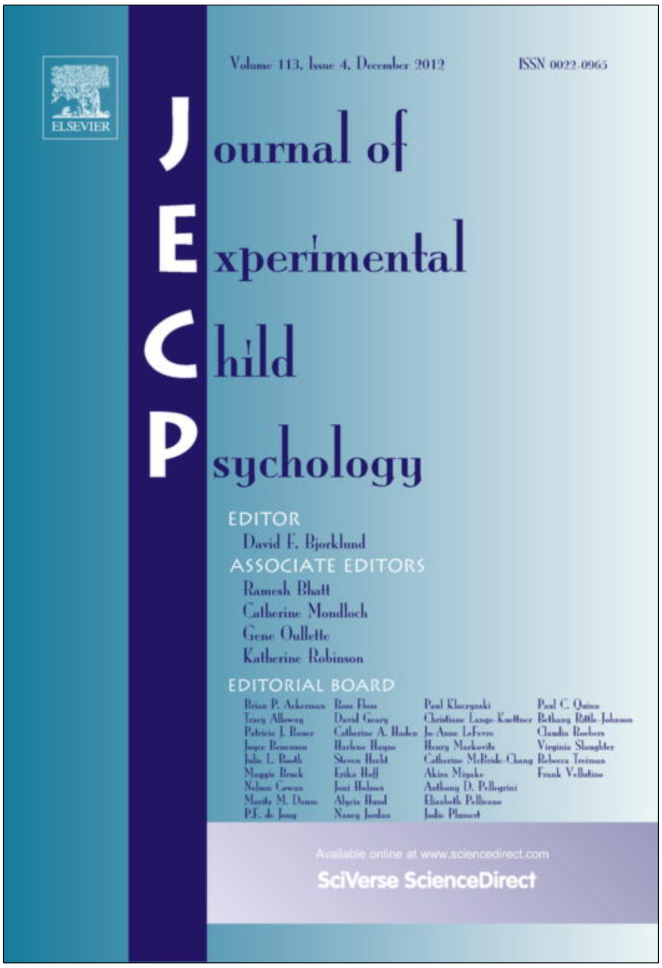
Volume 113, Issue 4, December 2012
ISSN 0022-0965
ELSEVIER
Journal of Experimental Child Psychology
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Journal of Experimental Child Psychology 113 (2012) 523–534

Contents lists available at SciVerse ScienceDirect

Journal of Experimental Child Psychology

journal homepage: www.elsevier.com/locate/jecp

Colorful success: Preschoolers' use of perceptual color cues to solve a spatial reasoning problem

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ARTICLE INFO

Article history:
Received 7 February 2012
Revised 21 June 2012
Available online 9 August 2012

Keywords:
Spatial reasoning
Perceptual cues
Problem-solving skills
Strategy acquisition and generalization
Limitations of cue use
Gravity bias errors

ABSTRACT

Spatial reasoning, a crucial skill for everyday actions, develops gradually during the first several years of childhood. Previous studies have shown that perceptual information and problem solving strategies are critical for successful spatial reasoning in young children. Here, we sought to link these two factors by examining children's use of perceptual color cues and whether their use of such cues would lead to the acquisition of a general problem solving strategy. Forty-eight 3-year-olds were asked to predict the trajectory of a ball dropped into one of three intertwined tubes. Children who received additional perceptual cues in the form of distinctly colored tubes succeeded twice as often as those who did not receive the cues. A third group of children who received the additional cues on only the first half of the test trials succeeded while the cues were present but reverted to making errors once they were removed. These findings demonstrate that perceptual color cues provide preschoolers with answers to spatial reasoning problems but might not teach children a general strategy for solving the problem.

Introduction

Spatial reasoning is a necessary skill for everyday activity. The ability to predict the movement of objects and people allows children to reach for and learn about objects, navigate around their environment, and interact with other people in their daily lives. Early indicators of spatial reasoning emerge around 4 months of age, when infants begin to show anticipatory looking and reaching behaviors (Johnson, Amso, & Slemner, 2003; von Hofsten, 1980). Spatial reasoning skills continue to develop over

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0022-0965/$ - see front matter
http://dx.doi.org/10.1016/j.jecp.2012.06.012

the next several years, with children making increasingly accurate predictions about the trajectory of moving objects (Hood, 1995).

The development of spatial cognition in preschoolers has been studied extensively using a manual search task designed by Hood (1995). As shown in Fig. 1, a ball is dropped down one of three intertwined tubes and children are asked to determine where it will emerge. The correct answer can be derived by simply following the path of the tube into which the ball was dropped. However, until approximately 4 years of age, children expect the ball to fall straight down even though the arrangement of the tubes precludes such possibilities. Younger preschoolers continue to make this error even after extensive training and experience with the problem. Hood described this behavior as the product of a gravity bias; when faced with a difficult problem, children resort to a default assumption that objects will fall vertically due to the effects of gravity. Indeed, the pull of the gravity bias is so strong that even older children are unable to inhibit their prepotent, gravity-driven responses if their attention is taxed (Hood, Wilson, & Dyson, 2006), and nonhuman primates and dogs make similar mistakes (Hauser, Williams, Kralik, & Moskovitz, 2001; Hood, Hauser, Anderson, & Santos, 1999; Osthaus, Slater, & Lea, 2003; Tomonaga, Imura, Mizuno, & Tanaka, 2007). Younger preschoolers avoid such errors if they are freed from gravity-related constraints by solving the problem with horizontally oriented tubes or reasoning about an upward-moving ball (Hood, 1998; Hood, Santos, & Fieselman, 2000), providing additional evidence that children's difficulties with this spatial reasoning problem stem from a gravity bias.

