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Can a Preschooler's Mistaken Belief Benefit Learning?

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Young children erroneously believe that differences either in mass alone or in volume alone can predict differences in sinking speed. The current study was an attempt to teach preschool children that neither mass nor volume alone is predictive for sinking speed. Instead, it is the average density of an object that can predict differences in sinking speed. Twenty-four 4-to 6-year-olds participated. In an initial phase, children's mistaken beliefs about the effects of mass and volume on sinking speed were called to their minds. Then they were presented with demonstrations of sinking objects that disconfirmed these mistaken beliefs. The findings show that preschool children can replace mistaken beliefs and learn that two dimensions, originally thought of as being relevant, are indeed irrelevant. Children who did not perform correctly demonstrated a mass bias. The results also shed light on the origins of this bias.

Keywords: Preschoolers, physical knowledge, sinking objects

To understand a physical domain is to understand how physical dimensions are related to each other. For example, to understand the domain of sinking objects, children must understand how mass and volume are related to an object's sinking speed. Young children have the basic prerequisites to acquire this kind of knowledge; they are highly sensitive to physical regularities (e.g., Kloos & Amazeen, in press; Kohn, 1993; Schilling & Clifton, 1998; Sodian, Zaitchik, & Carey, 1991). However, the acquisition of such knowledge can be impeded by a tendency of children to hold on to existing beliefs (e.g., Karmiloff-Smith, 1984; Karmiloff-Smith & Inhelder, 1975; Kloos & Somerville, 2001; Kuhn, Amsel, & O'Loughlin, 1988; Penner & Klahr, 1996; Schauble, 1990; 1996; Somerville, 1974; Wiser & Amin, 2001). If existing beliefs are in conflict with new information, children will often ignore the conflicting evidence, misinterpret conflicting evidence to accommodate their existing belief, or incorrectly change existing beliefs to accommodate the new information.

Can children's learning be facilitated; can we overcome children's resistance to change their beliefs? Older children show some tendency to replace a mistaken belief when their mistaken belief is called to their attention during the training (for a review see Guzzetti, Snyder, Glass, & Gammas, 1993). This possibility was tested with preschoolers using the domain of sinking objects (Kloos & Somerville, 2001). Children believe incorrectly that larger objects sink faster than smaller ones. The opposite is true. With no difference in mass, a smaller object sinks faster than a larger one. Kloos and Somerville presented children with controlled demonstrations designed to convey the relation between volume and sinking speed. Some of the children participated additionally in an "interview" designed to evoke children's mistaken belief about this relation. These children were more likely to change their mistaken belief than children who did not participate in the interview.

What support does a procedure provide in which children call to mind their mistaken beliefs? Kloos and Somerville (2001) speculated that the procedure of calling to mind helps children to appropriately organize the observed demonstrations. Such an organization entails two nested aspects. One aspect refers to the objects themselves. Children must understand that a difference in behavior of two objects is related to a difference in magnitude of a shared dimension. For instance, a child must

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understand that demonstrated sinking speeds of concrete objects are related to objects' abstract dimensions such as mass, volume, or density. Without this understanding, children could assume that shown demonstrations are idiosyncratic to the actual objects.

The other aspect refers to physical relations. Children must understand that an observed physical relation (e.g., between volume and sinking speed) contradicts their existing belief about this relation. For instance, a child must understand that the demonstrations about sinking objects stand in contradiction to their prior expectations. The calling-to-mind procedure of Kloos and Somerville appropriately constrains children's focus to take in both nested aspects. Reminding the child of their belief about volume and sinking speed, for example, points out the relevant dimension volume and juxtaposes the child's mistaken belief in time with the contradictory evidence.

Are both nested aspects of the calling-to-mind procedure required to change young children's beliefs? The current study investigated whether young children would change their mistaken beliefs when a calling-to-mind procedure provides only one aspect of organization, not both. We asked whether children would change their belief when the contradiction between expected and observed outcomes is made salient but not the relevant dimension of the correct belief. Children were confronted with the shortcomings of their beliefs but the relevant dimension of the new correct belief was never pointed out to them. Under these conditions, children must discover on their own the insight that the demonstrations pertain to an implicit relevant dimension.

