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Everyday conceptions of object fall: Explicit and tacit understanding during middle childhood

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ABSTRACT

Adults make erroneous predictions about object fall despite recognizing when observed displays are correct or incorrect. Prediction requires explicit engagement with conceptual knowledge, whereas recognition can be achieved through tacit processing. Therefore, it has been suggested that the greater challenge imposed by explicit engagement leads to elements of conceptual understanding being omitted from prediction that are included in recognition. Acknowledging that research with children provides a significant context for exploring this "omission hypothesis" further, this article reports two studies with 6- to 10-year-olds, each of which used prediction and recognition tasks. Study 1 ($N = 137$) focused on understanding of direction of fall, and Study 2 ($N = 133$) addressed speed. Although performance on the recognition tasks was generally superior to performance on the prediction tasks, qualitative differences also emerged. These differences argue against interpreting explicit level understanding purely in terms of omission of tacit constructs, and the article outlines alternative models that may account for the data.

Introduction

Although philosophers and natural scientists have discussed the physics of object fall for centuries, psychological work on the topic only began during the 1980s, when research with undergraduates produced two important sets of results. The first set (e.g., McCloskey, 1983; Whitaker, 1983) covers the direction in which objects are predicted to travel when they fall after moving horizontally, as when balls roll over cliffs or litter is dropped from moving vehicles. The main message is that moving objects are predicted to fall vertically, travel backward, fall diagonally forward, or continue

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horizontally in space (due to an impetus-like force) before making a 90° turn and falling. However, they are seldom predicted to trace the parabolic paths in a forward direction that they actually follow. The second set of results relates to the speed with which objects are expected to fall, emphasizing fall from rest (e.g., Champagne, Klopfer, & Anderson, 1980; Gunstone & White, 1981) but occasionally considering fall after horizontal motion (e.g., Maloney, 1988; Whitaker, 1983). One message is that when objects vary only in mass, heavy items are typically predicted to fall faster than light items, not travel at speeds that, even taking air resistance into account, are actually almost identical. Another is that, regardless of mass, objects are expected to reach maximum velocity quickly and then fall with constant velocity.

Nevertheless, in marked contrast to these prediction errors, undergraduates have proved successful at differentiating anomalous fall from veridical fall. For example, Kaiser, Proffitt, Whelan, and Hecht (1992) found that when undergraduates viewed computer-simulated kegs falling from aircraft, they consistently judged forward parabolas as correct and other trajectories as incorrect. Yet the trajectories they drew in prediction displayed all of the errors listed above. When Shanon (1976) presented videotapes of balls falling with constant or accelerating velocity, he found constant velocity to be consistently judged as incorrect, whereas acceleration was regarded as correct. Yet on a prediction task, many students anticipated constant velocity. This gap between recognition and prediction has been widely construed in terms of relative explicitness (e.g., Karmiloff-Smith, 1992; Kim & Spelke, 1999). Prediction requires explicit engagement with conceptual knowledge; that is, scenarios must be related to underlying conceptions and relations must be considered and used to draw inferences. In other words, there is "deliberation" (Hogarth, 2001) and "reflection" (Plessner & Czenna, 2008). By contrast, recognition of veridicality demands only that scenarios be matched with conceptions. Matching does not necessitate consideration and inference, so in principle nonreflective, perhaps unconscious, processing suffices. Kim and Spelke (1999) and Hogarth (2001) referred to this form of processing as "tacit."

Noting the additional steps (and hence greater challenge) associated with explicit engagement, Kim and Spelke (1999) proposed that the gap between prediction and recognition may result from omission at the explicit level of elements that are tacitly appreciated. This "omission hypothesis" concurs with much of the above research given that much could be interpreted as discounting forward velocity when predicting direction or considering one moment (rather than comparing across time) when predicting speed. Moreover, in addition to providing a straightforward account of task performance, the hypothesis also suggests a plausible model of conceptual development: Notions of object fall that initially are only grasped tacitly gradually become accessible at the explicit level (see also Karmiloff-Smith, 1992). Yet despite these appealing features, the omission hypothesis can be questioned. Addressing number (not motion), Carey (2009) identified conceptions that are accessed at the explicit level that cannot be partial versions of tacit knowledge. Moreover, when students recognize forward parabolas as correct after horizontal motion, it is difficult to regard the impetus-like forces and backward trajectories (which, as noted, they sometimes predict) as explicit-level omissions of what is tacitly understood. On the face of it, they introduce something new rather than omit what exists. Yet their status is unclear given that they could, in principle, reflect tacit conceptions from some earlier stage. Just because undergraduates recognize the veridicality of forward parabolas does not necessarily mean that children do this as well. Perhaps there is a period when children judge impetus-laden or backward trajectories as correct, and this exerts residual influence when they engage explicitly.

Acknowledging the omission hypothesis's attractive yet uncertain status, we report two studies that compare performance on tasks that require and do not require explicit engagement with conceptions about object fall. The studies' primary aim was to establish whether errors on the former tasks could be interpreted as omission at the explicit level of what is tacitly understood. In the interest of obtaining comprehensive information about object fall, one study addressed direction and the other addressed speed. Noting the developmental significance of the issue together with potential ambiguities in research with adults, the studies were conducted with children.

