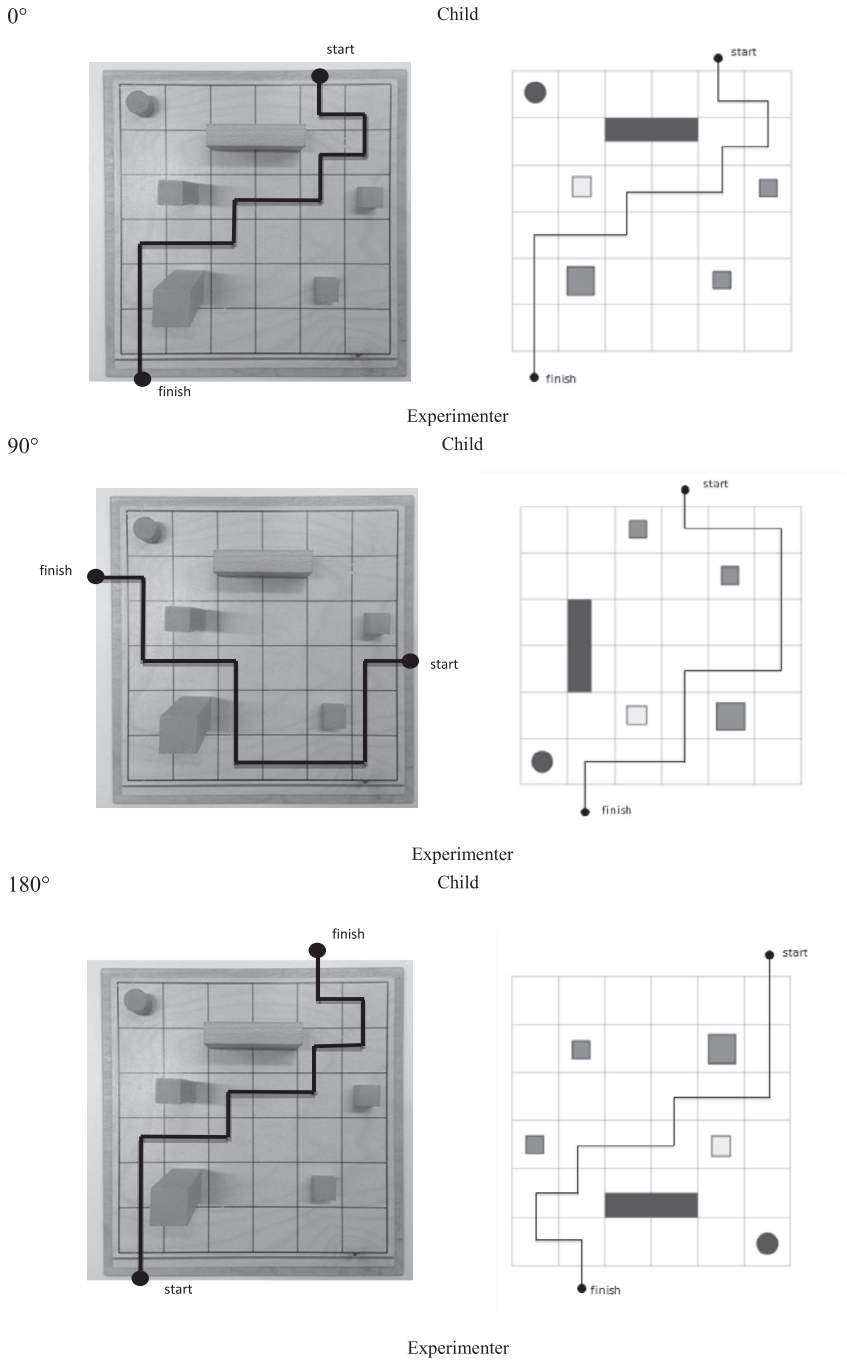**Fig. 1.** Examples of trials in respectively the 0° (upper panel), 90° (middle panel), and 180° (bottom panel) conditions. Each left panel shows the array with blocks, and each right panel shows the map with the route that the child needs to walk. On the map, the buildings are rotated either 0° (upper panel), 90° (middle panel), or 180° (lower panel) to the layout of blocks. The black line in each left panel shows the correct route.

draftsman was confused when drawing the map and drew everything "the wrong way around" by rotating the city either a quarter turn (90°) or a half turn (180°). The researcher showed these rotations to the child by gesturing the movement of the layout to the point corresponding to the map. In addition, the researcher demonstrated to the child the difference between the model city and the map by saying, "As you can see, the round building which is in reality in the upper left corner [researcher points to the corresponding wooden block] is situated here on the map [researcher points to the map in the lower right corner]. The same happened to the other buildings. Do you see that all the buildings are in another position?" Furthermore, the children were hinted at a stepwise solution when the researcher said, "As a first step, try to find the point where the doll is when starting the route." When a child failed on the practice trial, instructions and both the demonstration and practice trials were repeated. In case of an incorrect answer on the practice trial, the following hint was always given: "Try to inspect the position of the buildings carefully." All children completed the six trials in the same trial order. During the administration of the test, we registered for each trial the exact route as the child walked it, and with a stopwatch we recorded the time it took to start and complete the route.