The changes of beliefs in the study of Kloos and Somerville (2001) were refinements of existing beliefs (about how volume predicts sinking speed) rather than the full replacement of a belief. Children needed only to learn that volume affects sinking speed in a way opposite to their original beliefs, and volume was the relevant dimension throughout. Thus the children need not replace their entire belief about what dimension predicts sinking speed to predict correctly which object sinks fastest. In the present study, a correct prediction of sinking speed requires a child to ignore volume (and mass) in favor of a different dimension altogether. The current study asks whether young children ever fully replace their belief when a calling-to-mind procedure only makes salient that volume and mass are unreliable dimensions.

Laboratory Worlds of Sinking Objects

In the Kloos and Somerville (2001) study, children were presented with a simplified laboratory world of sinking objects, a world in which only one dimension was varied at a time. Children were presented with pairs of objects that differed in volume (while mass was held constant, for example). In this simple laboratory world, smaller objects always sank faster than larger objects.

A more complex laboratory world can be created when pairs of objects differ in both mass and volume. In this more complex world, neither mass by itself nor volume by itself reliably predicts the faster sinking object. Mass can be manipulated so that either the larger or the smaller of two objects sinks fastest in water. Similarly, volume can be manipulated so that either the heavier or the lighter of two objects sinks fastest in water. The actual predictor of sinking speed is average density. This more complex laboratory world is ideal to study whether beliefs can change when the correct dimension is never pointed out specifically. Calling to mind children's beliefs about the effects of mass and volume on sinking speed makes the shortcomings of these beliefs salient, but it does not point out density as a reliable predictor of sinking speed.

Note however that children appear to have an a priori difficulty with density. The classic observations of Inhelder and Piaget (1958) found that children under 10 years of age cannot predict correctly which objects will sink and which objects will float when presented with ordinary spoons, candles, matches, etc. These basic findings were corroborated in tasks that operationalized density as 'the heavier kind of stuff' (Smith, Carey, & Wiser, 1985), or the faster sinking object (Penner & Klahr, 1996; Hewson & Hewson, 1983). Children seem to attend to density only in a highly structured setting, when objects differ to a greater extent in density than on other dimensions (Kohn, 1993).

Given such difficulty with density, this dimension is not a practical manipulation for the current experiment. Hence, in the present, complex laboratory world, no understanding of density was required to predict the fastest sinking objects. Instead we used a dimension that was more easily detectable by young children: the extent of empty space in a transparent cylinder. The more empty space in a cylinder, the more slowly it sank in water. The cylinders differed in height and thus in the number of weights that could be placed inside. The number of weights that were missing in a cylinder determined its emptiness. Children readily detect differences in number of weights (mass), so they should also detect differences in number of missing weights (emptiness).

The emptiness of an object is closely related to its density. One could say that this dimension is in fact a visual guide to density (cf., Smith, Snir, & Grosslight, 1992). There is an important difference between the two dimensions, however. The density of an object is based on a ratio (i.e., the ratio of mass over volume), whereas an object's emptiness is not. Emptiness as used in this study is an absolute value, namely the height in a transparent object that is not filled with weights.

Overview

Children participated in three sessions. In the first session, children's beliefs were called to mind about how mass and volume, each considered separately, would affect the sinking speed of toy submarines. In two separate interviews, one concerning mass and one concerning volume, they were asked to predict the fastest of two submarines. Each interview was followed by a set of demonstrations that conveyed to children the shortcomings of their beliefs. Pairs of sinking objects were created that were then released in a tall water tank. In the demonstrations about the effect of mass on sinking speed, volume was manipulated to make the heavier submarine sink faster in some trials and more slowly in others. Alternatively, in the demonstrations about the effect of volume on sinking speed, mass was manipulated to make the larger submarine sink faster in some trials and more slowly in others.

The second session presented children with a new set of demonstrations. In one third of demonstrations the heavier and larger objects sink faster than the lighter and smaller ones; in another third of demonstrations, the heavier and smaller objects sink faster than the lighter and larger ones; and in the final third of the demonstrations, the lighter and smaller objects sink faster than the heavier and larger ones. Across these trials, differences in emptiness between objects reliably predicted relative sinking speed. Mass and volume were unreliable predictors.

In the third and last session, children were presented with a training phase similar to the one in the second session, and then were tested in their ability to predict the fastest sinking object. The presented pairs of objects differed in mass and volume. Again, the trials differed in the way the objects within a pair were put together. In one third of the trials, the fastest sinking object was heavy and big; in another third of the trials, the fastest sinking object was heavy and small; and in the final third of the trials, the fastest sinking object was light and small.

