Preschoolers' Understanding of Gravity

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Abstract

Previous research suggests that preschoolers have logical or cognitive deficits that limit their understanding of gravity as an explanatory concept. Four experiments were designed to test whether, in contrast to the results from previous research, preschoolers have a coherent, consistent and theoretical understanding of gravity. In each study, preschoolers made judgments regarding objects' behavior in at least one gravity-related event (e.g., speed of falling objects, trajectory of thrown objects, the behavior of balance scales). Predictions were made about children's performance based on the hypothesis that preschoolers understand gravity to be a property of objects. Predicted age-related changes in causal judgments were found on each task, as were positive correlations in performances across the tasks. The results support the claim that preschoolers understand gravity as a property of objects, an understanding that undergoes conceptual change.

Introduction

Research from a variety of theoretical perspectives within cognitive-developmental psychology suggests that children's knowledge about the nature of the gravity develops over age. However, there is disagreement about the nature and process of the developmental change. Selman, Krupa, Stone, and Jacquette (1982) found a contingency between 5- to 20-year-olds' responses to an interview measure of gravity knowledge and measures of logico-mathematical reasoning. It was claimed that children in Piaget's preoperational stage, who lack logically reversible assimilatory structures, are only able to understand gravity as a cause-and-effect relation between an act (e.g., releasing an object) and an outcome (e.g., an object falling). These authors claimed that a complete understanding of gravity as an explanation of the behavior of objects is acquired only by adolescents who have previously acquired formal operations. Research from an information-processing perspective has focused on developmental changes in performance on gravity-related tasks. For example, Kaiser, Proffitt, and McCloskey (1985, Exp. 1) found that preschoolers incorrectly predicted that an object launched from a table would fall in a straight-down or inverted-L rather than a parabolic trajectory, regardless of whether the object was launched passively from a moving object or actively from an inclined plane. They also found (Exp. 2) that preschoolers predicted a straight-down trajectory for objects launched from a table at different speeds. Kaiser et al. claimed that young children lacked the necessary cognitive capacity and relevant experience to recognize that an object moves in a parabolic trajectory when launched from a table. Young children, they claimed, are only able to make predictions on the basis of the rule that objects fall straight-down when unsupported. Nussbaum and Novak (1976) also found that young children hold a straight-down direction rule when predicting the trajectory of objects falling in space.

These representative studies suggest that young children's understanding of gravity as an explanation of the behavior of objects is limited or constrained by cognitive or logical deficits. In this paper we present evidence from 4 studies testing the results from previous research. The major goal of this research is to demonstrate that young children have a theoretical, general, and consistent, albeit incorrect understanding of gravity as a property of objects.

Experiment 1: Preschoolers' Causal Knowledge About Gravity and Light

Children's ability to form theories has been questioned by studies showing that preschoolers lack the cognitive tools to explain many physical phenomena. For example, it is claimed that preschoolers do not understand that gravity (Selman et al., 1982) and light (DeVries, 1979; Piaget & Garcia, 1974) involve the action of a causal force. These studies were based on children's verbal explanations of weightlessness and free-fall (gravity-related events), and projection and shadows (light-related events). The first study tests this claim by assessing preschoolers' causal judgments (not verbal explanations) about the status of four variables with regard to gravity and light. Subjects made judgments regarding each variable's effect on the speed of falling objects and the length of objects' shadows. If children lack causal knowledge about light or gravity, then they should show an inconsistent pattern of judgments regarding the causal status of the variables.

Nine 4- and 5-year-olds (4 girls and 5 boys) were the subjects in the experiment. The children judged whether variation in height, distance, orientation, and weight influences the speeds of objects in free-fall and the length of objects' shadows. The free-fall task involved dropping two objects that landed on the table or an elevated box (distance), from one of two positions on a stand (height). The shadow task involved illuminating two objects that were placed on the table top or elevated on a box (distance), with flashlights placed in one of two positions on a stand (height). Each task was presented twice to subjects, using small rectangular wooden blocks and a six-piece lego structure. Both height and distance are causal variables (they influence the outcomes), whereas orientation and weight are not causal.

