*Chapter 5*

# Building Blocks of Physical Knowledge: Can Children Learn How Two Dimensions Are Correlated?

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## Abstract

This study investigates preschoolers' ability to learn the positive and negative correlation between two physical dimensions. Four sets of objects, two for each correlation, were created. The objects differed either in mass and volume, two dimensions that are commonly related in children's environment, or in height and length of separate object parts, two dimensions that are commonly unrelated. Children between 4 and 5 years of age were asked in an initial phase to order the objects according to each dimension separately. During the testing phase, the objects were placed behind a partial screen in such a way that the magnitude of one dimension was visible to the child, whereas the other one was not. Children were asked to order the objects behind the screen according to the occluded dimension. Their performance differed as a function of trial number. During the first testing trials, children had most difficulty with the negative height-length correlation. During the last testing trials, however, children's performance was nearly perfect independently of the correlation or the dimensions involved. These results suggest that young children are highly sensitive to the correlation between two physical dimensions, this sensitivity being affected initially by both domain-general and domain-specific constraints.

A basic requirement for understanding physical events is the ability to recognize the relations that exist between physical dimensions (Piaget, 1930; Spelke, 1991). Even something as simple as balancing on a seesaw (or balancing a block on a rod; Karmiloff-Smith & Inhelder, 1975) requires a child to know how his mass relates to his distance from

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the pivot. Research in this field has focused primarily on physical relations in which one of the dimensions is the outcome of the other (e.g., Kister-Kaiser, McCloskey, & Proffitt, 1968; Kohn, 1993; Kotovsky & Baillargeon, 1998; Levin, Siegler & Druyan, 1990; Penner & Klahr, 1996; Schauble, 1990; 1996; Schilling & Clifton, 1998; Smith, Carey, & Wiser, 1985). There is however research demonstrating a role for correlated features, of which neither feature is the outcome of the other (e.g., Barrett, Abdi, Murphy, & Gallager, 1993; Malt & Smith, 1984; Rosch, 1978; Younger, 1985; 1990; Younger & Mekos, 1992). Adults, children, and even infants note that certain attributes in nature cluster together (e.g., animals with wings have feathers) and structure their categories around these correlations. Such features were categorical (e.g., wings, legs), which allowed children to remember associations between pairs of values as a way of understanding the correlation (e.g., wings-feathers, legs-fur). Physical dimensions on the other hand lay on a continuum between two poles instead of being categorical (Smith, 1984). Can children learn a correlation when simple associations are not possible? The present study investigates this question.

## CONSTRAINTS ON LEARNING CORRELATIONS

The ability or inability to learn correlations should reflect the constraints that are operating in children's cognition. Traditionally, domain-general constraints have been used to explain children’s ability to take in information about relations (Halford, Wilson, & Phillips, 1998; Klahr & Wallace, 1976; Piaget, 1950; Trabasso, 1975). These constraints emerge from the context-independent, formal structure of the information, such as the number or elements or the type of relations. More recently, domain-specific constraints were proposed to account for the effect of specific task content (Ahn, Kalish, Medin & Gelman; 1995; Barsalou, 1982; Carey, 1985; Chi and Ceci, 1987; Glaser, 1984; Keil, 1981; Kracsum & Andrews, 1998; Murphy & Medin, 1985; Pazzami, 1991; Wright & Murphy, 1984). These constraints emerge from a specific knowledge that a perceiver may have, such as being familiar with a particular relation or understanding an underlying mechanisms. Each constraint is discussed in more detail below.

### Domain-General Constraints

Across a variety of domains, children and adults are better at learning positive correlations than negative ones (for a review see Alloy & Trabashnik, 1984; Kareev, 1995). For example, preschoolers and 10- to 14-year-olds readily learn that mass correlates positively with an object’s sinking speed, but they fail to understand the negative correlation between sinking speed and volume, even after extensive training. Instead, they misinterpret the negative correlation to be positive (Penner & Klahr, 1996). And when no information is presented about the direction of the correlation, children, and even infants, expect a positive correlation between dimensions (Hauert, Mounoud, & Mayer, 1981; Kotovsky and Baillargeon, 1998; Mounoud & Hauert, 1982).