Each child's pattern of performance across the test trials was sufficient to determine the child's final belief (see Table 1). A child who understands how relative emptiness is linked with relative sinking speed would perform correctly across all three types of trials. A child who relies on their original (incorrect) belief would perform incorrectly in some trials. For example, a child who retains their original mass belief would err on test trials in which the lighter submarine is the faster sinking object.

Table 1
Possible Patterns of Response across the Test Trials

	Test trials		
Children's understanding	Heavy\Large vs. Light\Small	Heavy\Small vs. Light\Large	Light\Small vs. Heavy\Large
Correct understanding			
The fuller object sinks fastest	correct	correct	correct
Mass bias			
Original mass belief (The heavier object sinks fastest)	correct	correct	incorrect
Inverted mass belief (The lighter object sinks fastest)	incorrect	incorrect	correct
Volume bias			
Original volume belief (The larger object sinks fastest)	correct	incorrect	incorrect
Inverted volume belief (The smaller object sinks fastest)	incorrect	correct	correct

Note. Two objects are presented in each test trial that differ in mass and volume. Each object can be characterized by its mass and volume (heavy or light, large or small). The object in bold is the winning object of the test trial. Each type of test trial occurred four times during the test.

Method

Participants

Twenty-four 4- to 6-year-olds participated in this experiment: eight 4-year-olds (*M* = 4.6, *SD* = .35), eight 5-year-olds (*M* = 5.3, *SD* = .51), and eight 6-year-olds (*M* = 6.3, *SD* = .27). The children were recruited from local daycare centers and tested in a quiet room in their school. Three additional children were tested for whom we do not report results. Two of them did not meet the selection criteria in the interview (see Procedure), and one refused to participate in the last session.

Materials

The sinking objects, referred to as submarines, were baby-food jars (diameter = 4.4 cm) that could be closed on top with a lid. Submarines of different heights were used to manipulated volume: a *small* submarine 3.5 cm high, a *medium* submarine 5 cm high, and a *tall* submarine 6.5 cm high. The manipulation of mass was accomplished by inserting disc-shaped aluminum weights into the submarines (weight's diameter = 4 cm, height = 1 cm). Up to three weights could fit in the small submarine, four in the medium submarine, and six in the tall submarine. A few weights were drilled to have a 1 cm hole in the middle. These weights were surreptitiously inserted into submarines that would sink more slowly in a submarine race. This did not change the outcome of the submarine race but slightly amplified the difference in sinking speed. Pilot testing showed that children easily distinguish between the different heights and the different number of weights in the submarines. The tall submarine with a single aluminum weight floats in the water. Two weights are sufficient to sink a tall submarine, and one weight is sufficient to sink medium and small submarines.

A tall water tank (100 cm tall, 60 cm wide, 30 cm deep) was used to demonstrate sinking speeds of objects. The tank was made of transparent Plexi-glass with a "starting line" painted at the top and a "finishing line" painted at the bottom. A vertical dividing wall created two separate racing lanes, which insured that water turbulence created by one sinking object did not interfere with the other sinking object. At the start of the race, each submarine was held by its top with the weights at its bottom, partially submerged, and level with the starting line. This allowed a relatively stable accelerating descent to the finishing line (at the bottom of the tank).

Schematic pictures of submarines were used to call to mind children's initial beliefs. They were identical to the ones used in Kloos and Somerville (2001), which allows a comparison between the two studies. Each pictured submarine had a red hatch (3 × 5 cm) that could be lifted up. A hatch completely covered a variable number of black spots (diameter = 1 cm) referred to as "weights." Two sets of five pictures were created. The pictures in one set were used to illustrate differences in mass. They differed in the number of weights underneath the hatch (1 to 5 dots). The pictures in the other set were used to illustrate differences in volume. They differed in their overall area (ranging from 30 to 90 cm^2), all having three dots underneath the hatch.

Procedure

Children participated in three sessions, a minimum of 2 and a maximum of 7 days apart. The first session was designed to call to mind children's mistaken beliefs and confront them with evidence that could challenge these beliefs. The second session was a training session. It was designed to make salient that mass and volume alone do not reliably predict the outcome of submarine races and, covertly, that relative emptiness does. Finally, the third session consisted of another training session followed by a test of children's understanding of sinking objects.