These latter variables were manipulated by turning the block or lego structure around (orientation), and by adding either another block or lego piece (weight). Subjects were randomly presented with either the shadow or gravity task first, then completed the second task. Use of the blocks or lego first was also randomly assigned for each subject. Each task was completed with the blocks and legos before the second task was presented.

Each problem was posed in the following way; for the free-fall task: "When I let them go, will the blocks (legos) hit the ground at the same time or at different times?" and for the shadows problem: "When I turn on the flashlight, will the blocks (legos) have shadows of the same length or different lengths?" If subjects judged that the objects' lengths or speeds would be different, they were then asked to specify the object that would hit first or have the longer shadow. Subjects' responses were coded as correct or incorrect. Subjects' mean percentage of correct judgments on the free-fall task (M= .65) was significantly higher than their mean on the shadow task (M= .38). Statistically, subjects' mean percentage of correct responses on the shadow task did not differ from the percentage expected from random responding (M= .33), whereas it did differ on the free-fall task. Moreover, the means for all variables on the free-fall task, except distance, were significantly different from random responding (*p*'s<.01), whereas none of the variables on the shadow task was significantly different (see Figure 1). That children predicted that weight was a noncausal factor was particularly interesting since many adults use a "heavier-faster" prediction strategy regarding the behavior of objects in free-fall (Gunstone & White, 1981).

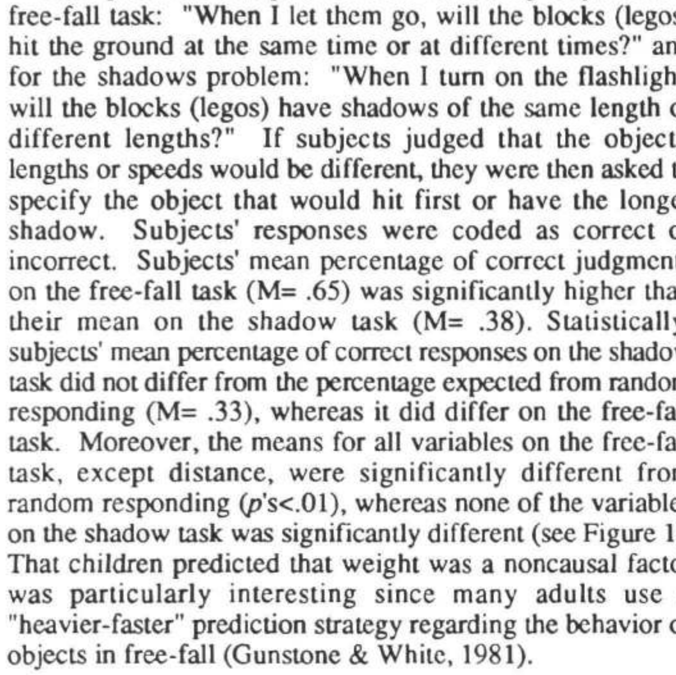

Figure 1: Percentage of correct predictions, Experiment 1

The results show that preschoolers make consistent judgments about the causal status of the variables regarding free-fall but not shadows. Two explanations can explain the task differences in preschoolers' performance. Preschoolers may have had more experience with gravity- (e.g., free-fall) than light-related events (e.g., shadows), which can account for the differences in task performance. Experience alone is likely an insufficient basis for making consistent judgments about the non-causal status of variables. However experience alone could be a necessary, but not a sufficient basis for making non-causal judgments because there are an infinite number of variables that are non-causally-related to an outcome. The second explanation of the results is that preschoolers have different concepts available to understand free-fall and shadows. It is proposed that childrens' performances are based on a materialistic understanding of gravity and a non-materialistic understanding of light. In a materialistic understanding it is assumed that light and gravity have a physical, material basis (Reiner, Chi, & Resnick, 1988). Without a materialized concept of light, children may know that light causes or produces shadows but have no basis for understanding how it does so. As a consequence, they would have no basis for inferring how variation in height and distance influences the length of shadows, or why weight and orientation are non-causal variables. On the other hand, children's material concept of gravity involves understanding that there is a force or mechanism that makes things fall. Shultz (1982) has demonstrated that an understanding of mechanisms is the fundamental basis of preschoolers' causal inferences. With respect to gravity, a material understanding supports inferences about the conditions under which the force or mechanism is the same for two objects (e.g., the non-causal variables of orientation and weight) or different for two objects (e.g., the causal variable of height).

