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Evidence for “Dumb” Local-to-Global Integration in Children’s Judgments about Motion

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Abstract

We investigated cue use for object movement in preschoolers and adults. Participants’ task was to predict the direction of an object’s motion: whether the object moves across the floor of a room, or whether it floats to the top. While the direction of object motion stayed the same across trials, the types of cues were manipulated to differ along two factors. The factors were (1) spatial proximity (one cue being spatially close to the object, and the other cue being at a distance from the object) and (2) causal relevance (one cue being causally meaningful for the object’s motion, and the other one being causally irrelevant). The results show the following developmental progression: 3-year-olds used only the proximal cue, while 4-year-olds used both proximal and distal cue to judge object motion. However, neither group of children distinguished between causally meaningful and causally meaningless cues. Only adults were able to ignore the meaningless cues. The pattern of findings supports the idea that development progresses from local to global integration of pieces of information, with spatial cues being available more readily than causal relevance. The results undermine a common assumption that young children perform on the basis of domain-specific knowledge only.

Keywords: Cue-use; preschoolers; cognitive development; attentional processes.

Introduction

What is it that develops in a child? After the waning of Piaget’s influence on what it is that might develop, no solid theory has taken its place to answer this question (e.g., Bjorklund, 1997). In fact, the latest handbook on cognitive development (Goswami, 2002) provides no encompassing

theory at all, just a large collection of findings that do not lend themselves to an overarching theory about how development might progress. The problem seems to be that children’s performance differs as a function of the specific content domain that is employed in a task (e.g., Brown, 1990). For example, the same 3-year-old can appear less knowledgeable in an unfamiliar domain, but highly sophisticated in a familiar domain. Clearly, simply attaching particular information-processing competencies to particular age groups does not provide a coherent view of cognitive development.

A viable approach then might be to analyze each content domain separately and map out the development of children’s competencies in each of these content domains (e.g., for a review of such an approach, see Wilkening & Huber, 2002). The guiding assumption is that domain-specific content matters. Children’s performance – successful or unsuccessful – might be based on children’s knowledge about domain-specific, cause-effect relations (e.g., Booth & Waxman, 2002; Corrigan & Denton, 1996; Defeyter & German, 2003; Fiddick, Cosmides, & Tooby, 2000; Gottfried & Gelman, 2005). According to such a knowledge-based approach, children early in life have only simplistic knowledge about how the world works, which is enriched over time via their experiences in the world. In other words, what develops according to this approach is children’s knowledge.

While this knowledge-based approach can provide a coherent pattern of developmental progression, it has an important down-side. Findings show that children’s performance is not only affected by the specific content domain, but also by the precise task context in which a child is asked to act. A good example pertains to tasks that deal with children’s knowledge about solidity, knowledge that

solid objects cannot pass through other solid objects. When tested with a habituation paradigm, even 2.5-month-old infants appear to recognize when the solidity constraint is violated (e.g., Spelke, Breinlinger, Macomber, & Jacobson, 1992). But when tested with a search task, 2-year-old toddlers do not show knowledge about solidity (e.g., Berthier, DeBlois, Poirier, Novak, & Clifton, 2000).

Strong context dependence is, of course, not limited to solidity tasks. Quite the opposite is the case. Context-dependent performance is the rule, not the exception, in developmental psychology (e.g., Elman, Bates, Johnson, Karmiloff-Smith, Parisi, & Plunkett, 1999; Gigerenzer & Richter, 1990). The mere configurations of stimuli will affect how much ‘knowledge’ children seem to have (for a discussion, see Kloos & Van Orden, in press). This makes it difficult to frame development in terms of amount of knowledge. A developmental theory needs to explain both immediate context dependence as well as gradual progression across age.