Accuracy. The number of correct steps per trial (i.e., per route) was counted. That is, we counted the amount of squares (out of the 12 squares comprising the route) that were "hit" by the child during navigation independent of the child starting at the correct square or an incorrect square. For example, a child starting at a wrong square, but returning to the route after 2 incorrect steps, received an accuracy score of 10. The same score was given for a route that was started at the correct square but contained 2 missteps at the end. For each trial, we computed the percentage correct squares on the total number of squares (12).

Speed. We recorded for each item the *start-up speed* (i.e., the time between the start of the trial and the first step of the child, representing the time the child needed to decide about the first step) and the *navigation speed* (i.e., the time the child needed to complete the route from first step to last step). The time was recorded in seconds, with a maximum of 180 s.

Starting point. We assessed for each trial whether the child started at the correct point and, if not, where else the child started. We distinguished the following types of starting points (see Fig. 2):

1. *Correct starting point:* The route was started from the correct point.
2. *Correct starting side:* The route was started from the correct side, but not from the correct point.
3. *Other starting side:* The route was not started from the correct or egocentric side, but from one of the other two sides.
4. *Egocentric starting side:* The route was started from the own (egocentric) side of the layout. That is, the child did not make a 90° or 180° rotation.

Working memory

To assess working memory, we administered the computerized Mental Counters task (Huizinga et al., 2006), requiring children to retain numerical information active in their working memory while keeping track of the values of two "counters." The counters consisted of a horizontal line, above or below which squares appeared. Children were required to add 1 to the value of the counter when a square appeared above the line and to subtract 1 when it appeared below the line. When any counter reached a given criterion value (e.g., 2, 4), participants needed to press a button. In each trial (15 in total), series of five or seven consecutive squares were presented. The variable of interest was the percentage of correct answers on the total number of trials.

Non-verbal intelligence

To assess non-verbal intelligence, we used the Raven Standard Progressive Matrices (SPM; Raven, Raven, & Court, 2000). The Raven SPM consists of 60 items (arranged in five sets of 12), all of which involve completing a pattern or figure with a part missing by choosing the correct missing piece from among six or eight alternatives. Within each set, the items become increasingly more difficult.

Position of the layout

Route from the 180° condition

1) Correct starting point (and route)
(accuracy = 12)

2) Correct starting side, incorrect starting point
(accuracy = 10)

3) Other starting side
(accuracy = 5)

4) Egocentric starting side
(accuracy = 10)
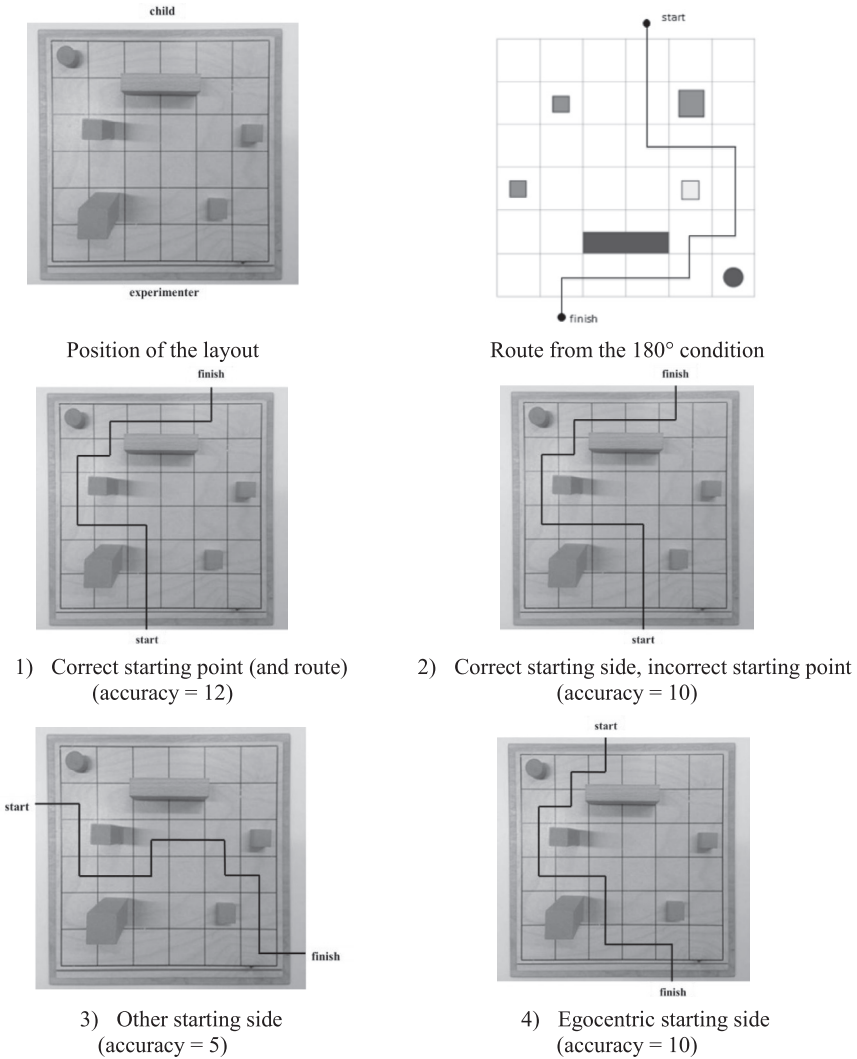
Fig. 2. The four different types of starting points and the corresponding accuracy scores.