Recent studies have investigated the conditions under which children inhibit their gravity-driven responses. The findings suggest that perceptual information and problem solving strategies play important roles in the development of spatial cognition. For example, Bascandziev and Harris (2011) presented 3-year-olds with additional visual information about the tube mechanism by removing the "chimneys" (shown in Fig. 1 as the gray pieces connecting the tubes to the frame) from the apparatus and dropping the ball directly into an uncovered tube. This subtle modification improved children's performance significantly—so much so that it allowed them to make correct predictions even after the chimneys were reintroduced in later trials. Rather than increasing the availability of

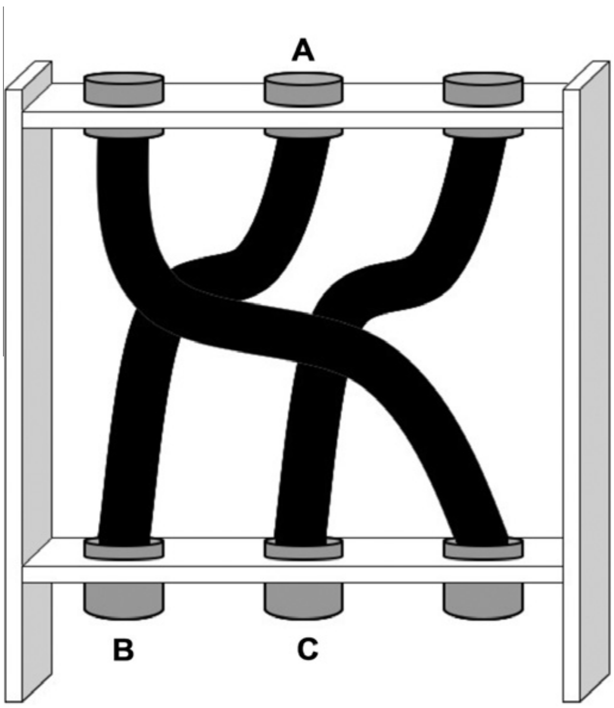

Fig. 1. Three plastic tubes were fitted into the top and bottom braces of the frame in a diagonal fashion, preventing a ball dropped down any tube from falling straight down. Children were invited to predict the path of the ball by placing a cup under the opening from which they expected the ball to emerge. For example, if the ball was dropped into the opening labeled A, then the children should place the cup in Location B (correct prediction). Location C represents a gravity bias prediction in which preschoolers expect the ball to fall down vertically regardless of the path created by the connected tube.

perceptual information, Joh, Jaswal, and Keen (2011) provided 3-year-olds with a visual imagery problem solving strategy by instructing them to "imagine the ball rolling down the tube" before each trial. Children who received this instruction made twice as many correct choices compared with children in control conditions who did not receive such instructions. These results showed that with a little help, young children are able to use and benefit from a visual imagery strategy while solving difficult spatial problems. Similarly, Bascandziev and Harris (2010) successfully provided 3.5-year-olds with a visual tracing problem solving strategy by asking them to "follow that tube with your eyes". Unlike Joh and colleagues, however, they prompted the children to use this strategy on only two practice trials; after the two practice trials, they stopped reminding the children to use the strategy. They found that children continued to avoid making gravity bias errors on subsequent trials, demonstrating the effectiveness of a visual tracing strategy for children learning to inhibit prepotent gravity-driven responses.

The current study sought to extend the previous findings by linking together perceptual cues and problem solving strategies. In particular, we examined whether a salient perceptual cue such as the color of a pathway could facilitate spatial reasoning in children and whether children's use of the cue could lead to the adoption of an effective, generalizable problem solving strategy. We presented children with color cues because of young children's familiarity with using perceptual information from color. Adults frequently quiz children about colors (e.g., "What color is the ball?"), and children witness other people using color to describe objects (e.g., "red ball") and locations (e.g., "in front of the blue chair"). In particular, children quickly learn that color, although not inherently spatial in nature, can provide important information about everyday spatial events. Children are taught, for example, that pedestrians walk on the sidewalk, cyclists ride in bike lanes, and motorists drive on the road; the three pathways are distinguishable by color (among other cues). If children must venture out onto the road, then they are taught to remain in the white crosswalk to avoid moving cars.

Furthermore, we presented children with color cues because children are adept at discriminating and using color information. By 4 months of age, infants show adult-like perceptual discrimination of primary colors such as red, yellow, and blue (Bornstein, Kessen, & Weiskopf, 1976; Franklin & Davies, 2004). By 4.5 months of age, infants use information about color, in conjunction with other features such as shape and pattern, to individuate one object from another (Needham, 1998; Wilcox & Baillargeon, 1998). Between 7.5 and 11.5 months of age, infants learn to rely solely on color information to discriminate objects (Wilcox, 1999; Wilcox & Chapa, 2004). By 1 year of age, infants can use color cues to find a hidden object in an otherwise unmarked room (Bushnell, McKenzie, Lawrence, & Connell, 1995). By 2 years of age, children sort and match objects by color even if they cannot verbally label the objects by color (Soja, 1994). And at around 3 years of age, children show a shift in preference for color over shape when making similarity judgments about geometric figures (Melkman, Koriat, & Pardo, 1976).