The domain-general constraint that affects children’s understanding of physical relations may be a ‘more = more’ principle. Support for this hypothesis comes from a comparison between the effects of polar and non-polar dimensions on perceived correlations (Smith & Sera, 1992). A polar dimension has two clearly defined poles of ‘more’ and ‘less’ (e.g., ‘big’ and ‘small’ for the dimension *size*, or ‘loud’ and ‘quiet’ for the dimension *loudness*). A non-polar dimension, on the other hand, has ambiguous poles. An example is *achromatic color* that could have for the ‘more’ pole either ‘more gray’ or ‘more white’. When presented with pictures of two differently sized mice and asked to pick the one that would make the louder noise, preschoolers and adults are likely to link the larger mouse with the louder noise, and the smaller mouse with the softer noise. However, they do not show this systematic behavior when asked to pick the mouse that would be of darker color than the other.

## Domain-Specific Constraints

There is also evidence to suggest that the constraints being used are not general but rather specific to the domain of interest. The strength of these constraints is such that participants will rely on existing knowledge to the point of ignoring or misinterpreting new information: They are likely to ‘perceive’ a non-existent relation when they hold a belief about it (e.g., Schauble, 1990), and they are likely to ignore a relation when they did not expect it (e.g., Schauble, 1996). Furthermore, when both belief-consistent and belief-neutral correlations are present, children and adults are more likely to base their decision on the belief-consistent ones (e.g., Ahn et al., 1995; Barrett et al., 1993; Murphy & Medin, 1985). Finally, children are likely to misinterpret the direction of a correlation to be consistent with their initial beliefs (Kloos & Somerville, 2001; Kuhn, Amsel, & O’Loughlin, 1988; Penner & Klahr, 1996; Schauble, 1990).

However, this tendency to ignore or misinterpret inconsistent information might not have a lasting impact. For example, a majority of the 10- to 14-year-olds presented with sinking objects was able to gain a better understanding of the domain after a phase of self-exploration (Penner & Klahr, 1996). In fact, existing knowledge might help rather than hinder children in their attempt to understand new information (Kloos & Somerville, 2001). Karmiloff-Smith & Inhelder (1975) suggested that an existing belief, even when incorrect, could provide a framework for taking in a physical relation that is lacking for children who do not have any prior knowledge. A similar conclusion was offered to explain why children profit from an interview procedure that calls to mind their mistaken beliefs (for a review see Guzzetti, Snyder, Glass & Gamas, 1993).

## Overview

In an effort to identify the operating constraints, the present study investigates whether children can learn the correlation between two physical dimensions. Two physical domains were used, one in which children were likely to expect a physical correlation, and one in which the correlation was likely to feel arbitrary to children. For half of the children the two covarying dimensions were mass and volume (familiar domain), for the other children, the two covarying dimensions were the sizes of two separate object parts (arbitrary domain). Within each of these domains, a child was presented with either a positive or a negative correlation.

In an initial phase, children were presented with the set of objects. Then the objects were placed behind a screen that occluded one dimension and provided information about the other. To test whether the children were able to recognize and learn the correlation between the dimensions, they were asked to order the objects from greatest to smallest along the occluded dimension. It was expected that the children would be able to learn the correlation that was presented to them, but that some correlations would be more difficult than others. Such difficulties may indicate the extent to which domain-general and domain-specific constraints operate. More specifically, if domain-general constraints guide children's understanding of the correlations, then performance should differ only as a function of the direction of the correlation: children should be better at understanding the positive than the negative correlation. If domain-specific constraints impact children's learning, then performance should differ as a function of domain: children should be better at understanding the mass-volume correlation than the correlation between the sizes of two separate parts.

# METHOD

## Participants and Design

Twenty preschoolers were tested in this study (mean age in years = 5.0, *SD* = 0.53). They were recruited from local preschools and tested in a quiet room adjacent to their classroom. Children were tested in one of the four conditions. The conditions differed in the types of dimensions (mass-volume vs. height-length) and the direction of the correlation (positive vs. negative.

## Materials

Two sets of objects were created, the objects in one set differing in mass and volume, and the objects in the other set differing in the height of one part and the length of another part. The exact dimensions of these objects and the kind of apparatus used in each setting are described below.

*Mass-Volume correlation*. Black cylinders (diameter = 5cm) closed with lids on each end were used as stimuli. The mass and volume of the cylinders varied. To manipulate mass, each cylinder contained a piece of lead that was glued onto Balsa wood to fill the rest of the cylinder. Four levels of mass were created: 130g, 200g, 300g, and 450g. To provide children with a visual cue to the heaviness of each object, white contact paper was placed on the bottom portion of each cylinder (see Figure 1), with heavier cylinders having more contact paper than lighter cylinders. To manipulate the volume of the cylinders, the height of the objects was manipulated. Four levels of height were created: 6cm, 9cm, 13cm, and 19cm. The levels of mass and volume were combined to create two sets of four objects, one in which mass and volume correlated positively, and one in which mass and volume correlated negatively. The levels of mass and volume (height) for the positive correlation were: 130g-6cm, 200g-9cm, 300g-13cm, and 450g-19cm. The levels of mass and height for the negative correlation were: 130g-19cm, 200g-13cm, 300g-9cm, and 450g-6cm.