Children were required to solve as many of these analogical reasoning problems (maximum = 60) in 15 min.

Procedure

Testing consisted of three sessions. The administration of the tasks was fully standardized, and all children received the same instructions and uniform testing conditions. We started with a short oral introduction about the background and procedure of the study. After the introduction, children completed the Raven SPM in a classical session. Later that week, children received two individual sessions taking place in a quiet room in the school. In the first session (10 min), the computerized working memory task was administered. In the second session (15 min), the children were administered the spatial perspective-taking task.

Results

Four sets of analyses were carried out to investigate age effects (i.e., Hypothesis 1: developmental progress) and rotation effects (i.e., Hypothesis 2: use of mental self-rotation strategy) in performance on the spatial perspective-taking task. First, we investigated the effects of age and angle on accuracy and speed of perspective taking. Second, we investigated the distribution of starting points across age groups and rotation angles. Third, we examined accuracy and speed differences between the 90° and 180° angles for two specific types of "high-performance" trials, that is, for trials started at the correct point and for trials completed with the maximum score. Fourth, we investigated relations between accuracy of perspective taking and working memory capacity while controlling for effects of age and non-verbal intelligence.

Age and rotation effects on accuracy and speed

Accuracy

To test for age and rotation effects on accuracy, we computed a repeated measures analysis of covariance (ANCOVA) with the accuracy percentages on the different angles (0°, 90°, or 180°) as a within-participants variable and age as a covariate. The results showed a main effect of age, $F(1, 243) = 24.96$, $p < .001$, $\eta_{p}^2 = .09$, with accuracy increasing with age. There was also a main effect of angle, $F(2, 486) = 29.11$, $p < .001$, $\eta_{p}^2 = .11$. Post hoc tests with Bonferroni correction showed higher accuracy in the 0° condition than in the 90° condition ($M_{diff} = 26.28$, $p < .001$) and higher accuracy in the 0° condition than in the 180° condition ($M_{diff} = 16.67$, $p < .001$). In contrast to the mental self-rotation hypothesis, children were more accurate in the 180° condition than in the 90° condition ($M_{diff} = 9.61$, $p < .001$). In addition, there was a significant interaction effect of age and angle, $F(2, 486) = 15.49$, $p < .001$, $\eta_{p}^2 = .06$, indicating that the age effect differed across conditions. There was no age effect in the 0° condition ($B = 0.42$, $SE = 0.30$, $t = 1.40$, $p = .16$). Accuracy increased with age in the 90° condition ($B = 7.38$, $SE = 1.34$, $t = 5.51$, $p < .001$, $\eta_{p}^2 = .11$) and in the 180° condition ($B = 3.89$, $SE = 1.23$, $t = 3.17$, $p = .002$, $\eta_{p}^2 = .04$).