There were two goals for the current study. The first goal was to determine whether preschoolers are able to use perceptual color cues in a spatial reasoning task. We tested 3-year-olds in a task adapted from Hood's (1995) spatial reasoning task. An experimenter held a ball above one of three intertwined tubes and asked children to predict where they thought the ball would emerge by placing a cup under one of the tubes to catch it (this general procedure was also used by Joh et al., 2011). However, rather than presenting all participants with three visually identical tubes, we presented some children with visually distinct tubes. The tubes were red, yellow, and blue—primary colors that are easily discriminated by typically developing children. If children are able to learn that the color of the tubes provides hints about where the ball will emerge, then the participants who completed the task with colored tubes on all 12 test trials (All Distinct condition) should outperform the children in a control condition who never received colored tubes (All Identical condition).

The second goal was to assess the generalizability of the color cues—whether children's use of color cues would teach them a useful strategy that could be used to solve the difficult spatial problem even after the color cues were removed. Thus, we presented a third group of children with colored tubes on the first six trials only (Half Distinct/Half Identical condition) to provide them with an initial learning opportunity. On the last six trials, children in this condition solved the problem with three visually identical tubes. This manipulation was motivated by the finding that children were able to acquire a visual tracing strategy after only two trials (Bascandziev & Harris, 2010). If the presence of color cues during the first six trials allows children to learn a general problem solving strategy, then they should continue to make correct predictions even after the removal of the colored tubes on the last six trials. However, if children do not acquire a general problem solving strategy from their initial use of the color cues—for example, if children learn to match the top and bottom of the tubes by color without learning to trace the entire length of a relevant tube—then they should revert to gravity-driven responses on the last six trials.

We tested 3-year-olds between 36 and 42 months of age because previous work showed that at this age most children consistently make gravity-driven responses (Hood, 1995). Thus, if the color cues were useful to the children, then we should see an increase in correct predictions, as well as a corresponding decrease in gravity bias errors, in the children who received the additional perceptual information. In addition to condition-related differences in correct predictions and gravity bias errors, we also examined children's switching behaviors. A previous study showed that children who switched spontaneously—physically tried out different possibilities before committing to a particular response—were more likely to make correct predictions (Joh et al., 2011). In particular, children who were invited to visualize the movement of the ball switched more frequently, as if the prompt led them to question their default gravity-driven assumptions. Therefore, we also assessed switching behaviors to determine whether the presence of color cues and their possible facilitation of a general problem solving strategy encouraged children to try out alternative outcomes before making a prediction.

Methods

Participants

A total of 48 children were tested between 36 and 42 months of age ($M = 39$ months, $SD = 2.15$). Half of the participants were girls and half were boys. All participants were healthy and born at term. Most were from middle-class families from the Raleigh–Durham area of North Carolina in the eastern United States. Participants were White ($n = 40$), African American ($n = 3$), Asian ($n = 1$), and other/unidentified ($n = 4$). An additional 2 children were excluded from the final sample due to parental interference or refusal to complete the test trials. Children received a ball or T-shirt and a photo souvenir from the session for their participation.

Parents of four participants reported a family history of colorblindness, but none reported concerns about colorblindness in their own children. Because children were assigned randomly into the experimental conditions before the test session, one of these children participated in the All Distinct condition. However, it is unlikely that he was unable to perceive distinct colors given that he succeeded on all 12 test trials. The other three children participated in the All Identical condition in which they were not given color cues.

Materials

A large wooden frame (62.5 cm high, 59.1 cm wide, and 8.9 cm deep), containing three openings at the top and three at the bottom, was used during the session (Fig. 1). Each opening was marked by a white plastic "chimney" (5.7 cm in diameter and 6.4 cm long) that allowed tubes to be connected to the apparatus. Three flexible, opaque plastic tubes (each 4.4 cm in diameter and 67.6 cm long) were fitted from a top opening to a bottom one to create a winding pathway for a small Styrofoam ball. One set of tubes was composed of three distinctly colored tubes (red, blue, and yellow). A second set was composed of three visually identical tubes (black with thin dark blue ridges). A small cardboard cup was used to catch the ball.

Procedure

Participants sat in a booster seat facing an experimenter across a table. Participants' parents sat behind their children in the testing room. Parents were asked to encourage their children (e.g., "Good job!") without providing any hints (e.g., "Follow the red tube") or answers (e.g., "Move the cup to the left") about the task. Each session was videotaped for later data coding.

Children were assigned to one of three conditions in which they were presented with distinctly colored tubes on all test trials (All Distinct condition), on only the first half of the trials (Half Distinct/Half Identical condition; received identically colored tubes on the last half of the trials), or on no test trials (All Identical condition; received identically colored tubes on all trials). Each condition was counterbalanced for gender.

Familiarization

Each session began with a familiarization phase to acclimate the participants to each component of the task. First, to demonstrate that the tubes created pathways for the ball, the experimenter placed a single tube horizontally on the table and invited the participants to take turns rolling a ball through it. The experimenter never drew the participants' attention to the color of the tubes during this or any other phase of the experiment.

Next, the experimenter taught the children to use the cardboard cup to make a prediction. After removing the single tube from the table, she handed the cup to the children, held a ball over it, and told them that the cup is used to catch the ball, emphasizing that she could not release the ball until the children said that they were "ready". Children practiced catching the ball with the cup after saying that they were ready.