Alternative Approach

The current study tests an alternative approach, one that is not tied to age-related domain-general competencies proposed by traditional information-processing theories, nor does it require new knowledge-based competencies for each specific task context. The approach is based (1) on recent insights about children’s ‘dumb’ attentional processes, and (2) on research on children’s propensity to interconnect pieces of information. First, attentional processes controlled by the immediate context are strongly predictive of children’s performance, independently of causal relevance (e.g., Amsel & Brock, 1996; Smith, Jones, & Landau, 1996; French, Mareschal, Mermillod, & Quinn, 2004; Sloutsky, 2003). Children quickly detect correlational patterns in the immediate task context and make use of it in their performance. Second, children (and adults) are prone to link pieces of information into an integrated whole, into a good Gestalt so to speak, and to ignore pieces of information that do not fit that larger organization (e.g., Franz, 2001; Kloos, 2007; Thagart, 2000). Such integration seems to happen automatically, seemingly without effort and without being explicitly elicited.

These advancements suggest a view of development that centers around developing processes of attention and integration, not on processes of knowledge improvement. Early in a child’s life, attentional processes of integration make use of local perceptual correspondences (i.e. links between stimuli that are close to one another in space and time), followed by more global correspondences (i.e. links between stimuli that have a greater separation in space and time), and then causal domain-specific correspondence (i.e. links between stimuli that are based on cause-effect relations). This developmental progression of attention in terms of gradually expanding the number of interconnected pieces of information is domain-general; The same processes can explain differences observed across ages, as well as differences observed between adult novices and experts (e. g.,

Chi, Feltovich, & Glaser, 1981). Furthermore, the attention-integration approach can explain high context sensitivity because attention is controlled by the immediate structure of the task context. Differences in performance (such as those described above around the concept of solidity) might therefore be due to differences in structural properties of the task, rather than due to knowledge-based components of the mind.

The current study aims to provide evidence for this alternative approach. The specific questions pertain to (1) the degree to which children integrate pieces of information locally, then gradually towards more global information, and (2) whether children prefer to rely on perceptual correspondences over knowledge about a domain.

Cue Use in Judgment about Motion

To answer these questions, we looked at cue use in preschool children and adults. Cue-use tasks are ideal for the current purposes, for three reasons. First, any change in performance as a function of a change in the cues demonstrates the process of spontaneous integration. This is because cues are separate from the target object, and cues are not emphasized during instructions. Second, distance between cue and target can be manipulated systematically to investigate the developmental progression of local-to-global integration. We predict that children first integrate the proximal cue, and only later the more distal cue. And third, the causal relevance of a cue can be manipulated systematically to assess the importance of domain-specific knowledge in participants’ performance.

The specific domain used in this study involves judging the direction of an object’s motion as a function of the shadow’s motions. This domain was investigated before with adults (e.g., Kersten, Mamassian, & Krill, 1997) and is illustrated schematically in Figure 1.

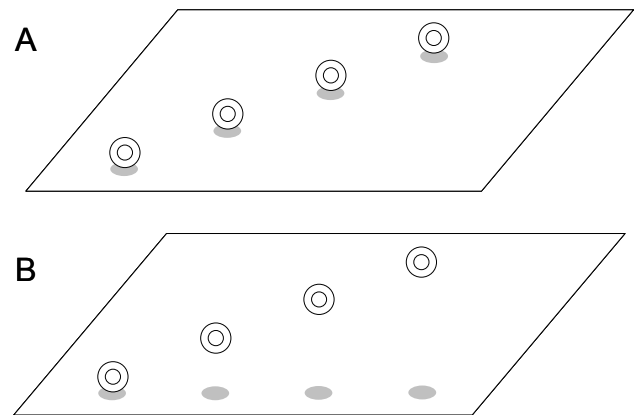


Figure 1: Schematic representation of the shadow effect. The bull-eyes represent a target moving diagonally across a surface, and the gray ellipses represent the shadow moving either parallel with the target (A) or at an angle (B).

A target moves diagonally across a surface, and the task is to judge the direction of its motion. The motion of a shadow

is added to the display. In one case, the shadow is close to the object and moves parallel with the object (Panel A: proximal cue); and in the other case, the shadow moves horizontally at an angle from the object (Panel B: distal cue). Results show that adults judge an object to move on the ground when the shadow moves close to the object; and they judge the same diagonal motion of the target object to be floating off the ground when the shadow moves at an angle. In other words, adults judged the direction of the object differently depending on the distance between the object and the shadow cue.