Speed

A repeated measures ANCOVA with *start-up speed* on the different angles (0°, 90°, or 180°) as repeated measures and age as a covariate revealed a significant main effect of age, $F(1, 243) = 10.03$, $p = .002$, $\eta_{p}^2 = .04$. With age, children spent less time on calculating the starting point. In addition, a main effect of angle was observed, $F(2, 486) = 12.18$, $p < .001$, $\eta_{p}^2 = .05$. Post hoc tests with Bonferroni correction showed that children were faster in the 0° condition than in the 90° condition ($M_{diff} = 13.42$, $p < .001$) and faster in the 0° condition than in the 180° condition ($M_{diff} = 8.70$, $p < .001$). In contrast to the mental self-rotation hypothesis, children were faster in the 180° condition than in the 90° condition ($M_{diff} = 4.72$, $p = .001$). In addition, there was a significant interaction effect of age and angle, $F(2, 486) = 7.11$, $p = .001$, $\eta_{p}^2 = .03$, suggesting that the age effect differed across conditions. There was no age effect in the 180° condition ($B = -1.06$, $SE = 0.71$, $t = 1.50$, $p = .14$). Children were faster with age in the 0° condition ($B = -0.34$, $SE = 0.08$, $t = 3.80$, $p < .001$, $\eta_{p}^2 = .06$) and in the 90° condition ($B = -4.01$, $SE = 1.24$, $t = -3.24$, $p = .001$, $\eta_{p}^2 = .04$).

The repeated measures ANCOVA on *navigation speed* revealed a main effect of age, $F(1, 243) = 14.29$, $p < .001$, $\eta_{p}^2 = .06$. The total time spent on navigating the routes decreased with age. In addition, a main effect of angle was observed, $F(2, 486) = 7.65$, $p = .001$, $\eta_{p}^2 = .03$. Post hoc tests with Bonferroni correction showed faster speed in the 0° condition than in the 90° condition ($M_{diff} = 29.11$, $p < .001$) and faster speed in the 0° condition than in the 180° condition ($M_{diff} = 28.65$, $p < .001$). Interestingly, there was no speed difference between the 90° and 180° conditions ($M_{diff} = 0.46$, $p = 1.00$), which is in contrast to our hypothesis on the use of the mental self-rotation strategy. In addition, there was no significant interaction effect of age and angle, $F(2, 486) = 2.67$, $p = .07$, suggesting that the age effect was the same across conditions.

Taken together, we found both age and rotation effects on children's accuracy and speed of perspective taking. Regarding the age effect, older children were more accurate and faster in the rotated
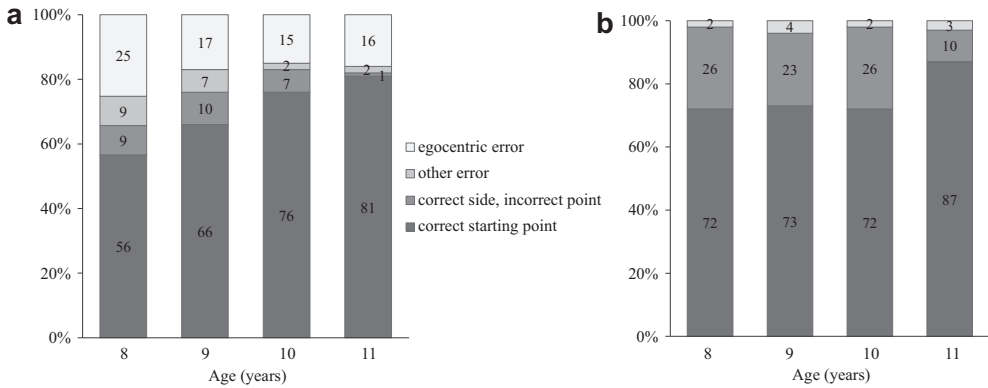
Fig. 3. (A) Percentages of different types of starting points in the 90° condition per age group. (B) Percentages of different types of starting points in the 180° condition per age group.

conditions than younger children. These findings support the first hypothesis on developmental progress in perspective taking. Regarding the rotation effect, we observed higher accuracy and faster start-up speed in the 180° condition than in the 90° condition. There were no differences between the two conditions in navigation speed. These findings are in contrast to the second hypothesis on the use of the mental self-rotation strategy, stating that children would be more accurate and faster in the 90° rotation than in the 180° rotation.

Age and rotation effects on distribution of starting points

As a second step, we investigated age effects on children's distribution of starting points separately for the different conditions (see the Appendix and Fig. 3A and B). We distinguished the following types of starting points: (a) *correct starting point*, (b) *correct starting side* (incorrect starting point and correct starting side), (c) *other starting side* (no start at the correct or egocentric side, but at one of the two remaining sides), and (d) *egocentric starting side* (starting position is incorrectly one's own side). For these analyses, we used age as a categorical variable; that is, we compared 8-, 9-, 10-, and 11-year-olds.

Age effects

We investigated with Pearson's chi-square tests the effect of age group on the distribution of starting points separately for each condition.