Session 1: Familiarization, Interviews, and Demonstrations

This session consisted of three parts: a familiarization phase and two interview phases paired with the corresponding demonstrations. One interview-demonstration pair concerned the effect of mass on sinking speed, and the other interview-demonstration pair concerned the effect of volume on sinking speed. The order in which the interview-demonstration pairs were presented was counterbalanced across children.

Familiarization

Children were shown a medium sized submarine and were given weights to place inside. After the child placed the weights inside the submarine, the experimenter released it into the water tank and explained: "This is how our toy submarine sinks to the bottom of the water tank. Can you help me find out what makes a submarine sink really fast?"

Interview-Demonstration Pair Concerning Mass

The goal of this interview was to call to mind children's beliefs about how mass affects sinking speed. Children were presented with the five submarine pictures that depicted differences in mass. In each of three trials, children were presented with two submarine pictures and asked: "Which submarine would sink fastest in water?" To be included in the study, children had to give consistent responses across the three trials. They either had to pick the picture with the heavier submarine across all trials, or they had to pick the picture with lighter submarine across all trials. All consistent responders predicted that the heavier submarine would sink fastest.

At the onset of the demonstration trials, the experimenter explained: "Let's find out if a heavy submarine sinks faster than a light submarine". The demonstration phase consisted of three demonstration trials. The first trial presented a child with two small-sized submarines, one containing two weights and one containing three weights. The two submarines were dropped into the water tank and children were asked to observe the race. The submarine with three weights reached the finishing line of the tank before the submarine with two weights – as children would have predicted.

For the second demonstration trial, the small submarine with three weights was modified in front of the child: The three weights were removed from the small submarine and placed into a medium submarine. The new pair of submarines (small submarine with two weights and medium submarine with three weights) was released into the water while children observed the tank. Here, the two submarines reached the finishing line approximately at the same time.

In the last demonstration trial of this set, the medium submarine was replaced with a tall submarine, with no changes in the number of weights. The resulting pair of submarines (small submarine with two weights and tall submarine with three weights) was dropped into the water tank. Children observed that the submarine with two weights reached the finishing line of the tank before the submarine with three weights – opposite of what children would have predicted. Without changing the mass contrast across the three demonstration trials (two weights vs. three weights), we demonstrated to children that mass does not predict sinking speed by itself.

Interview-Demonstration Pair Concerning Volume

The goal of this interview was to call to mind children's beliefs about how volume affects sinking speed. Children were presented with the five submarines pictures that depicted differences in volume. In each of three trials, children were presented with pairs of these submarine pictures and asked: "Which submarine would sink fastest in water?" Again, children had to respond consistently across these three trials to be included in the study. They had to pick either the larger picture across all trials or the smaller one as the faster sinking object. All consistent responders predicted that the tall submarine would sink faster than the small submarine.

Three demonstration trials followed in which children observed pairs of sinking objects. For the first trial, a small submarine and a tall submarine was used, both full of weights (three weights and six weights, respectively). Full of weights, the small and tall submarines would sink at similar speeds. The pedagogy of our demonstration (to confirm children's existing belief initially) required however that the tall submarine wins. To make this happen, the weights in the small cylinder had holes, which lowered the average density of the submarine. Note that this first demonstration trial does not make apparent the importance of an object's emptiness. Perceived emptiness was eliminated in this pair (each submarine was full of weights) and was held constant, while mass and volume correlated. The outcome of this race is thus uninformative about the relevance of emptiness.

For the second demonstration trial, one weight was removed from the tall submarine. This time, the two submarines (tall submarine with five weights and small submarine with three weights) sank to the bottom of the tank in approximately the same time. Finally, for the last demonstration trial, a further weight was removed from the tall submarine. Once released in the water tank, the tall submarine (now with four weights) reached the finishing line after the small submarine – opposite to what children would have predicted. Without changing the volume contrast across the three demonstration trials (tall submarine vs. small submarine), we demonstrated to children that volume does not predict sinking speed by itself.