Note that the motion of a shadow is a causally appropriate cue to the motion of the object that casts the shadow. For an object that moves on the ground, its shadow is indeed close to the object; and for an object that moves above the ground, suspended in air, its shadow is at a distance. Of course, if the “shadow” was a distinct object with features that do not match the target object, then the “shadow” would be a causally inappropriate cue for indicating the movement of the target object. For example, if the grey ellipse in Figure 1 would be replaced by a picture of a mouse, the same motion would be meaningless to the motion of the target object. Whether the mouse moves in parallel with the target object or at an angle, it would not affect whether the target object moves on the ground or suspended in air.

Of course, shadows are not foreign to young children. Children are likely to have extensive experience with shadows, they know the word *shadow*, and even infants can link the motion of an object with the motion of a shadow, whether the display involves 3D real-life projections (e.g., Van de Walle, Rubenstein, & Spelke, 1998) or 2D computer animations (e.g., Yonas & Granrud, 2006). If performance is merely a function of such domain-specific knowledge, even the youngest children should be able to ignore causally irrelevant cues. If on the other hand, performance is driven by attentional processes of integration, participants have to engage in deliberate ignoring of causally irrelevant pieces of information, a process that develops relatively late (cf., Kloos & Sloutsky, in press).

Overview

Two goals were pursued in the current study: (1) to test whether children’s use of a cue for object movement progresses from using local to more global information, and (2) to test the degree to which causal relevance plays a role in children’s judgments. The task was to predict the direction of an object’s motion: whether the object moves across the floor of a room, or whether it floats to the top of the room. As was done in Kersten et al. (1997), the direction of the object stayed the same across trials, with only the feature of the shadow cue changing across conditions.

To test whether using a proximal cue happens developmentally earlier than using a distal cue, the cue could move either parallel with the target or away from the target. To test whether perceptual correspondence (either local or global) is used more readily in making judgments than causal information, the cue was either the causally appropriate shadow or the causally inappropriate mouse. The resulting 2 X 2 design (perceptual proximity by causal relevance) was

used with preschool children between 3 and 4 years of age and adults.

If development is a matter of local-to-global integration in the immediate context, the youngest children should be more likely to use the proximal cue (the shadow cue that moves in close proximity of the target object) than the distal cue (the shadow cue that moves at an angle from the target object), and older children should use both proximal and distal shadow cues. Conversely, if children base their judgment on domain-specific knowledge about shadows, they should distinguish early on between causally relevant and causally irrelevant displays. Clearly, even the youngest children tested in this study can distinguish between a shadow and a mouse.

Method

Participants

Children were recruited from suburban middleclass preschools, and adults were recruited from the subject pool of Introduction to Psychology classes. Adults received course credit in return for their participation. The final sample consisted of 21 3-year-olds (14 girls and 7 boys; mean age: 42.8 months, SD = 2.6 months), 25 4-year-olds (12 girls and 13 boys; mean age: 53.9 months, SD = 2.7 months), and 32 adults (19 women and 13 men; mean age: 19.9 years, SD = 2 years). One additional adult was tested and omitted from the sample because of distraction.

Visual Displays

Kersten et al.’s (1997) ball-in-the-box display was modified to fit a child-friendly cover story. The ‘box’ was a barn that housed two animals, a chicken and a duck. One of the animals sat in the lower back corner of the barn, and the other animal sat in the front top corner of the barn. Figure 2 shows an example of the display. The ‘ball’ was an egg that moved from one end of the barn to the other (see Figure 2). The task was to determine whether an egg belonged to the chicken or to the duck. If an egg moved toward the chicken, it belonged to the chicken, and if it moved toward the duck, it belonged to the duck.