0° condition. In the 0° condition, there was no association between age and the type of errors made, $\chi^2(3) = 4.22$, $p = .24$. At all ages, nearly all trials were started at the correct starting point.

90° condition. In the 90° condition, the pattern of starting points was different across age groups, $\chi^2(9) = 29.40$, $p = .001$, Cramer's $V = .14$, $p = .001$. In line with the first hypothesis, more trials were started from the correct point with age, from 56% in the 8-year-olds to 81% in the 11-year-olds. Approximately 10% of the trials completed by the 8- to 10-year-olds were started from the correct side but incorrect point. This type of starting point error decreased significantly with age, to 1% in the 11-year-olds. The percentage of egocentric starting points fluctuated at around 20% and, unexpectedly, did not decrease with age. At all ages, only a small percentage of the routes were started from one of the other incorrect sides (i.e., on average 5% of the trials).

180° condition. Also in the 180° condition, the pattern of starting points was different across age groups, $\chi^2(6) = 13.96$, $p = .03$, Cramer's $V = .12$, $p = .03$. In line with the first hypothesis, more trials

were completed from the correct starting point with age, from approximately 72% in the 8-, 9-, and 10-year-olds to 87% in the 11-year-olds. In the 8-, 9-, and 10-year-olds, approximately a quarter of the trials were started from the correct side but from the incorrect point. This type of error was less common in the oldest age group (i.e., 10%). At all ages, only a small percentage of the trials were started from the egocentric side (i.e., on average 3% of the trials). None of the trials in this condition was started from another side than the correct or egocentric side.

Rotation effects

Pearson's chi-square tests revealed that the number and type of starting points differed between the 90° and 180° conditions, $\chi^2(3) = 116.77$, $p < .001$, Cramer's $V = .15$, $p = .001$. There was no difference between the 90° and 180° conditions in the percentage of trials started at the correct point, $\chi^2(1) = 0.77$, $p = .38$. However, in the 90° condition, more egocentric errors were committed, $\chi^2(1) = 27.25$, $p < .001$, and more other errors were committed, $\chi^2(1) = 13.00$, $p < .001$. In the 180° condition, more trials were started at the correct side but incorrect point than in the 90° condition, $\chi^2(1) = 17.38$, $p < .001$. These findings are in contrast to the mental self-rotation hypothesis (i.e., better performance in the 90° condition than in the 180° condition).

Summarizing, the findings on the distribution of starting points showed age and rotation effects. Children committed fewer starting point errors with age, both in the 180° condition and in the 90° condition, which is line with the first hypothesis on developmental progress. More egocentric errors were committed in the 90° condition than in the 180° condition, and this number did not decrease with age. In the 180° condition, most errors were 'starting at the correct side but incorrect point' errors, and this number decreased with age. These rotation effects are in contrast to the second hypothesis on the use of a mental self-rotation strategy (i.e., more accurate and faster performance in the 90° condition than in the 180° condition).

Rotation effect in high-performance trials

As a third step, we investigated whether there were additional indications for a mental self-rotation strategy by focusing on two specific subsets of trials. Specifically, we investigated rotation effects in trials characterized by "high performance," that is, trials started at the correct point and trials with the maximum score (i.e., accuracy of 100%). It was hypothesized that especially in these trials accuracy and speed patterns would point at a mental self-rotation strategy (i.e., better performance in the 90° condition than in the 180° condition).

Trials started at the correct point

First, we examined differences in accuracy, start-up speed, and navigation speed between trials started at the correct point in the 90° condition (339 of 490 trials) and trials started at the correct point in the 180° condition (372 of 490 trials). Because the data for this analysis are not independent (i.e., one participant may have multiple data points), we used a generalized estimating equation model in SPSS with accuracy, start-up speed, and navigation speed as dependent variables, angle (90° or 180°) as an independent variable, and identification (ID) number as a participant variable to account for dependency in the data. The results showed higher accuracy for the 180° trials than for the 90° trials and no differences between the 180° and 90° trials in start-up speed and navigation speed (see Table 1).

Trials with maximum score

Second, we examined differences in start-up speed and navigation speed between trials with the maximum accuracy score in the 90° condition (157 of 490 trials) and trials with the maximum accuracy score in the 180° condition (259 of 490 trials). The generalized estimating equation model with start-up speed and navigation speed as dependent variables, angle (90° or 180°) as an independent variable, and ID number as a participant variable revealed slower start-up speed in the 90° trials compared with the 180° trials and no differences between the two angles in navigation speed (see Table 1).

Table 1

Mean (*SD*) accuracy, start-up, and navigation speed for trials started at the correct point and trials with the maximum score and results of the generalized estimating equation model.