Experiment 2: The Nature of Preschoolers' Understanding of Gravity

Despite having a material understanding of gravity, young children may still understand gravity not as an attraction between masses, but as a property of objects (Reiner, Chi, & Resnick, 1988). Experiment 2 tests the claim that young children have a material, object-oriented understanding of gravity. We hypothesized that with an object-oriented understanding of gravity, children would judge that the gravitational force within an object changes when its appearance or structural integrity is altered. In particular, it was predicted that children with an object-oriented understanding of gravity would make different predictions regarding the gravity-related behavior of objects that differ in appearance or integrity.

To test the hypothesis, 24 preschool, 24 first grade, 12 third/fourth grade, 12 sixth/seventh grade and 12 college students were given a free-fall task and a weight conservation task. The tasks were presented in random order. In the weight conservation task, subjects saw three transformations (rolled into sausage, cut in half, and cut into many pieces) of one of two identical play-doh balls, and, after each transformation, were asked: "Which one weighs more, or do they weigh the same?" The free-fall task involved presenting two play-doh "bricks" of equal size. The subject was then asked, "If the identical bricks are dropped at the same time and from the same height, will they land at the same time or at different times?" Upon agreeing that the bricks would land at the same time, the experimenter cut one brick into two, stuck the two pieces back together, and again asked "If the bricks are dropped at the same time and from the same height, will they land at the same time or at different times?" The subject could answer that the two would land at the same time (correct), that the intact object would land faster (intact faster), or that the altered object would land faster (altered faster). The task was repeated 10 times, with subjects being told that the brick would be cut into hundreds of pieces on the last repetition. It was predicted that if children conceive of gravity as a property of objects, then by destroying the integrity of one brick, the two bricks would be predicted to hit the table at different times.

Subjects were very consistent in their judgments, with over 95% of the subjects giving the same response on 6 out of 10 items. There was a statistically significant age-related increase in the percentage of subjects who consistently made correct predictions, and an age-related decrease in the percentage of subjects who consistently made intact faster predictions (see Figure 2). Perhaps predictions on the gravity task simply reflect a misunderstanding that the weight of the play-doh brick changes when it is cut up. That is, subjects may judge that the transformed object weighs a different amount than the intact object, and because of the difference in weight, predict that the intact and transformed objects behave differently. However, there was no contingency between performance on the conservation of weight task and the free-fall task within any age group.