The direction of egg’s motion stayed the same across trials. What changed was the cue that informed about the direction of the egg’s motion. In the *Shadow* condition, the egg had a shadow rolling with it. The shadow moved either in parallel with the egg (giving the appearance that the egg rolled diagonally along the floor of the barn), or it moved at an angle from the egg (giving the appearance that the egg floated to the top of the barn). In the *Mouse* condition, the shadow was replaced by a colorful picture of a mouse that had the same size as the shadow. Children could clearly recognize the mouse and made reference to it repeatedly. The motion of the mouse was identical to that of the shadow: it either moved in parallel with the egg (proximal cue), or at an angle to the egg (distal cue).

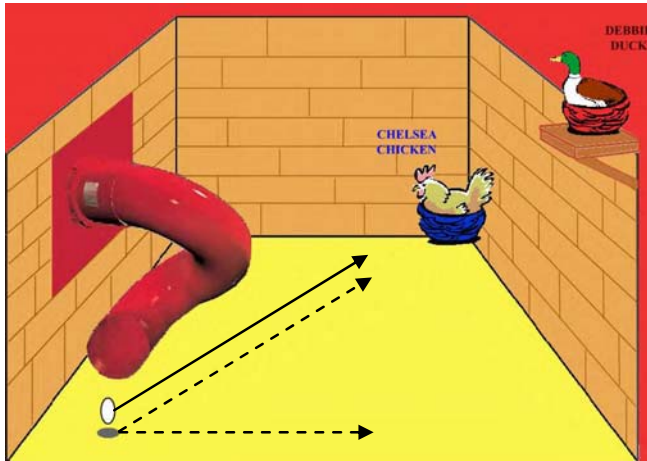


Figure 2: Schematic representation of the display used in the shadow condition. The arrows indicate the motion of the egg (solid arrow) and shadow (dashed arrow). The egg moved diagonally, and the shadow moved either parallel with the egg, or away from the egg.

Procedure

The experiment was administered on a computer and controlled by Presentation 9.90 software. Participants were tested in a quiet room (either in their preschool or in the lab) by female hypothesis-blind experimenters.

The cover story involved a farmer named Fred who owns the chicken Chelsea and the duck Debbie. On sunny days, these two birds are outside the barn, where they also lay their eggs. At the end of the day, Farmer Fred collects all the eggs in a basket and puts them through a tube at the left side of the barn. After an egg rolls through the tube and arrives in the front bottom corner of the barn, the egg starts moving diagonally. The task is to determine whether the egg moves toward Chelsea, in which case it is Chelsea’s egg, or whether the egg moves toward Debbie, in which case it is Debbie’s egg.

The procedure started with two warm-up trials in which participants were familiarized with the task. They were presented with a ‘view-from-above’ picture of the barn, in which the two birds sat in opposite corners of one end of the barn, and the egg rolled from the other end either toward Chelsea or Debbie. All participants performed correctly on these warm-up trials, indicating that they understood the task instructions.

Testing trials started immediately after the warm-up trials. They consisted of 16 shadow trials (where the egg is followed by a shadow), and 16 mouse trials (where the egg is followed by a mouse). The order of trials was blocked by trial type with some participants starting with shadow trials, and the other participants starting with the mouse trials. Within each set of 16 trials, the cue (shadow or mouse) moved in parallel with the egg (8 trials), or at an angle to the egg (8 trials). Once the participant judged whether the egg belonged to

Chelsea or Debbie, no feedback was provided, and a new trial started.

Results and Discussion

The following scoring scheme was applied to participants’ responses: if the cue moved parallel with the object, the *correct* response was to judge that the egg moved across the floor to the back corner of the barn. If the cue moved at an angle to the object, the *correct* response was to judge that the egg moved to the top of the barn. Note that neither of these judgments are correct when the cue is the causally irrelevant mouse.

Performance during shadow trials is likely to reflect participants’ baseline performance of using the cue in the task. Participants who pay attention to causal relevance of the cue are expected to show a drop in performance for mouse trials.