Type of trial		90°	180°	Rotation effect Wald χ^2
Correct starting point	*n*	339	372	
	Accuracy	83.53 (21.40)	90.70 (17.55)	$\chi^2(1) = 25.96, p < .001$
	Start-up speed	10.73 (9.38)	9.59 (8.77)	$\chi^2(1) = 3.53, p = .06$
	Navigation speed	41.64 (31.77)	43.23 (37.62)	$\chi^2(1) = 0.37, p = .54$
Maximum score	*n*	157	259	
	Start-up speed	10.18 (10.80)	8.48 (7.70)	$\chi^2(1) = 4.16, p = .04$
	Navigation speed	35.92 (29.33)	40.84 (35.87)	$\chi^2(1) = 0.37, p = .54$

Taken together, the current results do not show evidence for a mental self-rotation strategy in these specific subsets of trials. Even in the "high-performance" trials there were no indications that 90° rotations were easier than 180° rotations.

Role of working memory

In the fourth set of the analyses, we investigated relations between perspective-taking performance and working memory capacity. First, we computed correlations between children's accuracy scores and working memory in the different conditions. Larger working memory capacity was related to higher accuracy in the 90° and 180° conditions (*r* = .45 and *r* = .38, *p*s < .001), but not to accuracy in the 0° condition (*r* = .12, *p* = .07). Second, we performed three separate linear hierarchical regression analyses, one for each condition, to predict perspective-taking accuracy from children's working memory capacity. By adding age and non-verbal intelligence in the first step, we controlled for developmental differences between children. The results showed that working memory explained unique variance in spatial perspective taking. Higher working memory capacity predicted higher accuracy in the 90° condition (*β* = .26) and 180° condition (*β* = .23) but not in the 0° condition (*β* = .01) (see Table 2). The regression coefficient of working memory was not significantly different between the 180° condition and the 90° condition (*z* < .001, *p* > .05). These results underscore the role of working memory in spatial perspective-taking performance.

Discussion

The current study tested two hypotheses, namely that children's spatial perspective-taking performance increases with age and is specifically related to working memory capacity (Hypothesis 1) and that children, like adults, use a mental self-rotation strategy during perspective taking (Hypothesis 2). In contrast to previous studies that focused mainly on basic forms of perspective taking during early childhood, we examined more complex perspective-taking skills in children between 8 and 12 years of age.

Previous research investigating developmental patterns in perspective taking showed that children's reconstructions of another person's perspective become more accurate with age in that the number of purely egocentric errors (i.e., the child's reconstruction equals the own perspective) and the number of reconstructional errors (i.e., the child's reconstruction does not equal the own perspective but contains front–back and/or left–right reversals) decrease. Despite this progress, the perspective taking of children at around 8 years of age is certainly not fully free of errors (e.g., Frick et al., 2014; Roberts & Aman, 1993). The main goal of this study was to better understand these developmental patterns by focusing on the underlying processes and strategies.

The perspective-taking task administered in this study required 8- to 12-year-old children to "walk" a route with a token through a layout of wooden blocks. First the children needed to determine the correct starting point of the route, which was either 90° or 180° rotated to their actual position,

Table 2

Non-verbal intelligence, age, and working memory as predictors of accuracy on the three conditions of the perspective-taking task.

	0°		90°		180°	
	R^2 (ΔR^2)	β	R^2 (ΔR^2)	β	R^2 (ΔR^2)	β
Step 1	.06		.28[*]		.18[*]	
IQ		.25[*]		.44[*]		.39[*]
Age		.002		.18[*]		.08
Step 2	.06 (.00)		.34[*] (.05[*])		.22[*] (.04[*])	
IQ		.25[*]		.38[*]		.30[*]
Age		.002		.17[*]		.07
WM		.01		.26[*]		.23[*]

Note. IQ, non-verbal intelligence; WM, working memory.

[*] $p < .01$.

and after that they needed to work out a route of 12 steps. We examined children's perspective taking by investigating the accuracy and speed of performance and by differentiating "egocentric" starting points (i.e., started from own side of the board, no rotation) from "non-egocentric" starting points (i.e., started from a rotated side). In addition, we investigated relations between perspective-taking performance and working memory.

The first hypothesis concerned developmental progress in children's perspective-taking ability and its specific relation to working memory. In line with this hypothesis we found clear age effects, with the older children having higher accuracy, faster start-up speed, and faster navigation speed than the younger children in the 90° and 180° conditions of the perspective-taking task. However, the decrease in egocentric errors was not significant. We found positive relations between perspective-taking accuracy and working memory after controlling for the effects of age and non-verbal intelligence, suggesting a significant role of working memory in children's perspective-taking performance.