Finally, the experimenter introduced the different configurations of the tubes in the frame. She placed the wooden frame on the table, pointed to each of the six openings in the frame, and explained that the openings, tubes, cup, and ball are used together. After connecting a single tube from the top left opening to the bottom right opening, the experimenter held a ball over the top opening and asked the children to make a prediction by placing the cup under the bottom opening from which they expected the ball to emerge. To reinforce the prediction task, the experimenter released the ball only after the children said that they were ready. To acclimate the participants to the different possible tube configurations, the experimenter repeated the same single-tube familiarization two more times, once with the tube connected to the top middle and bottom left openings and once with the tube connected to the top right and bottom middle openings.

Test trials

Immediately following the familiarization phase, the experimenter fitted all three tubes into the frame, handed the cup to the participants, held a ball over a predetermined top opening, and invited the participants to predict the landing location of the ball by placing the cup beneath it. As in the familiarization phase, the experimenter released the ball only after the participants made a prediction by placing the cup under an opening and indicated that they were ready.

All participants received 12 test trials. In the All Identical and All Distinct conditions, the same set of tubes was used during all test trials (a set of black tubes for the All Identical condition; a set of red, blue, and yellow tubes for the All Distinct condition). In the Half Distinct/Half Identical condition, the red, blue, and yellow tubes were used during the first 6 trials and the black tubes were used during the last 6 trials. In this condition, the experimenter quickly switched the tubes after the first 6 trials without drawing the participants' attention to the change in the apparatus and immediately continued with the test trials. In all conditions, to prevent children from forming associations between specific ball-drop and ball-landing locations, the apparatus was rotated 180° after each trial.

Data coding

A primary coder scored each trial from video using MacSHAPA, a computerized behavioral coding software program (Sanderson et al., 1994). Each prediction was scored as either a *correct prediction* (participant held the cup under the opening from which the ball emerged), a *gravity bias error* (participant held the cup under the opening directly beneath the location where the ball was dropped), or a *miscellaneous error* (participant held the cup under the remaining opening). The coder also noted the number of switches, if any, that occurred before the children made their predictions. A switch was defined as initially holding the cup under an opening for at least 2 s, without the participant indicating that he or she was ready, before moving it to a different location. For example, if a participant initially held the cup under the left opening for at least 2 s and then moved it to the middle opening before finally saying "ready," then his or her prediction was coded as the middle opening with one switch.

A second coder independently scored 33% of all trials for reliability. Coder agreement ranged from 99.5 to 100% of trials for the categorical variables (κ = .99–1.00). The correlation coefficient for the number of switches was .98. Disagreements were resolved through discussion.

Results

Patterns of predictions

Overall, participants rarely made miscellaneous errors ($M = 0.90$ of 12 trials, $SD = 1.55$). Instead, they were more likely to make correct predictions ($M = 6.46$, $SD = 4.13$) or gravity bias errors ($M = 4.65$, $SD = 3.86$). Thus, subsequent analyses focused on correct predictions and gravity bias errors.

A 3 (Condition) × 2 (Prediction Type: correct or gravity bias) repeated-measures analysis of variance (ANOVA) revealed condition-related differences in prediction patterns. The ANOVA confirmed a trend for prediction type, $F(1,45) = 3.44$, $p = .07$, $\eta_p^2 = .07$, and yielded a significant interaction between condition and prediction type, $F(2,45) = 8.95$, $p < .01$, $\eta_p^2 = .29$. The interaction was due to the fact that in the All Distinct condition, children made more correct predictions ($M = 9.06$, $SD = 3.43$) than gravity bias errors ($M = 1.88$, $SD = 1.96$) ($p < .01$). In contrast, in the Half Distinct/Half Identical condition, children made an equal number of correct predictions ($M = 6.19$, $SD = 3.80$) and gravity bias errors ($M = 5.06$, $SD = 3.49$) ($p = .54$). In the All Identical condition, children appeared to make more gravity bias errors ($M = 7.00$, $SD = 4.03$) than correct predictions ($M = 4.13$, $SD = 3.74$), but the difference did not approach significance ($p = .15$). As shown in Fig. 2, such condition-related differences also existed at the level of individual participants, $\chi^2(2, N = 48) = 12.70$, $p < .01$. In the All Distinct condition, 14 of 16 participants made more correct predictions than gravity bias errors. However, in the Half