Session 2: Demonstrations

Each child was presented with 24 demonstration trials in one of two random orders or the two respective reverse orders. In two trials, volume was held constant and mass was varied. In another two trials, mass was held constant and volume was varied. In the remaining 20 trials, both mass and volume was varied and the race could have one of three outcomes. On 4 of these 20 trials the winning submarine was heavier and taller (e.g., medium submarine with four weights vs. small submarine with one weight). On a different set of eight trials, the winning submarine was heavier and smaller (e.g., small submarine with three weights vs. tall submarine with two weights). On the remaining eight trials, winning submarine was lighter and smaller (e.g., small submarine with two weights vs. tall submarine with three weights). Every trial presented a unique contrast between submarines.

For each trial, the child held the submarines in hand and then reported which of the submarines was larger and which one was heavier (when there were actual differences in mass and volume). Then the child was asked to predict which submarine would sink fastest in water. Finally, the experimenter dropped the submarines into the water tank, and children were asked to observe the actual race.

Session 3: Demonstrations and Test

Demonstrations

Each child was presented with 12 demonstration trials of unique pairs of submarines. The child was asked again to report the heavier and larger object and predict which one would sink fastest. Then, the objects were dropped in the water tank and the child observed the race. The winning submarine was heavier and taller on four trials, heavier and smaller on another four trials, and lighter and smaller on the remaining four trials. The order of trials followed one of two random orders, or their reverse.

Test

Twelve test trials followed immediately after the demonstration trials. Each trial consisted of novel combinations of two sinking objects that differed in mass and volume. A child was asked which submarine would sink faster and to justify their choice. Submarines were never submerged in water – no race was run and hence no feedback occurred. To perform correctly, the child had to choose the heavier and larger object in four trials, the heavier and smaller object in another four trials, and the lighter and smaller object in the remaining four trials. Constructing the test trials in this way made is possible to determine potential biases towards mass or volume. The trials were presented in one of two random orders, or their reverse.

Results

Three systematic patterns of response were observed: the correct pattern of response and two patterns of response that suggest biases towards mass (children's choices were based on a simple difference in mass alone). No child produced a pattern of performance that suggested a bias towards volume. The children's performances are described in more detail below.

Five children (two 4-year-olds, one 5-year-old, and two 6-year-olds) produced the correct pattern of response. They chose correctly the winning submarine on every test trial (12 of 12). And in their justifications, each child made reference to the emptiness of the containers in at least one of the trials (e.g., "this one will loose because it has a lot of air inside"). The probability to performing correctly across all trials by chance alone is smaller than 0.01 (binomial probability assuming a chance probability of p = .5 per trial).

Despite performing correctly, these five children also frequently used justifications that were based on mass alone (e.g., "it sinks faster because it is heavy"). Table 2 shows the average number of trials for which children gave a particular justification for their prediction. In fact, mass-based justifications occurred much more frequently (mean

Table 2
Mean Number of Trials for Which Children Gave a Specific Justification

	Patterns of response		
"The faster sinking object is ...:	Correct responder ($n = 5$)	Mass bias ($n = 14$)	Inverted mass bias ($n = 2$)
Mass justification			
... heavier"	7.4 range = 5–11 ($n = 5$)	7.5 range = 4–10 ($n = 14$)	0.0
... lighter"	0.0	0.0	7.5 range = 6–9 ($n = 2$)
Volume justification			
... larger"	0.8 range = 0–2 ($n = 3$)	0.5 range = 0–2 ($n = 5$)	0.0
... smaller"	0.0	0.0	1.0 range = 1 ($n = 2$)
Mass\Volume justification			
... heavier and larger"	0.6 range = 0–1 ($n = 3$)	2.0 range = 0–4 ($n = 10$)	0.0
... lighter and smaller"	0.0	0.0	3.0 range = 3 ($n = 2$)
Correct justification			
... fuller"	1.8 range = 1–2 ($n = 5$)	0.0	0.0

Note. The means are based on the number of children in each category of patterns or response. The number of children who gave a particular justification at least once is given in parentheses).

number of trials = 7.4 out of 12) than volume-based justifications (e.g., "it sinks faster because it is big") or justifications that included both mass and volume (e.g., "this one wins because it is heavy and big").

Fourteen children (four 4-year-olds, five 5-year-olds, and five 6-year-olds) performed correctly on all trials in which the heavier submarine sank fastest (eight trials) and incorrectly on all trials in which the lighter submarine sank fastest (four trials). This pattern of responses shows the mass bias. The children performed as though they believed that heavier objects always sink faster than lighter objects, independently of volume. Again, children were highly likely to justify their choices in terms of mass alone (the faster sinking object is heavier). They used this justification on an average of 7.5 trials (out of 12) (see Table 2).