Each participant obtained four proportion-correct scores, two scores that reflect their performance on shadow trials (when the shadow moved parallel and at an angle to the egg), and two scores that reflect their performance on mouse trials (when the mouse moved parallel and at an angle to the egg).

The first analysis pertained to whether children could distinguish between the causally relevant shadow trials and the causally irrelevant mouse trials. Accuracy scores were calculated for each participant on the basis of hits on proximal-cue trials and false alarms on distal-cue trials. An accuracy score of zero is expected by chance alone. Preliminary results indicated no significant difference in accuracy as a function of order with all independent-sample *t*s < 1. Participants’ accuracy scores were therefore collapsed across block order.

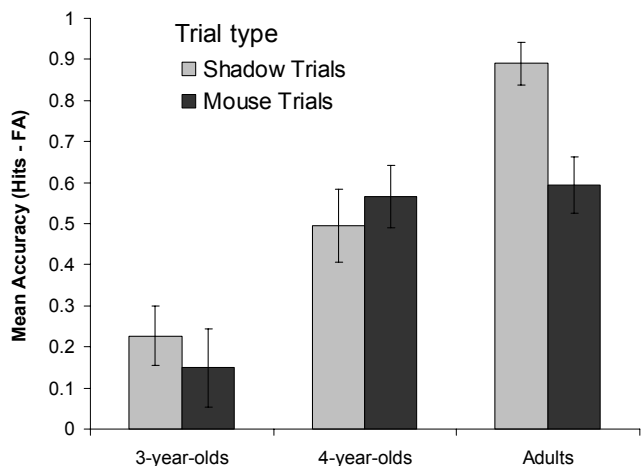


Figure 3: Mean accuracy of participants’ performance as a function of age and trial type. Chance performance is at zero. Error bars represent standard errors.

Figure 3 shows the mean accuracy scores as a function of trial type (shadow trials vs. mouse trials) and age (3-year-olds, 4-year-olds, and adults). A 2 x 3 mixed-design ANOVA

was conducted, with trial type as the within-subjects factor and age as the between-subjects factor. The most important finding was a significant age x trial type interaction ($F(2,75) = 6.7, p < 0.01$). While 3- and 4-year-olds did not perform differently as a function of trial type (paired-sample t s < 1), adults had higher accuracy scores on shadow trials ($M = 0.89$) than on mouse trials ($M = 0.59$), paired-sample $t(31) = 4.2, p < 0.01$. This indicates that adults, but not children, could ignore the causally irrelevant cue. Even though, if considering mouse trials alone, 4-year-olds performed on the same level as adults, only adults showed a discrepancy in performance across trial type.

Another interesting finding was a significant effect of age ($F(2,75) = 19.0, p < 0.01$), with adults performing better than 4-year-olds, and 4-year-olds performing better than 3-year-olds; independent-sample t s $> 4.2, p < 0.03$. This indicates a linear developmental progression of children's ability to integrate the cue with the target objects. Importantly, given that a sizable progression happened already within one year of age (between 3- and 4-year-olds), it is likely that a progression of similar magnitude might happen between 4 and 5-year-olds.

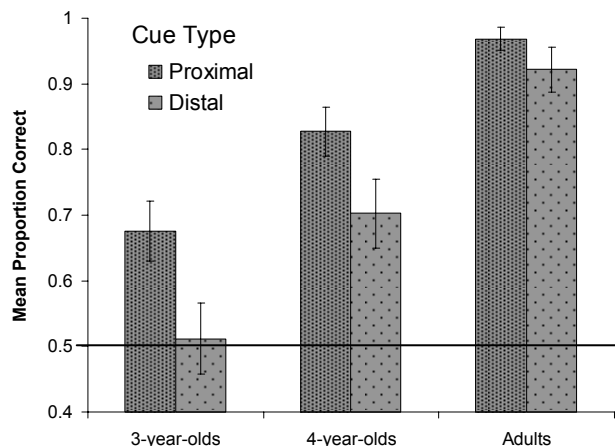


Figure 4: Mean proportion of correct performance as a function of age and motion type. Chance performance is at 0.5. Error bars represent standard errors.