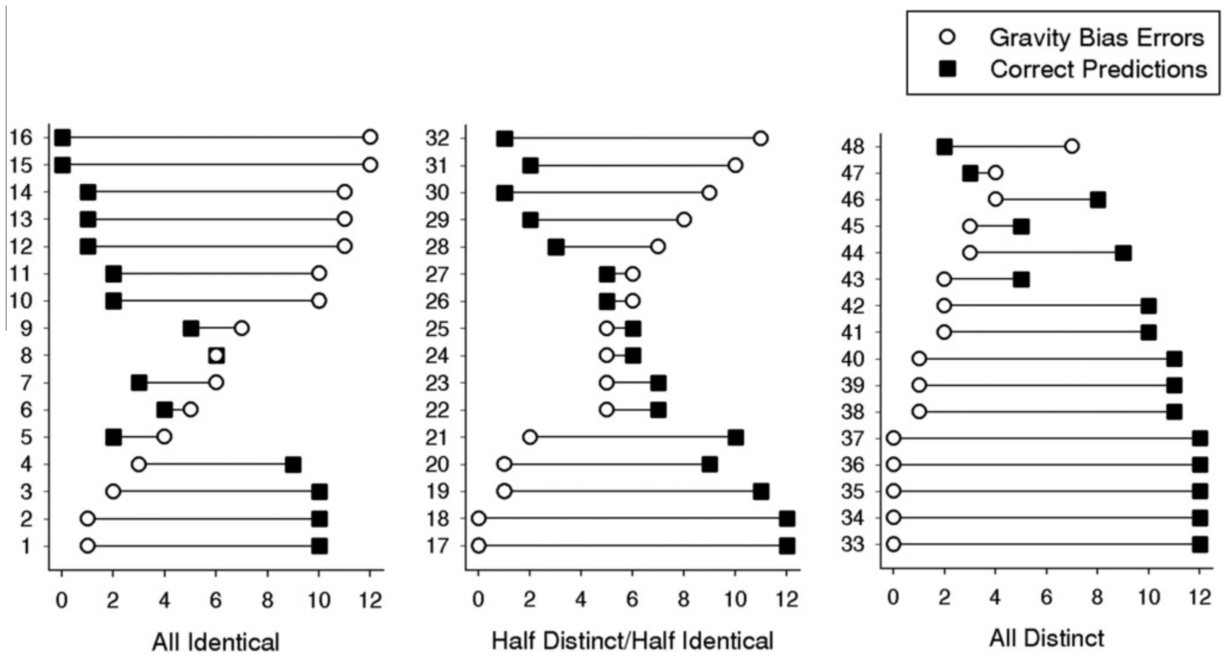

Fig. 2. The numbers of correct predictions and gravity bias errors made by individual participants are shown. The *y* axis represents participant numbers; each pair of symbols represents predictions made by one participant. The participant numbers correspond to those used in Table 1. The *x* axis represents the numbers of trials in which participants made each type of response; correct predictions (filled squares) appearing to the right of gravity bias errors (open circles) show that the participants made more correct predictions than errors, whereas the reverse pattern shows that the participants made more gravity bias errors than correct predictions.

Table 1
Numbers of correct predictions, gravity bias errors, and miscellaneous errors, respectively, made by individual participants during Block 1 (Trials 1–6) and Block 2 (Trials 7–12).

All Identical			Half Distinct/Half Identical			All Distinct		
P#	Block 1	Block 2	P#	Block 1	Block 2	P#	Block 1	Block 2
1	5, 0, 1	5, 1, 0	17	6, 0, 0	6, 0, 0	33	6, 0, 0	6, 0, 0
2	4, 1, 0	6, 0, 0	18	6, 0, 0	6, 0, 0	34	6, 0, 0	6, 0, 0
3	5, 1, 0	5, 1, 0	19	6, 0, 0	5, 1, 0	35	6, 0, 0	6, 0, 0
4	3, 3, 0	6, 0, 0	20	6, 0, 0	3, 1, 2	36	6, 0, 0	6, 0, 0
5	1, 3, 2	1, 1, 4	21	6, 0, 0	4, 2, 0	37	6, 0, 0	6, 0, 0
6	4, 2, 0	0, 3, 3	22	6, 0, 0	1, 5, 0	38	5, 1, 0	6, 0, 0
7	1, 3, 2	2, 3, 1	23	2, 4, 0	5, 1, 0	39	5, 1, 0	6, 0, 0
8	2, 4, 0	4, 2, 0	24	4, 2, 0	2, 3, 1	40	6, 0, 0	5, 1, 0
9	0, 6, 0	5, 1, 0	25	4, 2, 0	2, 3, 1	41	4, 2, 0	6, 0, 0
10	1, 5, 0	1, 5, 0	26	3, 3, 0	2, 3, 1	42	4, 2, 0	6, 0, 0
11	1, 5, 0	1, 5, 0	27	4, 2, 0	1, 4, 1	43	4, 1, 1	1, 1, 4
12	0, 6, 0	1, 5, 0	28	1, 4, 1	2, 3, 1	44	5, 1, 0	4, 2, 0
13	1, 5, 0	0, 6, 0	29	2, 3, 1	0, 5, 1	45	3, 2, 1	2, 1, 3
14	0, 6, 0	1, 5, 0	30	1, 3, 2	0, 6, 0	46	2, 4, 0	6, 0, 0
15	0, 6, 0	0, 6, 0	31	0, 6, 0	2, 4, 0	47	2, 1, 3	1, 3, 2
16	0, 6, 0	0, 6, 0	32	1, 5, 0	0, 6, 0	48	1, 3, 2	1, 4, 1

Note: Each participant number (P#) corresponds to that used in Fig. 2.

Distinct/Half Identical and All Identical conditions, only 9 and 4 children, respectively, made more correct predictions than gravity bias errors. Further individual data are shown in Table 1.

Because there were three possible prediction locations (left, middle, and right) on each of the 12 test trials, children were deemed to be performing better than expected by chance if they made 8 or more correct predictions during the session (binomial $p < .05$). We also found condition-related differences on the number of children performing better than chance, $\chi^2(2, N = 48) = 9.65$, $p < .01$. As shown in Fig. 2, in the All Distinct condition, 12 of 16 participants (75.0%) performed above chance. However, in the Half Distinct/Half Identical and All Identical conditions, only 5 (31.3%) and 4 (25.0%) participants, respectively, performed above chance.

Color cues and correct predictions

The color cues influenced children's behaviors from the start of the session. On the first trial, 9 of 16 children (56.3%) in the All Distinct condition and 7 of 16 children (43.8%) in the Half Distinct/Half Identical condition overcame the gravity bias to make a correct prediction. In comparison, only 3 of 16 children (18.8%) in the All Identical condition were able to do so.