Two children (5 and 6 years old) performed correctly on all trials in which the lighter submarine sank fastest (four trials) and incorrectly on all trials in which the heavier submarine sank fastest (eight trials). In their justifications, one child made reference to mass in six trials, and the other in nine trials. Notably, both children claimed that the lighter of two objects sinks faster than the heavier one. This pattern of responses shows an inverted mass bias.

The remaining three children (two 4-year-olds and one 5-year-old) did not perform systematically. These children performed correctly in at least one trial of each kind. The most common justification was mass based (mean number of trials = 5.0 out of 12), but they also produced volume based justifications (mean number of trials = 2.3 out of 12) and justifications that included both mass and volume (mean number of trials = 2.3 out of 12).

Discussion

The current study had two interrelated goals. One goal was to investigate whether young children ever replace completely an existing belief. To do so, they must discover that a dimension, originally believed to be relevant, is irrelevant. Children were presented with demonstrations in which an object's emptiness was a reliable predictor of sinking speed. To correctly understand these demonstrations, children needed to replace their existing beliefs. They needed to come to an understanding that neither mass nor volume, taken separately, reliably predict the fastest sinking object.

The other goal of the study was to investigate whether calling-to-mind children's mistaken beliefs may benefit learning a reliable belief. The findings of Kloos and Somerville (2001) support this hypothesis. However, in Kloos and Somerville, the calling-to-mind procedure also pointed out the relevant dimension. In the current study, the calling-to-mind procedure did not point out the relevant dimension. Children were asked to reason about the effects of mass and volume on sinking speed, while the relevant dimension was an object's emptiness. The results are discussed in two sections according to the patterns of response the children produced.

Learning to Predict the Fastest Sinking Object

Five children performed consistently correct in the test, and made at least once reference to the relative amounts of air in the submarines to justify their choices. Also, these children often wiggled and shook the submarines to establish how "empty" they were. They performed as though they had adopted a belief of the form: The fuller an object is, the faster it will sink.

Sensitivity to the Relation between Fullness/Emptiness and Sinking Speed

How is it that children pick out the relation between relative emptiness and objects' relative sinking speed? Perhaps they have a general capacity to pick up reliable, meaningful, statistical relations in the environment, relations that have consequences for correctly performing in the laboratory world. For example, very young children appear to be sensitive to the statistical coherence of syllables in speech streams (Aslin, Saffran, & Newport, 1998; Saffran, Aslin, & Newport, 1996) as well as covariant relations among visual features (Fiser & Aslin, 2002). Even nonhuman primates and inanimate connectionist models exhibit a capacity for covariant learning (e.g., respectively, Hauser, Newport, & Aslin, 2001; Van Orden, Pennington, & Stone, 1990).

The capacity for covariant learning does not seem to be limited to any particular scale of spatial or temporal relations. Adults readily pick up higher-order statistical relations in the spatial structure of visual scenes (Fiser & Aslin, 2001) or between stimulus and response, such as whether visual targets are more or less correlated with response options in a button-pressing task (Hunt & Aslin, 2001). Likewise, infants are sensitive to higher-order relations among whole syllables (Gómez, 2002; Gómez & Gerken, 1999, 2000) and to relations among higher-order visual shapes (Fiser & Aslin, 2002). Thus it is at least plausible that the same general capacity could extend to the higher-order relations of the present laboratory world. Such a general capacity, not limited to particular modalities or scales, would seem to be the kind of capacity that could pick up the higher-order statistical relations among dimensions of objects and their relative sinking speeds.

A general capacity to pick up reliable, meaningful, statistical relations does not provide a sufficient account of the calling-to-mind phenomenon, however. It stops short of the benefits for changing beliefs that come from calling to mind a mistaken belief. Thus, a covariant learning account of the present findings (and those of Kloos & Somerville, 2001) would require additional assumptions. It would require assumptions to explain why reminding children of their existing beliefs facilitates a change of belief.

The Benefit of the Calling-to-Mind Procedure

The present study does not involve conditions in which the calling-to-mind procedure was directly manipulated. However, a contrast with children's performance in Kloos and Somerville's (2001) study may clarify the benefits of the present calling-to-mind procedure. Kloos and Somerville included one control condition that did not call to mind a mistaken belief and did not explicitly call attention to the relevant dimension. This condition consisted solely of demonstration trials. Thus, this control condition estimates the likelihood that children can pick up the relevant dimension by themselves (when no other dimension is pointed out to them). Only one child discovered the demonstrated relation between volume and sinking speed (6% of the total number of children).