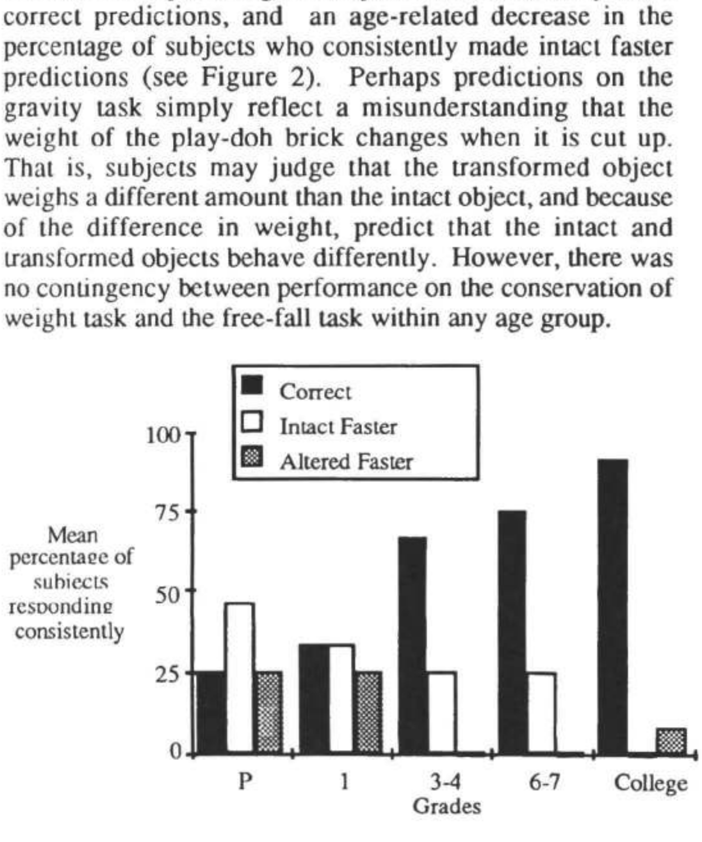

Figure 2: Subjects' responses on the free-fall task, Exp. 2

The results suggest that altering the integrity of objects influences preschoolers' predictions regarding the behavior of the objects in free-fall. But, by the elementary school years, children are no longer substantially influenced by the manipulation of the structural integrity of objects. When children make erroneous free-fall predictions, they are not based on a simple weight strategy (i.e., object perceived as heavier falls faster), since those subjects within each age group who conserved weight were no more likely to make correct free-fall judgments than those subjects who failed to conserve weight. Most significantly, the results suggest that preschoolers make predictions that could not be derived from experience alone. We suggest that the predictions are based on an understanding of gravity that is derived from theoretical assumptions as well as perceptual experiences. The theoretical assumption that children make is that gravity is a property of objects. No doubt preschoolers are capable of discovering properties of objects that affect their behavior; for example, that rubbery objects bounce, brittle objects break, and that spongy objects are pliable. In this case, children infer (rather than observe) that certain properties of an object are related to its behavior in free-fall.

Experiment 3: Predictions on the Free-fall and Trajectory Tasks

Experiments 1 and 2 provide evidence that children have a material and theoretical understanding of gravity as a property of an object. This result challenges Selman et al.'s claim that children are capable only of an empirical understanding of gravity due to general logical deficits (e.g., a lack of reversible operations). Experiment 3 focuses on Kaiser et al.'s claim that preschoolers employ a straight-down rule when making predictions regarding the trajectory of falling objects launched from a table. They claim that the straight-down rule results from preschoolers' cognitive limitations in integrating the horizontal and vertical vectors of motion and their lack of perceptual experience. We examine whether erroneous predictions regarding the trajectory of falling objects can be explained as due to children's understanding of gravity as a property of an object. If preschoolers' use of the straight-down rule reflects a material and theoretical understanding of gravity as a force internal to objects, then (a) use of the straight-down rule is theoretically deduced and not the result of cognitive limitations or perceptual inexperience, and (b) preschoolers will believe that there is a force internal to rather than operating on objects that causes them to fall in the straight-down trajectory. To test whether children believe that the straight-down rule reflects a theory-based belief regarding a force internal to objects, we tested whether preschoolers predict that objects launched from a horizontal plane can follow trajectories other than straight-down. If preschoolers predict that objects can follow a variety of different trajectories (including the parabolic trajectory), then use of the rule does not merely reflect a cognitive or perceptual deficit (they can integrate horizontal and vertical vectors) or a belief in an external force that operates on objects. In Experiment 3, preschool and college students made predictions regarding whether an object launched from a horizontal plane could follow a variety of different trajectories. Another purpose of Experiment 3 was to examine the generality of preschoolers' understanding of gravity. If their understanding of gravity is general, then there ought to be empirical relations between performances on the free-fall and trajectory tasks. This prediction is consistent with Carey's (1985) claim that children's knowledge of the world is structured in terms of theories with general explanatory concepts and causal beliefs used to understand a domain.