To examine the influence of color cues on children's problem solving abilities across trials, we separated the 12 test trials into two blocks (Block 1: Trials 1–6; Block 2: Trials 7–12) and analyzed the number of correct predictions with a 3 (Condition) × 2 (Sex) × 2 (Block) repeated-measures ANOVA. The ANOVA yielded a main effect for condition, $F(2,42) = 7.45$, $p < .01$, $\eta_p^2 = .26$, a marginal effect for sex, $F(1,42) = 3.33$, $p = .08$, $\eta_p^2 = .07$, and a Condition × Block interaction, $F(2,42) = 3.57$, $p = .04$, $\eta_p^2 = .15$. The main effect for condition was due to more correct predictions in the All Distinct condition than in the Half Distinct/Half Identical and All Identical conditions (*ps* < .03); there were no differences between the Half Distinct/Half Identical and All Identical conditions ($p = .13$). The trend for sex was due to the boys ($M = 7.42$, $SD = 4.19$) making more correct predictions than the girls ($M = 5.50$, $SD = 3.91$). Similar sex differences were also reported by Hood (1995).

To better understand the condition by block interaction, we performed separate one-way ANOVAs for each block (Fig. 3 and Table 1). For the first block, the ANOVA confirmed significant differences between conditions, $F(2,45) = 8.21$, $p < .01$, $\eta_p^2 = .27$. This effect was due to the children in the All Distinct condition ($M = 4.44$ of the first 6 trials, $SD = 1.67$) and the Half Distinct/Half Identical condition ($M = 3.63$, $SD = 2.22$) making more correct predictions than the children in the All Identical condition ($M = 1.75$, $SD = 1.84$) (*ps* < .02). During this block, children in the Half Distinct/Half Identical condition

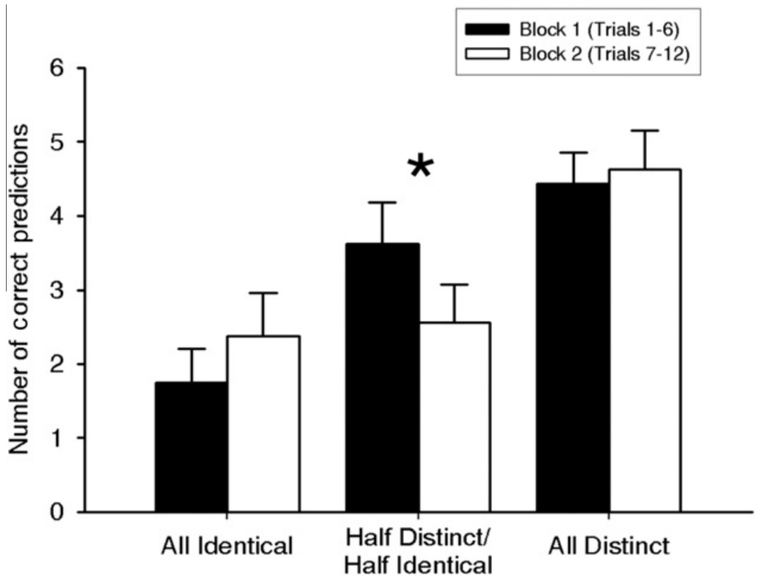

Fig. 3. Mean numbers of correct predictions by condition and block. Error bars represent mean standard errors. The number of correct predictions did not change across the two blocks in the All Identical and All Distinct conditions, but they decreased in the Half Distinct/Half Identical condition. $^{*}p < .05$.

succeeded equally as often as those in the All Distinct condition ($p = .46$). For the second block, the ANOVA also produced a significant effect for condition, $F(2,42) = 5.31$, $p < .01$, $\eta_p^2 = .19$. However, this effect was due to the children in the All Distinct condition ($M = 4.63$ of the last 6 trials, $SD = 2.09$) making more correct predictions than those in both the Half Distinct/Half Identical condition ($M = 2.56$, $SD = 2.06$) ($p = .03$) and All Identical condition ($M = 2.38$, $SD = 2.33$) ($p = .01$). During this block, children in the Half Distinct/Half Identical condition performed more like those in the All Identical condition ($p = .97$). Paired *t* tests confirmed that the number of correct predictions decreased from Block 1 to Block 2 in the Half Distinct/Half Identical condition ($p < .05$) but remained unchanged in the All Distinct and All Identical conditions (*p*s > .21).

Based on these findings, we next examined how quickly the children in the Half Distinct/Half Identical condition reverted to making gravity bias errors by comparing their performance on Trial 6 (the last trial before the colored tubes were replaced with the identical tubes) with their performance on Trial 7 (the first trial after the tubes were replaced). A paired *t* test showed that the decrease in performance occurred immediately after the switching of the tubes, $t(15) = 2.42$, $p = .03$, $d = 0.79$; whereas 62.5% of children made a correct prediction on Trial 6, only 25.0% did so on Trial 7.

Switching and correct predictions

Overall, participants did not switch frequently in the current study. Across conditions, they switched on 83 of 576 total trials (14.4%), and only one participant switched more than once on a single trial during the test session. Thus, the total number of trials with switches was 83, and the total number of switches was 84.