Are children more likely to use the proximal than the distal cue? To answer this question, we looked at children's performance on trials where the cue moved parallel to the egg (proximal cue) vs. trials where the cue moved at an angle to the egg (distal cue). Recall that children could either perform correctly or incorrectly; thus, the chance performance is $p = 0.5$. Figure 4 shows the mean proportion of correct responses as a function of cue type and age. Given that no difference was found for children across trial type (shadow vs. mouse), children's scores were collapsed across trial type. Adults' scores from the shadow condition are added for comparison.

A 2 X 3 mixed-design ANOVA (with cue type as the within-subjects factor and age as the between-subjects factor) revealed a significant age x cue interaction ($F(2,75) = 4.4, p < 0.01$). While 3-year-olds performed above chance only on proximal-cue trials (single-sample $t(20) = 4.2, p < 0.03, M = .63$), 4-year-olds performed above chance on both the proximal-cue trials and the distal-cue trials (single-sample t s $(24) > 5.4, p$ s $< 0.02, M_{\text{Shadow}} = 0.83, M_{\text{Mouse}} = 0.74$). The same pattern of age differences was found when only shadow trials were considered. As Figure 4 shows, the discrepancy in performance between the different types of cues decreased gradually across development, with a significant difference in 3-year-olds' performance (paired-sample $t(20) = 5.5, p < 0.03$), an only marginally significant difference in 4-year-olds' performance (paired-sample $t(24) = 4.2, p < 0.06$), and no significant difference in adults' performance (paired-sample $t < 1$). This suggests that, while 3-year-olds could make use of the proximal motion cue, only 4-year-olds could make use of the both the proximal and distal cues to motion. It is not until later that children can use both cues equally well.

An alternative interpretation needs to be considered for the 3-year-olds, however. It is possible that the youngest children in our study ignored the motions of target and cue altogether and considered only the static display after the egg came to a halt. Note that in the final frame, the egg was closer to the chicken than to the duck. In proximal-cue trials, the cue-object pair might have focused children's attention to the spatially close destination (the chicken), leading children to pick the chicken more frequently than the duck. Conversely, in the distal-cue trials, the cue might have acted as a distractor, yielding chance performance in the youngest age group. To rule out the possibility of these even more limited attentional processes (ones that fail to integrate motion), it would be necessary to create a display that lacks a destination marker. Rather than asking children about the destination of a moving target (bottom back corner vs. top front corner), it would be necessary to ask children about the mode of motion (rolling vs. floating).

Overall, the findings provide important insights about the kind of information children might use to make a judgment about the direction of motion. The task involved a familiar domain, that of objects casting a shadow as they move through space. Yet, preschool children had difficulty ignoring the 'shadow' cue if it was causally irrelevant. They integrated it with the motion of the object, whether it was a causally meaningful shadow or a separate entity of a mouse (note that even adults had difficulty completely ignoring the irrelevant mouse cue). This is *not* to say that young children are unable to appreciate causal relevance altogether. Instead, we argue that an understanding of causal relevance is scaffolded by simpler attentional processes (c.f., Samuelson & Smith; 2000). Children will ignore causal knowledge when it requires deliberate ignoring of pieces of information, and hence when it is in conflict with their automatic attentional processes of integration.

The developmental progression reported here cannot be interpreted as a progression in content knowledge. This is

because the rapid change in performance between 3- and 4-year-olds does not correspond with a knowledge-based change of similar magnitude during this age span. Instead, the progression is likely to reflect a differences in lens size through which children understand the task. The lens of more experienced children is slightly larger, allowing them to integrate across slightly larger distances.

Of course, the single experiment reported here is not conclusive on the issue of what it is that might develop. However, its findings are in line with recent studies that question mere knowledge-based accounts. It shows that children are engaged in an active sense-making of the immediate task context that is controlled by simple attention to structure.

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