Nine preschoolers and 8 college students were given a revised version of Kaiser et al.'s trajectory task and a revised version of the free-fall task. The revised trajectory task involved presenting subjects with a block sitting on a cardboard box; near the box were arrangements of two hoops. Subjects were required to judge whether or not they could push the block off the box so that it would go though the arrangements of two hoops. The two hoops were arranged in five different ways to reflect three different trajectories. The two Violation trajectories involved arrangements of hoops that required the block to change its trajectory in midflight. The two Straight trajectories (straight-down and inverted "L") involved arrangements of hoops that required the block to follow a straight-down trajectory. Finally, the Parabolic trajectory involved the block following a parabolic trajectory. (See Figure 3.) The only feedback subjects were given was during a practice session in which they pushed the block through one hoop. In the revised free-fall task, subjects made 20 predictions regarding whether two objects (legos, blocks, and play-doh bricks) would hit the table at the same time or different times. The predictions were made in three conditions, reflecting whether (a) the objects were released from the same heights and there were no other differences between them (Identical condition), (b) the objects were released from different heights and there were no other differences between them (Relevant condition), and (c) the objects were released from the same height but one object was transformed in a way that altered its structural integrity, appearance, status as an object, or connection between components but not its mass (Irrelevant condition). Each subject made four predictions in the identical condition and eight each in the relevant and irrelevant condition.

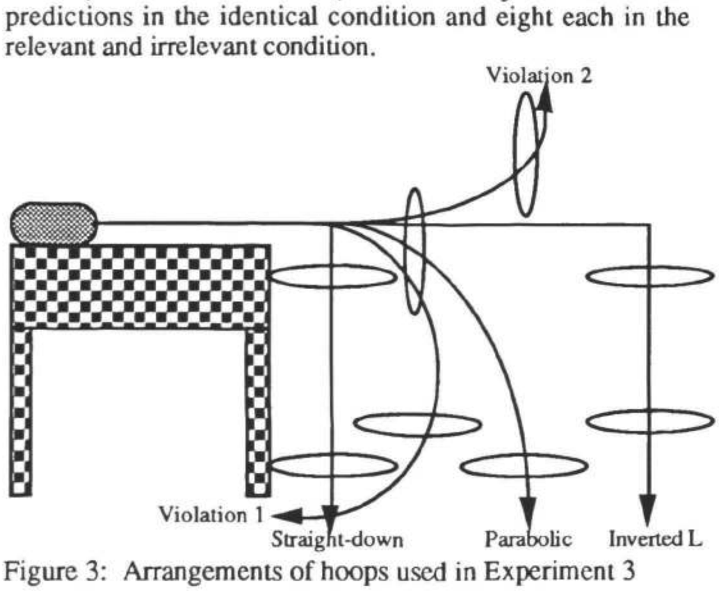

Figure 3: Arrangements of hoops used in Experiment 3

For the free-fall task, preschoolers' (M= .55) mean percentage of correct responses was significantly lower than adults' (M= .96). However, the mean percentage of correct responses by preschoolers was significantly above random responding in the identical (M= .66) and relevant (M= .61) conditions, but not in the irrelevant (M= .45) condition. Analyses of individual subjects suggested that 4 children consistently made the intact-faster judgment in the irrelevant condition, 1 made the transformed-faster, and 4 made correct judgments. A higher percentage of subjects consistently made correct predictions in this experiment (44%) compared to Experiment 2 (25%), although a chi-square analysis revealed no difference between the percentage of subjects in each experiment who made correct free-fall judgments.