The present calling-to-mind procedure focused children's attention on mass and volume, not the reliable dimension of emptiness. Nonetheless, 5 of 24 children (21%) discover the correct relation between emptiness and sinking speed. This apparent benefit of the calling-to-mind procedure indicates that young children can change their existing beliefs under more difficult circumstances – the contradiction between existing belief and new information was made salient but not the relevant dimension itself.

Note however, that additional benefits accrue when the relevant dimension is made apparent. The percentage of children who changed their mistaken belief in the current study (21%) is lower than the percentage of children tested in Kloos and Somerville (2001) who were asked to reason about the relevant dimension prior to the contradicting demonstrations (38%). Apparently, in order to change a young child's mistaken belief it is beneficial to make apparent both the abstract dimension and the juxtaposition between the mistaken belief and its contradiction.

How might children perform in an experiment in which they are misdirected to focus on mass and volume, and no calling-to-mind procedure is used? It is possible that children who are presented with the demonstrations of sinking objects would formulate narrow expectations about sinking objects without confronting the error of their mistaken belief. If the relevant dimension of emptiness becomes salient at all, they may nevertheless fail to confront the fact that mass and volume are unreliable predictors. Children may even sustain two contradictory ways of understanding sinking objects, one that includes their previous beliefs about the effects of mass and volume on sinking speed, and one that includes their new belief about the effect of emptiness on sinking speed (cf. Karmiloff-Smith, 1984).

Two children in the current experiment show how a correct and an incorrect belief can be sustained simultaneously. Although they chose correctly the fastest sinking object in every test trial, some of their justifications were in conflict with their choices. These two children claimed to have chosen the heavier submarine on trials in which they chose the lighter submarine. For example, one 6-year-old commented after choosing correctly the lighter submarine as the winner "This one is going to win because it is heavier. It does not look heavy but it feels heavy." Apparently, these children did not fully confront the shortcomings of their existing beliefs.

Showing a Mass Bias

Children who did not perform correctly in the present study were more likely to make predictions based on mass than on volume. Fourteen children consistently chose the heavier of the two submarines as the faster one, and two children consistently chose the lighter of the two submarines as the faster one. All these 16 children repeatedly justified their choices in terms of differences in mass alone. In comparison, no child's pattern of response in the test trials implicated a volume bias. While children made reference to differences in volume on some trials, they did not show a consistent pattern of volume bias in their choices.

A bias in which children focus on the heavier of two objects is not surprising in children's judgments that involve differences in density. Inhelder and Piaget (1958) reported that children were more likely to use differences in mass than differences in volume to predict whether an object would sink or float. In fact, even when objects differ solely in volume, some children will claim that actual differences in density come from non-existent differences in mass (Halford, Brown, & Thompson, 1986; Inhelder & Piaget, 1958). Similar results were found when children were asked to determine the object 'that is made of the heavier kind of stuff' (Smith et al., 1985). When objects differed in both mass and volume, children between 3 and 9 years of age were likely to choose the heavier object as the denser one, ignoring differences in volume.

A bias in which children focus on the lighter of two objects is unusual, however. Claiming that the lighter of two submarines sinks faster than a heavier object cannot be motivated by children's specific training experience. In the interview session, these two children showed the usual mass bias. They chose consistently the submarine with more weights to sink faster than the submarine with fewer weights. And across the training trials, the heavier submarines were winners more often than lighter submarines (two thirds vs. one third of the trials).

The finding that some children inverted their previous mass bias, despite mostly confirming evidence, is not unique to the current study. Kloos and Somerville (2001) report similar cases in which children invert their mass bias. Four children in the Kloos and Somerville study inverted their initial belief that heavier submarines are winning submarines. Eventually they chose consistently the lighter submarine as the winner in all test trials. They persisted in this choice despite being presented with six controlled demonstrations in which the heavier submarine was the winner. These findings shed light on the sources of the mass bias.