To test children's understanding of the mass-volume correlation, two screens (30 cm high and 45cm wide) were created (Figure 1). Each screen would allow children to see one dimension (mass or volume) but would occlude the other. The screen that allowed children to see mass, had a horizontal window along the bottom (height of opening = 5cm) (Figure 1a). Children were able to see the paper representing the mass of the cylinder, but not its height. The screen that allowed children to see the volume of the cylinder had a horizontal window along the top (height of opening = 15cm, distance between opening and bottom of the screen = 5.5 cm) (Figure 1b). Children were able to see the tops of the cylinders, but not the paper cues to mass.

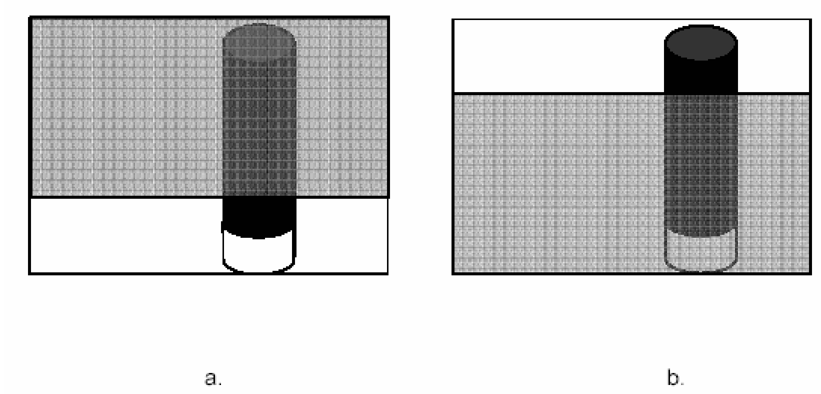


**Figure 1.** The partial screen covering the object in two different ways. The object was a black cylinder with white contact paper at the lower part of the cylinder to depicted the mass of the object (the higher the white portion, the heavier the object was). (a). The height of the white portion was visible to the child, and the height of the object was covered by the screen. (b). The height of the object was visible to the child, and the height of the white portion is covered by the screen

*Height-Length correlation.* The stimuli in these conditions were wood discs (thickness = 0.3cm) attached to rectangular bases made from the same material (Figure 2). The base for each stimulus was attached to the outer rim of the disc so that when the base was laid flat on the table, the disc would be oriented vertically. The height of the disc (diameter) and the length of the base were manipulated. There were four levels of disc diameter: 4cm, 5cm, 6cm, and 7cm; and four levels of base length: 4cm, 6cm, 9cm, and 12cm. The width of the base was always 2cm. The levels of height and length were combined to create two sets of four stimuli, one in which height and length correlated positively, and one in which height and length correlated negatively. The levels of height and length for the positive correlation were: 4cm-4cm, 5cm-6cm, 6cm-9cm, and 7cm-12cm. The levels of height and length for the negative correlation were: 4cm-12cm, 5cm-9cm, 6cm-6cm, and 7cm-4cm.

To test children's understanding of the height-length correlation, a screen with a window (height of window = 1cm) along the bottom was used (Figure 2). This screen would allow children to see one dimension (height or length) but would occlude the other. To present the length of the base to the children, the base was laid flat on the table so that it extended out of the opening towards the child while the height of the disc remained occluded behind the screen (Figure 2a). To present the height of the disc to the children, the disc was laid flat on the table so that it extended out of the opening towards the child while the length of the base remained occluded behind the screen (Figure 2b).