The frequency of correct responses by subjects for the Violation, Straight and Parabolic trajectories was analyzed. Only the mean frequency of correct responses for the two Violation trajectories showed a significant age effect; the mean frequency of correct responses of college students (M= 1.62) for Violation trajectories was significantly higher than the mean for preschoolers (M= 0.44). The college students' means for the two Straight (M= 0.38) and the one Parabolic (M= 1.00) trajectories were not significantly different from the preschoolers' means (M= 0.33 and M= 0.78 respectively). The results show that the children believed that the block could be pushed through the hoops no matter what their arrangement, but they were only correct in their predictions on the Parabolic trajectory. In contrast, the college students correctly recognized the impossibility of pushing the block through the hoops in the Violation trajectory. Finally, there was a significant positive correlation (r= +.46) between subjects' total percentage of correct responses on the free-fall and the trajectory tasks.

The finding that children and adults were no different in predicting that objects can fall in straight or parabolic trajectories casts some doubt on Kaiser et al.'s claim that children's use of the straight-down trajectory rule reflects cognitive limitations and perceptual inexperience. Contrary to Kaiser et al.'s conclusion, the present results show that (a) preschoolers are not completely insensitive to the possibility that objects fall with integrated horizontal and vertical vectors, and (b) college students do not completely reject the possibility that objects fall without integrated horizontal and vertical vectors. Rather than reflecting cognitive limitations or perceptual inexperience, we propose that children's use of the straight-down trajectory rule reflects a theoretical belief: Under most circumstances objects fall straight down when unsupported. However, this belief does not imply that preschoolers assume that there is an object-independent gravitational force at work -- a force operating on objects rather than one internal to objects. Children also may believe that the internal force can be compromised by the way in which an object is set in motion.

The positive correlation between subjects' performance on the free-fall and trajectory tasks is a basis for claiming that an understanding of gravity underlies performance on the tasks. Such generality in children's understanding of gravity seems to be what Carey (1985) has in mind when she describes children as having theories constituted by explanatory concepts, causal beliefs, and a domain of application. Preschoolers' understanding of gravity as a property of objects may well be an explanatory concept, supporting causal beliefs regarding the role of object integrity in predictions of free-fall rates and the role of how objects are set in motion in predictions of object trajectory. However, the positive correlation can only be treated as preliminary evidence in support of such a explanation.

Experiment 4: Predictions on the Free-fall and Balance Scale Task

Experiment 3 provides preliminary support for Carey's claim that preschoolers have general explanatory concepts (e.g., gravity) that are used in explanations of phenomena (free-fall rates, object trajectories) within a domain (behavior of objects). The purpose of Experiment 4 was to extend the analysis of phenomena that are influenced by preschoolers' understanding of gravity as a property of objects. In particular, we examine whether children's understanding of gravity is related to their knowledge of the operation of balance scales. Siegler (1976) examined developmental changes in reasoning about balance scales and found that between the ages of 5 and 10 years, children change in making predictions about the behavior of balance scales that are based exclusively on the weights of blocks placed on the arms (Rule I), to making predictions based on the blocks' weights and distances from the fulcrum (Rule II), although not based on integrated information regarding weight and distance. We propose that there are direct connections between changes in reasoning on the balance scale and free-fall tasks, each reflecting a change in children's understanding of gravity as a property of an object. We hypothesized three ways in which children's performance on the free-fall task would be related to performance on the balance scale task. First, children's use of Rule I or Rule II on the balance scale task would be related to their percentage of correct judgments on the free-fall task. Second, just as preschoolers judge that alterations in the appearance but not the mass of objects makes them fall at different rates in the free-fall task, so will they predict that alterations in the appearance of objects on the arms of a balance scale will cause the scale not to balance. Third, there will be a relation between predictions regarding the behavior of balance scales and objects in free-fall.