Sources of Mass Bias

Children's mass bias is not likely to be based on children's specific experience with the effect of mass on sinking speed. While children are likely to have observed objects that sink or float, it is unlikely that their experience includes anything as systematically informative as the multiple examples of the three training sessions in the current study. This training provided children with a balanced design in which mass and volume were equally unreliable predictors of relative sinking speed. Based on the training presented to them, children should not have shown a preferential bias towards mass over volume. And they certainly should not have shown an inverted mass bias.

It is possible that mass is more salient to children than volume in a setting that involves sinking objects. Children's experience with mass emerges out of their experience with the force that it takes to prevent objects from falling (Carey, 1991; Kloos & Amazeen, 2002). The salient facts of these experiences are that heavier objects require a greater lifting force and that heavier objects strike the ground with greater impact. This direct and pertinent experience of mass may make this dimension a salient predictor for falling objects. Given that a sinking motion is a falling motion, children's direct experience of mass may shape their beliefs about how objects will sink in the submarine world of the present study.

Why then an inverted mass bias? Children may have realized that their initial beliefs about the effects of mass and volume on sinking speed are not reliable across all trials. In fact, the faster sinking objects conformed to children's initial beliefs in only one third of the training trials. As a response to this destabilization, children may have made superficial changes to their existing belief. If heavier objects do not always sink faster than lighter objects, it must be the other way around. But perhaps children who showed an inverted mass belief were closer to a change to a correct understanding than children who retained their original mass belief. Even though these children performed worse after the training than before, they may have been on the verge of rejecting their existing beliefs entirely.

An Alternative Source of the Mass Bias

It is possible that children's experience with the wielding of objects is not the only basis for children's claims that heavier objects sink faster than lighter objects. Smith and Sera (1992) showed that children's mapping of dimensions is well described by a simple more = more rule (see also Lakoff, 1987). Preschoolers and adults who were presented with big and little cutouts of mice mapped the bigger mouse to a louder sound and the smaller mouse to a quieter sound, even though children's perception of size is unlikely to dependent on their perception of loudness. In the present study, the children who had a mass bias could also have simply matched the more end of mass (heavy) with the more end of sinking speed (fast).

Children's performances in the interview trials of the current experiment support a more = more hypothesis. Recall that children were asked in two sets of three trials which of two submarines would sink faster in water. The submarines of one set differed in mass only (number of weights carried by the submarine), and the submarines of the other set differed in volume only. If children's mass bias originates substantially from wielding, then they might have performed differentially with mass than volume in the interview trials. Yet, children performed consistently across the interview trials independently of whether they were asked to reason about mass or volume. Across all trials, they mapped the "more" pole of one dimension with the "more" pole of the other.

It is plausible that young children's reasoning about physical relations often follows a simple more = more rule, rather than being based on specific knowledge about mass or volume, for example (Kloos, 2003). But how would children perform in response to conflicting evidence if their judgments are solely based on the simple rule? To find out, it would be necessary to create a laboratory world in which the more = more rule would conflict with knowledge obtained from wielding.

In the current study, children's apparent belief about the effect of mass on sinking speed (heavier objects sink faster than lighter objects) matched exactly with their wielding experience (heavier objects fall with greater downward force than lighter objects). However, suppose we changed the submarine race such that submarines race from the bottom of the tank to the top – a race determined by buoyancy. In this case, the object moves upwards not downwards (as they would in falling). Nevertheless it remains plausible to invoke a more = more belief, such as heavier or larger submarines rise faster. After calling to mind such beliefs, children can be confronted with controlled demonstrations that disconfirm false beliefs. Neither differences in mass nor differences in volume alone reliably predict the faster rising submarine. Instead it is an object's buoyancy, or – in simpler terms – an object's emptiness. Children's tendency to replace or retain their existing beliefs in this modified experimental setup would shed light on the sources of their beliefs and their more general response to disconfirming evidence.

Summary and Conclusions

The strong mass bias found in this experiment suggests that, under conditions that pit mass against volume, children rely on their experience of mass, as in wielding, to reason about sinking speed. Also, like Kloos and Summerville (2001), we demonstrated that preschool children can change mistaken beliefs about how mass and volume affect the sinking speeds of objects. They learn that two dimensions originally thought to be relevant in a physical domain are indeed irrelevant. Unlike the study of Kloos and Somerville (2001), however, the present calling-to-mind procedure never pointed out the reliable dimension for predicting sinking speed. Nevertheless, calling-to-mind mistaken beliefs still helps children learn reliable beliefs.

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