The second hypothesis concerned children's use of a mental self-rotation strategy during spatial perspective taking. To confirm this hypothesis, children's performance should be better in the 90° condition than in the 180° condition. Studies with adults showed that larger rotation angles are associated with more errors and slower responding (e.g., Kessler & Thomson, 2010; Michelon & Zacks, 2006; Surtees et al., 2013b). According to this view, 180° self-rotations are the most difficult because they require the largest distance to "travel" from the own mental position to the target position (Newcombe, 1989). We found no evidence for this hypothesis. We did not observe better performance in the 90° condition than in the 180° condition of the task. Children were more accurate and faster in detecting a starting point in the 180° condition than in the 90° condition. The analyses on the distribution of starting points suggested a similar pattern. Children committed more egocentric errors in the 90° condition compared with the 180° condition. That is, more often they started from their own (egocentric) side of the board instead of rotating to the 90° or 180° side. In addition, we found no accuracy and/or speed advantage in the 90° condition for trials that were started at the correct point or that were completed without error.

Taking these findings together, it seems unlikely that children between 8 and 12 years of age succeeded in employing a mental self-rotation strategy in both the 90° and 180° conditions of the perspective-taking task. Based on studies with adults, we propose two alternative scenarios on children's perspective-taking strategies, namely that (a) children employ a mental self-rotation strategy in the 90° condition and employ an object-rotation strategy in the 180° condition and that (b) children employ an object-rotation strategy in both conditions. When using an object-rotation strategy, the child does not rotate the own reference frame but computes the route from the own stationary viewpoint, for example, by inverting the left–right and front–back axes or by rotating the scene (i.e., the city) (e.g., Dalecki, Hoffmann, & Bock, 2012; Gronholm et al., 2012). We consider the plausibility of these two alternative scenarios on the basis of children's accuracy, speed, and starting point patterns.

The first scenario concerns the employment of a mental self-rotation strategy in the 90° condition and an object-rotation strategy in the 180° condition. Studies with adults give some indications for

this scenario. For example, in a study with the relatively simple "own body transformation" paradigm with 180° rotations (i.e., making speeded judgments about the hand in which a front-view schematic figure holds a ball), approximately half of the adult participants reported that they mentally transformed their spatial orientation to align with that of the figure, but the other half reported an alternative strategy of transposing left and right without making a mental position change (Gronholm et al., 2012). Another study, using a manual tracking experiment on the computer, exposed participants to different rotation angles in a stepwise fashion (Bock, Abeele, & Eversheim, 2003). Results showed that for rotations up to an angle of 90°, adults gradually rotated their own reference frame (i.e., mental self-rotation). For 180° angles participants inverted left and right, and angles between 180° and 90° were achieved by moving these inversions "backwards" from 180° toward the target angle. Given this scenario, differences in the number of egocentric errors would be expected because the 180° condition requires no mental position change, and thus no interference of the actual view with the imagined view, but the 90° condition does. In accordance with this hypothesis, we observed that nearly all children, in all age groups, started from the correct side of the layout in the 180° condition. Approximately a quarter of the trials in this condition were started at the correct side but not at the correct point, indicating that the children experienced difficulties in accurately inversing the axes. Children, and especially the younger children, committed more egocentric errors and needed more time to find the correct starting position in the 90° condition, suggesting that they experienced interference from their actual view when mentally representing the rotated view. In addition, the number of "correct side but incorrect point" errors was smaller in this condition, suggesting few inversing problems.

The second scenario hypothesized that children did not mentally rotate their own perspective at all but applied the object-rotation strategy in both conditions. In this case, more navigation errors (i.e., lower accuracy) would be expected in the 90° condition than in the 180° condition. In the 90° condition, directions need to be computed across the left–right and front–back axes (i.e., left becomes front, right becomes back, etc.), which is more difficult than computing the directions in the 180° condition, which are within the axes (i.e., left becomes right, right becomes left; front becomes back, back becomes front) (Gzesh & Surber, 1985; Newcombe, 1989). We indeed found higher accuracy in the 180° condition than in the 90° condition. However, the finding of more egocentric errors in the 90° condition than in the 180° condition argues against this scenario. Egocentric errors indicate a conflict between the egocentric and imagined views. However, the object-rotation strategy does not elicit such a conflict, making differences in egocentric errors between the two rotation angles unlikely.