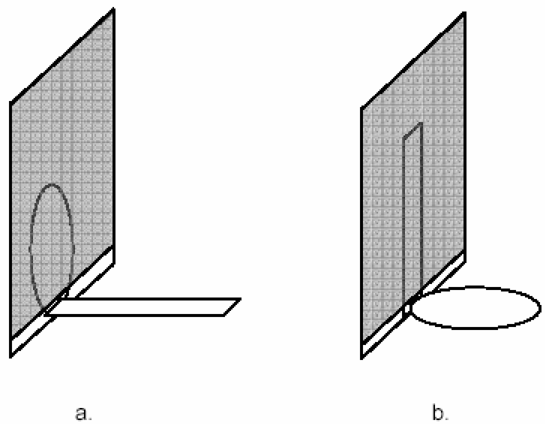


**Figure 2.** Partial screen covering the objects in two different ways. (a) The length of the rectangle was visible to the child, and the height of the disc was covered by the screen. (b) The height of the disc was visible to the child, and the length of the rectangle was covered by the screen

## Procedure

To familiarize children with the stimuli, they were shown one object of medium dimensions. In the mass-volume setting, the object was referred to as a can that contained some sand. Children were told that the height of the paper showed the amount of sand in the can. In the height-length setting, the object was referred to as lollipop with the disc being the candy and the rectangle being the handle.

After the initial familiarization, children were presented with the four stimuli in which the physical dimensions were correlated. To familiarize them with the set of objects, they were asked to order the objects according to each dimension separately, from greatest to smallest magnitude. The order of dimensions was counterbalanced. In the mass-volume setting, the experimenter asked: “Which one is the tallest (heaviest)? Let’s put the tallest one (heaviest one) over here. Which one is tallest (heaviest) of the ones that are left? Let’s put that one next to the one that we have picked already” etc. If children made mistakes in the first trial, the experimenter helped and the ordering was repeated. These orderings were the only means by which children were exposed to the correlation in the set of objects. Children had to order the objects along each dimension correctly twice in order to be included in the experiment.

To test whether children were able to recognize the correlation of the physical dimensions, they were shown one dimension and asked to order the objects along the occluded dimension. For this task, the objects were placed behind the screen. In the mass-volume setting, two screens were used, one to occlude mass and the other to occlude volume. Both screens were used for each child, the order being counterbalanced across children. In the height-length setting, only one screen was used, but the orientation of the objects was switched so that the screen occluded either height or length. Both object orientations were used for each child, the order being counterbalanced across children.

The ordering of the objects was conducted in two steps. First, the children were asked to order the objects according to the visible dimension. This step ensured that children were able to see the magnitudes of the visible dimension. All children performed correctly on this task. Second, children were asked to order the objects according to the occluded dimension. If volume was occluded, then children were instructed: “You cannot see how tall the cans are, but by just looking at how much sand they contain, can you remember from before which one was the tallest?” Children’s choice was placed on the left side of the screen followed by their next choice and so on. The objects were kept behind the screen until the ordering according to the visible dimension and the two orderings according to the occluded dimension were completed.

After these two ordering tasks were completed (one ordering according to the visible dimension, and the other ordering according to the occluded dimension), the screen was removed briefly and the child was encouraged to look at the objects. The objects were then placed behind the screen so that the previously visible dimension was now occluded and the two steps described above were repeated.

## RESULTS

Children always ordered the objects correctly along the non-occluded dimension. Therefore, the following analyses pertain only to the occluded dimensions. A rank order correlation was calculated comparing the correct ordering to the observed ordering on each trial. Each child ordered the stimuli twice along one dimension (e.g., mass) and then twice along the other dimension (e.g., volume), resulting in two trial blocks of two trials each (first trial block and second trial block). The data that are analyzed are the two mean rank order correlations for each child (one mean from the first trial block and the other one from the second trial block). The mean rank order correlation for each condition and each trial block are presented in Figure 3.

The two mean rank order correlations obtained for each child were transformed (Fischer’s z-transformation) to accommodate the assumption of normality. A 3-way mixed design analysis of variance (ANOVA) was conducted. The within-subject factor was trial block (first, second), and the two between-subject factors were dimension (mass-volume, height-length) and direction of the correlation (positive, negative). This analysis revealed that children improved significantly from the first trial block ($M = 0.69$, $SD = .53$) to the second trial block ($M = 0.98$, $SD = .05$), $F(1,16) = 10.48$, $p < .01$. The main effect of correlation direction was also significant, $F(1, 16) = 10.42$, $p < .01$, indicating that the children performed better with the positive correlation than with the negative correlation. However, there was also a significant interaction between correlation direction and trial block, $F(1,16) = 4.86$, $p < .05$. This significant interaction reflects the fact that most children performed perfectly during the second trial block. The effect of correlation direction was evident primarily in the first trial block. Neither the main effect of domain ($F < 1$) nor the remaining two-way interactions were significant ($p$s $> .05$). The final interaction, the three-way interaction, was marginally significant ($F(1, 16) = 3.94$, $p = .06$). Again, this interaction may reflect the near-perfect performance in the second trial block.