Twelve preschool, 12 first-grade, 12 third-fourth grade, and 12 sixth-seventh grade students who were used in Experiment 2 were also given a revised version of Siegler's (1976) balance scale task (Amsel & Goodman, submitted). In the revised balance scale task, subjects make judgments regarding the causal status of the causally-relevant (weight and distance) and causally-irrelevant (color and orientation) variables. Weight was manipulated by placing a different number of equally weighted rectangular blocks on the arms of the scale. Distance was manipulated by having an equal number of blocks on the arms of the scale placed at different distances from the fulcrum. Color was manipulated by having an opposite number of black and white blocks (i.e., the total number on each arm was the same) placed equidistant from the fulcrum. Orientation was manipulated having an opposite number of rectangular blocks "lying down" and "standing up" placed equidistant from the fulcrum. Subjects made 8 different weight, distance, orientation, and color judgments. The balance scales were drawn on cards, but subjects were shown a working balance scale during a practice session. The free-fall task was the one described in Experiment 2. Approximately half the subjects received the balance scale task first and the other half received the free-fall task first. Subjects' percentage of correct, intact-faster, and altered-faster judgments on the free-fall task was computed, as was their frequency of correct predictions regarding the Weight, Distance, Orientation, and Color variables on the balance scale task. Subjects were judged as using Siegler's Rule I if at least 6 out of 8 of their Weight predictions were correct, and if less than 6 out of 8 of their Distance predictions were correct. Twenty-nine subjects (with a mean age of 7 years, 3 months) fit the description of using Rule I. Subjects were judged as using Siegler's Rule II if at least 6 out of 8 of their Weight and Distance predictions were correct. Thirteen subjects (with a mean age of 10 years, 7 months) fit the description of using Rule II. The 6 subjects who fit neither Rule I or Rule II tended to be from the preschool and first grade groups. These findings replicate Siegler's results.

To test Hypothesis 1, Rule I and Rule II subjects' mean frequency of correct (out of 10) responses on the free-fall task was compared. The mean frequency of correct free-fall judgments by subjects using Rule I on the free-fall task ($M= 3.90$) was significantly lower than the mean of subjects using Rule II ($M= 7.54$). However, this statistically significant difference between the groups drops to a difference that only approaches statistical significance ($p=.09$) when frequency of conservation of weight scores is used as a covariate in an ANCOVA. The ANCOVA procedure was used so that the relation between the tasks do not reflect shared variance due to other general factors associated with cognitive development. To test Hypothesis 2, developmental changes in performance on the Color and Orientation variables on the balance scale task were examined. Preschoolers' mean frequency (out of 8) of correct color judgments ($M= 6.67$) was significantly lower than the means for the 5th/6th-graders ($M= 8.00$), but not different than the 1st- ($M= 7.73$) and 2nd/3rd-graders ($M= 7.75$). Similarly, preschool ($M= 3.92$) and 1st-grade ($M= 4.18$) students' mean frequency of correct Orientation predictions were significantly different then the 6th/7th-grade students' mean ($M= 7.50$), but not different than the 2nd/3rd-grade students' mean ($M= 6.00$). To test Hypothesis 3, children's frequency of correct predictions on the free-fall task (maximum score of 10) was correlated with their frequency of correct predictions regarding the causal status of the orientation and color variables (maximum score of 8 for each variable). A partial correlation procedure was used which removed children's performance on a conservation of weight task. Subjects' frequency of correct free-fall judgments was significantly ($p<.05$) and positively correlated with their frequency of correct judgments regarding the noncausal status of Color ($r= .25$) and Orientation ($r= .31$).

The results suggest that age-related changes in predictions regarding the behavior of balance scale variables are directly related to age-related changes in predictions regarding the rate of objects in free-fall. Why should this be? We propose that it is best explained as a restructuring in children's understanding of gravity. Children who believe that gravity is a property of objects should make incorrect free-fall predictions because the change in the appearance of the blocks marks different amounts of gravity in the blocks. Moreover, such children should predict that variation in blocks' orientation and color (an appearance-altering transformation) makes a difference in the behavior of the balance scale, whereas variation in distance (a transformation that does not alter appearance) makes no difference. This pattern of results seem to capture the performance of 5-year-olds, who made correct free-fall, distance, orientation and color judgments less often than older subjects. In contrast, 11-year-olds made correct free-fall, distance, orientation and color judgments more often than younger subjects. By 11 years of age it seems that children recognize that gravity involves some relation between an object and the earth, rather than exclusively being a property of objects.