Despite the low frequency of switching, however, a 3 (Condition) × 2 (Sex) × 2 (Block) repeated-measures ANOVA on the number of switches revealed significant main effects of sex, $F(1,42) = 5.89$, $p = .02$, $\eta_p^2 = .12$, and block, $F(1,42) = 4.76$, $p = .04$, $\eta_p^2 = .10$. These results were due to boys ($M = 0.19$, $SD = 0.16$) switching more frequently than girls ($M = 0.10$, $SD = 0.12$) and to children switching more during the first block ($M = 0.18$, $SD = 0.21$) than the second block ($M = 0.11$, $SD = 0.15$). In addition, the ANOVA showed a marginal effect for condition, $F(2,42) = 2.79$, $p = .07$, $\eta_p^2 = .12$, which was due to more switches in the All Identical condition ($M = 0.21$, $SD = 0.19$) compared with the Half Distinct/Half Identical condition ($M = 0.09$, $SD = 0.10$) ($p = .06$). No differences were found between the All Identical and All Distinct conditions ($M = 0.14$, $SD = 0.12$) ($p = .31$) or between the All Distinct and Half Distinct/Half Identical conditions ($p = .68$).

Table 2
Numbers of switches made after children made an initially incorrect choice and their effect on predictions.

	All Identical	Half Distinct/Half Identical	All Distinct
Initially correct choice	34	88	132
Initially incorrect choice	158	104	60
No switch	119	87	40
Switch	39	17	20
Switch to incorrect prediction	7	5	1
Switch to correct prediction	32	12	19
Total correct predictions[a]	66	99	145

Note: The total number of trials was 192 for each condition (12 trials per participant, 16 participants per condition).
[a] On rare occasions, children switched from an initially correct choice to an incorrect prediction (1 trial in the Half Distinct/Half Identical condition and 6 trials in the All Distinct condition). These switches are reflected in the number of initially correct choices and total correct predictions.

In addition, although infrequent, when children did consider alternative possibilities, they were more likely to make a correct prediction (Table 2). Across conditions, 75.9% of switches (63/83 overall switch trials) resulted in a correct prediction; the remaining switches resulted in gravity bias or miscellaneous errors. Switching appeared to benefit those who needed it most—children in the All Identical condition who were not aided by the color cues. When children in the All Identical condition switched, they made a correct prediction on 82.1% of trials (32/39 switch trials). In contrast, when they did not switch, they made a correct prediction on 22.2% of trials (34/153 no-switch trials). Children in the Half Distinct/Half Identical condition also appeared to benefit from switching, albeit not as dramatically as children in the All Identical condition: they made a correct prediction on 66.7% (12/18) of switch trials and 50.0% (87/174) of no-switch trials. Children in the All Distinct condition did not need to switch to succeed: they made a correct prediction on 73.1% (19/26) and 75.9% (126/166) of switch and no-switch trials, respectively.

Discussion

The goal of this study was to examine preschoolers' use of color cues during a difficult spatial reasoning task and to determine whether their use of the cues could lead to the acquisition of an effective problem solving strategy. We focused on color cues because they are a type of perceptual information that is inherent in spatial problems but is not inherently spatial in nature. Moreover, previous studies have shown that children learn early in development that color cues can be used to solve a variety of problems and become adept at using them by approximately 2 years of age (Bushnell et al., 1995; DeLoache, 1986).

We found that young children benefited from the presence of additional color cues in a difficult spatial task. The only procedural difference between the All Identical and All Distinct conditions was the color of the tubes during the test trials. Unlike in previous studies using the same task, none of the children in the current study were provided with explicit verbal hints about the task, strategies, or solutions. Yet, the children in the All Distinct condition made twice as many correct predictions—and, correspondingly, fewer gravity bias errors—than their peers in the All Identical condition. In fact, the color cues were so helpful that the children in the All Distinct condition appeared to succeed more often than the children in a previous study who were told to use a visual imagery strategy before every test trial (*M*s = 75.5% vs. 60.4% of trials in color cues and visual imagery conditions, respectively) (Joh et al., 2011). It appears, then, that color cues provide useful perceptual information to preschoolers engaged in a difficult spatial problem.

We also found, however, that children's use of color cues was not without limits. Children reverted back to gravity-driven responses when the color cues were removed, indicating that this type of perceptual information is most useful when it is present during the task and does not appear to cause lasting changes in children's spatial cognition. During the first six trials, the performance of children in the Half Distinct/Half Identical condition was similar to that of children in the All Distinct condition.

During the last six trials, however, the performance of children in the Half Distinct/Half Identical condition was virtually indistinguishable from that of children in the All Identical condition. In fact, on Trial 6, 10 children (62.5%) in the Half Distinct/Half Identical condition made a correct prediction. However, on Trial 7, only 4 children (25.0%) were able to do the same, suggesting that any gains that were made in the presence of color cues disappeared as soon as the cues were removed. These findings strongly suggest that the presence of color cues allowed children to determine the answers to the spatial problems without learning *how* to solve the problem. That is, children learned to keep track of the color of the tube into which the ball was dropped so that they could place the cup under the tube of the same color, but they did so without learning to *trace* the path of the tube of a particular color—mentally, visually, or physically—to predict the movement of the ball. Children appeared to have learned a solution by color-matching the top and bottom portions of the tube (e.g., "Pick the bottom opening connected to the red tube because the ball was dropped into a top opening connected to the same tube") without learning a generalizable problem solving strategy (e.g., "Follow the path of the red tube because the ball was dropped into the opening connected to the red tube").