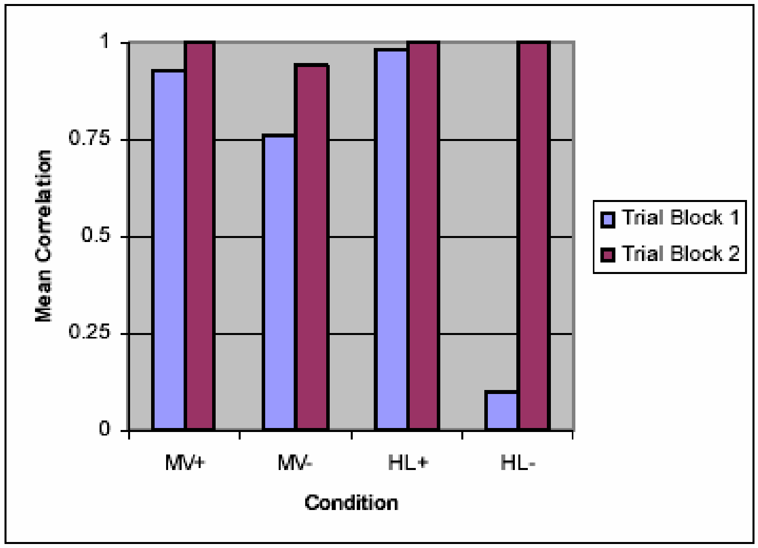


**Figure 3.** Mean rank order correlation across trial block 1 and trial block 2 for children in each condition. MV+: positive mass-volume correlation; MV-: negative mass-volume correlation; HL+: positive height-length correlation; HL-: negative height-length

Because the near-perfect performance during the second trial block may obscure the effects of dimension, correlation direction, and their interaction, a second 2-way ANOVA was performed using only the data from the first trial block. Again, children performed better with the positive correlation than with the negative correlation, $F(1, 16) = 7.6$, $p < .05$. There was no main effect of dimension, $F(1, 16) = 1.46$, *ns*. The interaction between dimension and correlation direction was marginally significant, $F(1, 16) = 3.19$, $p < .1$. A simple-effects analysis revealed that there was only an effect of correlation direction in the height-length setting, $F(1, 16) = 10.32$, $p < .01$, but not in the mass-volume setting, $F < 1$. The results of this analysis show that the negative correlation was overall more difficult, but primarily when the setting involved height and length.

## DISCUSSION

Preschool children's sensitivity to the positive and negative correlation of two physical dimensions was tested. The dimensions were either the mass and volume of cylinders or the extensions of two shapes (height and length). After being exposed to the set of objects and asked to order the objects according to each dimension separately, two blocks of test trials were administered. In each test trial, children had to order the objects according to the dimension that was not visible to them when information about the other dimension was given.

During the first trial block, children's performance differed as a function of both the direction of the correlation and the specific dimensions used – a finding that sheds light on the constraints that guide children's understanding of correlations. During the second trial block, children performed correctly during a majority of the trials, independent of the direction of the correlation and the kind of dimensions. This sensitivity to correlated dimensions sheds light on the possible underpinnings of children's physical knowledge.

## Constraints on Children's Understanding of Correlations

Two types of constraints have been hypothesized to affect children's ability to understand how physical dimensions correlate: domain-general and domain-specific constraints. Domain general constraints are likely to affect children's performance in the height-length setting, given that children were unlikely to have any knowledge-based expectation about the height-length correlation prior to the experiment. Domain-specific constraints, on the other hand, are likely to affect children's performance in the mass-volume setting, given that children are likely to expect that heavier objects are larger than lighter objects (Hauert et al., 1981; Mounoud, 1986). As shown in previous work, both constraints have an impact on understanding new information (e.g., Carmichael & Hayes, 2000; Wisniewski & Medin, 1994;). The present results identify more precisely how these constraints affect children's understanding of physical correlations.

*Domain-general constraints.* When the objects differed in height and length, children were more likely to make mistakes when the dimensions correlated negatively rather than positively. In fact, some children in the negative correlation condition consistently ordered the objects from smallest to greatest magnitude suggesting that they assumed a positive correlation between the two dimensions. This finding supports the idea that children adhere to a simple 'more = more' principle when thinking about physical relations (Smith & Sera, 1992). In the absence of any specific knowledge about how the height of a shape would relate to the length of another shape, children mapped the poles of height onto the poles of length, making mistakes when the two dimensions correlate negatively.