While many other phenomena no doubt develop during the years between 5 and 11 that may underlie development on both the free-fall and balance scale tasks, there is some reason to believe that the relation is direct and not due to a third variable associated with cognitive development. There were significant correlations between correct free-fall judgments and correct orientation and color judgments, despite removing the influence of subjects' conservation of weight scores. However, the difference between Rule I and Rule II subjects in their frequency of correct free-fall judgments only approaches significance when conservation of weight score is used as a covariate.

Conclusion

The major goal of this research was to demonstrate that young children have a theoretical, consistent, and general, albeit incorrect, understanding of gravity as a property of objects. Evidence for the theoretical nature of preschoolers' understanding of gravity as a property of objects comes from Experiment 1, in which preschoolers were shown to have a material understanding of gravity and Experiments 2 and 3, in which preschoolers were shown to believe that free-fall is influenced by an object's structural integrity, a variable which in reality does not make a difference. Evidence for the consistency of preschoolers' understanding of gravity as a property of objects comes from Experiment 2, in which (a) almost all subjects made consistent predictions regarding the rate of free-fall of two objects that were identical except that one object's structural integrity was damaged, and (b) a majority of the preschoolers predicted that the intact object would fall faster. This latter result was replicated in Experiment 3, in which 4 of 9 preschoolers predicted that an object's free-fall behavior is affected when its structural integrity (and other transformations in an object's appearance) is altered. Evidence for the general nature of preschoolers' understanding of gravity as a property of objects comes from Experiments 3 and 4, in which performance on the free-fall task was correlated with performance on the trajectory and balance scale tasks. The claim that preschoolers have a theoretical, consistent, and general, albeit incorrect, understanding of gravity as a property of objects is inconsistent with hypotheses based on previous research that preschoolers' understanding of gravity is the result of a deficit. Hypotheses following from the notion that children's understanding of gravity was due to logical limitations, or both a cognitive deficit and perceptual inexperience were tested and rejected in Experiments 1 and 3. In general we prefer a conceptual-change explanation of the data (Carey, 1985; Vosniadou & Brewer, 1987). According to this explanation, preschoolers' understanding of gravity as a property of objects serves as an explanatory concept within a theory regarding the behavior of objects and also serves as a basis for causal and non-causal beliefs across a variety of tasks.

References

Amsel, E., & Goodman, G. (Submitted). Developmental changes in children's understanding of the behavior of balance scales.

Carey, S. (1985). *Conceptual change in childhood.* Cambridge MA: MIT.

DeVries, R. (1979). Children's concept of shadow phenomena. *Genetic Psychology Monographs, 112*, 479-530.

Gunstone, R., & White, R. (1981). Understanding gravity. *Science Education, 65*, 291-299.

Kaiser, M., Proffitt, D., & McCloskey, M. (1985). The development of beliefs about falling objects. *Perception and Psychophysics, 38*, 533-539.

Nussbaum, J., & Novak, J.D. (1976). An assessment of children's concepts of the earth utilizing structured interviews. *Science Education, 60*, 535-550.

Piaget J., & Garcia, R. (1974). *Understanding causality.* New York: W.W. Norton.

Reiner, M., Chi, M., & Resnick, L. (1988). Naive materialistic belief: An underlying epistemological commitment. *Conference of the Cognitive Science Society, 10*, 544-551.

Selman, R., Krupa, M., Stone, C., & Jacquette, D. (1982). Concrete operational thought and the emergence of the concept of unseen force in children's theories of electromagnetism and gravity. *Science Education, 66*, 181-194.

Shultz, T.R. (1982). Rules of causal attribution. *Monographs of the Society for Research in Child Development, 47*, (1, Serial No. 194).

Siegler, R. (1976). Three aspects of cognitive development. *Cognitive Psychology, 8*, 481-520.

Vosniadou, S., & Brewer, W. (1987). Theories of knowledge restructuring in development. *Review of Educational Research, 57*, 51-67.