Given this pattern of results, we suggest that the first scenario is most plausible; children rotate their own reference frame for 90° rotations and invert the axes for 180° rotations. One possible explanation for the relatively easy computations of the reversals for the 180° rotations, and not for the 90° rotations, is that children experience many face-to-face interactions with other persons in daily life compared with interactions with people positioned beside them. Repeated exposure to and practice with 180° interactions may result in a relatively efficient and effortless computation of such a reversed view on the world. An alternative explanation relates to working memory capacity. Mental self-rotation is a cognitively demanding strategy because it requires the child to ignore and suppress the own perspective while representing and transforming the other person's perspective. This conflict between perspectives places strong demands on the developing working memory system. The participants in this study might have been able to employ this strategy for small rotation angles (i.e., 90°). However, for 180° rotations, in which the distance between the own and target perspectives is larger and the rotation process is cognitively more demanding, the majority of children may have reverted to an object-rotation strategy.

The task used in this study included several attributes to maximize chances of measuring Level 2 spatial perspective-taking ability. First, we used rotation angles of 90° and more to elicit real perspective-taking strategies and to discourage visual matching strategies (Janczyk, 2013; Kessler & Thomson, 2010; Kozhevnikov & Hegarty, 2001). Second, to stimulate the use of a mental self-rotation strategy, we developed a task with a navigation component. Navigating the route required

children to determine the spatial relations between the token and the objects and to compute the left–right and front–back directions, which is most effective when the own body is used a reference point. Third, object rotation was discouraged by using symmetric objects without a clear front or face, making it more difficult to infer their orientation and, thus, to rotate them (Newcombe, 1989). It is important to note, however, that some children might have used the buildings as landmarks during the navigation process. That is, they might have used the buildings as anchors or reference points either relative to each other (e.g., "I have to start at the orange building and walk to the yellow building") or relative to their own body (e.g., "The building is right in front of me, so I can't go straight ahead"). Although these landmarks might have played a supportive role during children's way finding, navigating such a complex route with multiple direction changes is not possible without making exact left–right and front–back computations.

The current study gives some indications on children's spatial perspective-taking strategies under different rotation angles. Future studies should take a closer look at individual differences in children's strategy choices. Whereas this study inferred children's strategies from error and speed patterns, future work might profit from more direct measures, for example, by using eye-tracking. When using a navigation task, it is recommended to shed more light on the separate processes of choosing the correct starting point and the actual navigation. This can be achieved by providing children with the correct starting point and testing their subsequent navigation ability. In addition, it would be valuable to categorize children on the basis of their strategy use. The results of this study suggest that, overall, children used different strategies for different rotation angles. However, it is also possible that some children used different strategies for the same angle and that others used the same strategy for different angles. A focus on these individual differences in strategy use allows for subsequent examination of individual difference factors that contribute to these strategy choices such as sex, age, and cognitive abilities. Finally, the inclusion of adult participants would help to answer the question of whether adults' and children's perspective taking is based on common strategies, executed with different efficiencies, or whether adults and children employ different strategies (Apperly, Samson, & Humphreys, 2009; Epley, Morewedge, et al., 2004).

In conclusion, our study showed developmental progress in 8- to 12-year-old children's ability to represent different spatial perspectives. Children's accuracy and speed of perspective taking increased with age, and older children detected the correct starting point of the route more accurately than younger children. Perspective-taking performance was related to individual differences in working memory after controlling for the relations with age and non-verbal intelligence. The finding that children, and especially the children under 10 years of age, had more difficulties in resisting their own perspective in 90° rotations than in 180° rotations argues against the hypothesis that children use a mental self-rotation strategy for both rotations. Alternatively, these findings suggest differences in strategy use between the two rotation angles. We propose that children rotated their own reference frame for 90° rotations and used an object-rotation strategy for 180° rotations. Further research about the strategies of perspective taking could reveal developmental stages and individual factors related to developmental progress.

Acknowledgments

Appendix

Type of starting points (in percentage of total number of trials) in the three conditions of the task per age group (N trials = 490 per condition).

Age (years)	0°		90°				180°		
	Correct point	Correct side	Correct point	Correct side	Other	Egocentric	Correct point	Correct side	Egocentric
8	100[a]	0[a]	56[a]	9[a]	9[a]	25[a]	72[a]	26[a]	2[a]
9	100[a]	0[a]	66[a,b]	10[a]	7[a]	17[a]	73[a]	23[a]	4[a]
10	99[a]	1[a]	76[b,c]	7[a,b]	2[a]	15[a]	72[a]	26[a]	2[a]
11	100[a]	0[a]	81[c]	1[b]	2[a]	16[a]	87[b]	10[a]	3[a]
Total	100	0	69	7	5	19	76	21	3

Note. Each subscript letter denotes a subset of age categories whose row proportions do not differ significantly from each other at the .05 level. In the 0° condition, no "egocentric errors" or "other errors" were committed. In the 180° condition, no "other errors" were committed.

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