It may be the case that the previously reported failure of children to produce negative relations (e.g., Kloos & Somerville, 2001; Kotovsky & Baillargeon, 1998; Penner & Klahr, 1996) is at least partly a function of such domain-general constraints (for a similar claim see Hartford et al., 1998). For example, the finding that 10-month-olds expect larger objects to roll furhter (Kotovsky & Baillargeon, 1998) may demonstrate a general ability of infants' to associate the poles of two dimensions rather than an ability to reason about physical causality (cf. Thelen & Smith, 1994).

*Domain-specific constraints.* Children's difficulties with a negative correlation found in the height-length setting were not confirmed in the mass-volume setting. Even though children were likely to express surprise about the smallest object being the heaviest, most children performed correctly in the ordering task. In fact, their ability to learn a negative mass-volume correlation did not differ from their ability to learn a positive mass-volume. Hence, children exposed to the mass-volume setting had an advantage over children exposed to the height-length setting.

The difference in children's performance between the mass-volume setting and the height-length setting might be based on children's existing expectations about these correlations. Children are likely to expect a positive mass-volume correlation (Hauert et al., 1981; Mounoud, 1986), yet they are unlikely to have any expectation about the height-length correlation. The expectation that mass and volume are correlated may have prepared children to take in relational information. Without any basic expectation that two dimensions would be correlated (as was the case with height and length), children may have focused initially on irrelevant information such as the overall shape of the objects, failing to take into account the correlation.

This interpretation is consistent with previous conclusions that young children's existing knowledge scaffolds the taking in new information, even when the new information contradicts the existing knowledge (Karmiloff-Smith & Inhelder, 1975, Kloos & Somerville, 2001; Kloos & Van Orden, in press). Hence, a claim that children would reject information that does not match with their existing knowledge might be too simplistic. It may be the case that the rejecting of inconsistent information is solely an initial response to new information, after which children are aided by their existing knowledge to focus on the relevant pieces of the information. In the current study, children may have profited from having had prior experience with the mass-volume correlation in overcoming their bias towards a more = more principle.

## Underpinnings of Physical Knowledge

Even though children's performance in the current study was affected by both domain-general and domain-specific constraints, these constraints had only a minor impact on children's performance during the final testing trials. After having seen the objects a second time, children's ability to order the objects behind the partial screen was nearly perfect in all four conditions. Hence, despite existing constraints, children were able to learn the correlation between dimensions after only a brief handling period and without explicit instruction. These findings are consistent with findings about acquisition of physical correlations in non-human species (for a review see Alloy & Trabachnik, 1984) and infants (Younger, 1990; Younger & Cohen, 1983; Schilling & Clifton, 1998).

Do children structure their physical knowledge around the correlations that they observe in their physical environment? Correlated attributes play a crucial role in children's categorization (cf. Rosch, 1975; Younger, 1995) and it is conceivable that this sensitivity to correlated dimensions would allow them to make inference about new relations. For example, knowing that two dimensions correlate positively may allow children to infer that increases in one dimension will have the same impact on the second dimension.

Indeed, when asked to justify their decisions about whether a particular object would sink or float (Inhelder & Piaget, 1974), some 7- to 10-year-olds used the dimensions mass and volume interchangeably. Even when two objects differed only in volume, and not in mass, children justified the difference in sinking speed by the difference in mass (Halford, Brown, & Thompson, 1986). Such findings were originally interpreted to show children's inability to distinguish between the two dimensions mass and volume (e.g., Inhelder & Piaget, 1974). This interpretation was criticized, however, on the basis of subsequent findings in which even 3-year-olds were able to make clear distinctions between mass and volume (e.g., Smith et al, 1985). Further work would be necessary to establish whether children's inferences change as a function of their knowledge about physical relations.

## CONCLUSION

When asked to learn the correlation between two continuous dimensions, the preschool children tested in this study were likely to be affected by both domain-general and domain-specific constraints during the initial testing phase. They were biased towards assuming a positive correlation between dimensions, and they were biased towards assuming that mass and volume are correlated, whereas sizes of two different shapes are not. However, children were quickly able to override both biases. At the end of the testing phase, children performed nearly perfect in all conditions, independently of domain-general and domain-specific constraints. This finding suggests that children have a strong tendency to attend to physical relations, this tendency possibly forming an initial building block for their physical understanding.

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