Why were the participants unable to extract a more general problem solving strategy from their use of the color cues even after six trials of experience with the color cues? This is a puzzling question, particularly in light of previous findings that children could acquire an effective visual tracing strategy after only two trials (Bascandziev & Harris, 2010). One factor that does not appear to be critical is the manner in which the additional perceptual information was delivered to the participants. That is, children did not fail to acquire a problem solving strategy because we did not instruct them to use the color cues. Although in some previous studies children were given explicit verbal prompts about strategies or answers (Bascandziev & Harris, 2010; Jaswal, 2010; Joh et al., 2011), other work showed that such instructions are unnecessary for successful performance. For example, when Bascandziev and Harris (2011) removed the "chimney" covering the tubes from the apparatus, they did so without telling the children that the purpose of the removal was to help the children learn about the tube mechanism so that they could succeed in the task. Regardless, children were able to learn to avoid gravity bias errors. These results provide strong evidence that young children are able to spontaneously pick up and use visual information relevant to a spatial problem.

More likely, then, the nature of the available perceptual information prevented the children from acquiring a more general problem solving strategy. Color cues are useful and abundant for spatial events, but for everyday occasions they tend to co-occur with other kinds of information such as location. For example, we interpret two white lines to be a crosswalk when the lines are painted on the street and are parallel to each other, whereas two white lines painted on the playground might be construed in a different way. In addition, color cues are not invariant: different colors may signal the same event, and the same colors are informative for different events. For maximum visibility, a crosswalk may be painted white, yellow, or even red, depending on the color and texture of the ground. Finally, despite their familiarity and usefulness, color cues do not provide the most relevant information for spatial problems. Typically, the color of the path is not what makes it intrinsically dangerous; it is the color of the path in relation to other surrounding locations and events that can serve as a signal for dangerous ground. In our task, without extrapolation, children could not use the color cues to learn about how the ball travels through the tubes. Therefore, through these types of everyday experiences, children may have learned that color cues are context dependent and can change on a whim and that the children should not depend on them solely to solve novel spatial problems. There is some evidence that supports this notion: children appear to recognize the limits of color cues. Infants initially use color information in concert with other featural information (Needham, 1998; Wilcox, 1999; Wilcox & Baillargeon, 1998; Wilcox & Chapa, 2004), learn color words later in development (Bornstein, 1985; Soja, 1994), and show difficulties with using color-related landmarks to detect dangerous ground locations (Adolph, Joh, & Eppler, 2010; Joh & Adolph, 2006).

In addition, past research has documented a complex relationship between children's use of color cues and performance in problem solving tasks. Although young children are able to use color cues successfully when the task requires them to use the cues in a straightforward manner, they are unable to do so when the task requires extrapolation. For example, 1-year-old infants could find a small toy hidden directly under a green pillow in a large round playpen filled with blue pillows (Bushnell et al., 1995). However, when the color of the pillow became an indirect cue—for example, when the toy was hidden under a blue pillow *next to* the green one—infants failed to find the toy. A different study showed that 2-year-old toddlers could use the color and texture of a container to find a hidden piece of candy (DeLoache, 1986). In fact, they were so successful at using the visual appearance of the containers that they continued to succeed when the containers were used as cues rather than actual locations. When the four visually distinct containers were attached to the top of four visually identical boxes and the candy was hidden inside a box rather than a container, the children still continued to find the candy. However, children failed to find the candy when the boxes (still marked by the containers) were moved to a different location in the same testing room, suggesting that they could not use the color of the container to extrapolate the movement of the hidden candy. Similarly, 2-year-olds who were given color cues about the stopping location of a ball rolling down a ramp performed comparably to children who were not given color cues, attesting to the difficulty of using color information to anticipate the movement of an object (Kloos, Haddad, & Keen, 2006). DeLoache (1986), however, found that older children could use the visually distinct containers as location cues even when they were moved to different locations, showing that children's extrapolation from color cues improves with age.

Participants' switching behaviors also provide insight into the findings regarding the limits of color cues. Children rarely switched before making a prediction, and the absence of switching was especially pronounced in the Half Distinct/Half Identical and All Distinct conditions: these children switched on only 9.4 and 13.5% of trials, respectively. (In comparison, Joh et al. (2011) reported that preschoolers who were instructed to use a visual imagery strategy switched on 33.3% of trials.) This finding suggests that the children were confident with their initial choices, possibly because they could rely simply on the color of the tubes to determine where the ball would emerge. In the Half Distinct/Half Identical condition, children remained confident even after the colored tubes were replaced with visually identical tubes, perhaps because they had succeeded so often during the first half of the trials. In contrast, children in the All Identical condition may have been less certain about their initial choices because they rarely succeeded and were not privy to helpful color cues. As a result, they tended to switch more frequently (20.3% of trials) and appeared to benefit more from switching. Thus, paradoxically, children's success with the color cues may have contributed to their inability to acquire a more general problem solving strategy by increasing their confidence in their ability to make a correct prediction and reducing the need to expend additional effort into learning about the problem. In fact, the outcome of the second trial block for the children in the Half Distinct/Half Identical condition—low rates of switching and low rates of correct predictions—suggests that the salience of the color cues, as well as the ease with which they could use it to succeed, may have taught the children to ignore the spatial component of this problem.

In summary, our findings show that color cues can provide children with an answer, but not a strategy, to a difficult spatial problem. The limits of color cues show that not all types of information are equally useful for problem solving and highlight the complex nature of the development of spatial cognition. With age and experience, developments in children's ability to rely on perceptual cues and use problem solving strategies facilitate their ability to inhibit a prepotent but incorrect response, gradually leading to increasingly sophisticated reasoning about spatial events.

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