Children's understanding of object fall

Although research into children's understanding of object fall has been conducted, it focuses on tasks that require reflection and inference and, therefore, explicit engagement with conceptual knowledge. It does not typically make comparisons with tasks that can be completed tacitly. Moreover, even at the explicit level, specification is incomplete. For instance, there are studies concerned with children's expectations about the direction of fall after horizontal motion (e.g., Anderson, Tolmie, Howe, Mayes, & Mackenzie, 1992; Eckstein & Shemesh, 1989; Hood, 1995; Kaiser, Proffitt, & McCloskey, 1985; Krist, 2000; Marioni, 1989). Many use elicited predictions, but some invite children to plan and execute actions, for instance, dropping a ball while running so that it hits a target. Regardless of method, the main finding is widespread anticipation of vertical fall, with occasional reference to alternative trajectories. However, whereas Krist (2000) indicated increasing anticipation during middle childhood of forward (not necessarily parabolic) trajectories, Marioni's (1989) work with comparable age groups suggested increasing expectation of backward fall. The potential significance of backward fall has been noted already; therefore, the discrepancy requires resolution. At the same time, Anderson and colleagues (1992) indicated effects from object mass. Vertical fall is frequently anticipated with heavy objects (e.g., pirate chests from drifting ships); continued horizontal motion with a 90° turn is associated with light objects, especially with rapid pre-fall velocity (e.g., bullets from guns). Strangely, few studies have addressed the direction that children anticipate when there is no pre-fall motion. Vertical fall from stationary positions is presumed but not documented.

Complementing research that demands explicit engagement with conceptions, Kim and Spelke (1999) examined children's understanding of direction of fall when tacit processing suffices. Five studies were conducted with 7-month-olds, all involving the monitoring of gaze toward parabolic fall after horizontal motion (i.e., correct) and horizontal, diagonal, or vertical fall (i.e., incorrect). Following established traditions in infancy research, understanding was inferred to the extent that looking time was greater after incorrect motion than after correct motion. Seven further studies were conducted with 2- to 6-year-olds, some involving gaze monitoring and some involving judgments of whether the motion looked silly or not (akin to the approach used with undergraduates detailed above). From 2 years of age onward (and regardless of method), children were less willing to accept vertical fall as correct when compared with parabolic fall, suggesting some understanding. Yet there were no signs at any age of horizontal or diagonal motion being rejected in favor of parabolic motion, implying that understanding was incomplete. In addition, Kim and Spelke did not vary object mass even though, as noted, this has been found to influence predicted trajectories. Finally, the single study that tapped explicit engagement required children to predict the endpoint of fall, not the trajectory. Therefore, the results are not strictly comparable with the other data.

Research into children's understanding of the speed with which objects fall is restricted to tasks that require explicit engagement with conceptual knowledge with an emphasis on object effects (e.g., Chinn & Malhotra, 2002; Hast & Howe, 2009; Howe, 1998; Nachtigall, 1982; van Hise, 1988). Object mass has proved to be a significant factor for all age groups. However, some research (e.g., van Hise, 1988) indicates change during middle childhood from expecting light objects to fall quickly to expecting heavy objects to do so, whereas other studies (e.g., Hast & Howe, 2009; Howe, 1998) suggest a majority expectation at all ages that heavy objects fall fastest. At the same time, reference to object size is also widespread (Hast & Howe, 2009; Howe, 1998). Regarding speed change during fall, Hast and Howe (2009) and Nachtigall (1982) found that children have little understanding of acceleration through air. However, it is unclear (a) whether deceleration is anticipated or (like undergraduates in research summarized above) constant speed and (b) what is expected when the medium changes from air to, say, water. Children recognize the inhibitory properties of barriers when reasoning about horizontal motion (Gunstone & Watts, 1985; Howe, 1998; Howe, Taylor Tavares, & Devine, 2008), and they may see water as a barrier during fall, thereby anticipating deceleration on impact. On the other hand, children occasionally think that water sucks objects down (Howe, 1998), signaling that acceleration might also be expected.

To date, then, research relating to object fall provides limited and partially contradictory information about the understanding that children display when tasks require explicit engagement with conceptual knowledge. Research into the understanding displayed when tasks can be accomplished tacitly is restricted to direction, and even there it is incomplete. Thus, there is no evidence for performance gaps between the two types of task, let alone for consistency with the omission hypothesis. To address these limitations, our studies each used both types of task and ensured that task design optimized comparison. In particular, the studies employed *prediction tasks* to trigger explicit engagement with conceptual knowledge, specifically predictions about a ball's direction (Study 1) or speed (Study 2) when falling. As discussed, research relating to direction has sometimes required children to plan actions rather than predict outcomes, with both involving explicit engagement. Predictions were preferred because (a) they permit detailed exploration of trajectories and (b) although planning could be used to examine direction, its deployment with speed would be challenging. In addition, prediction allowed a closer match, especially over language demands, with the *recognition tasks* that were used to assess understanding when tacit processing suffices. These tasks involved watching computer-presented scenarios where a ball fell and judging whether the motion looked correct. Some scenarios showed correct motion, and others showed incorrect motion. As mentioned, recognition tasks that involve judgment of correctness have been used successfully with undergraduates and children. In view of the contextual factors that the literature identifies, prediction and recognition scenarios were varied over (a) whether the ball was stationary or moving prior to fall, (b) the ball's mass and size, and (c) whether the medium changed during fall or remained constant. The studies were conducted with 6- to 10-year-olds because middle childhood is when contradictions have emerged in the literature. The key question with both studies was whether, when compared with performance on the recognition tasks, performance on the prediction tasks is interpretable as omission at the explicit level of what is tacitly understood.

Study 1

Study 1 examined understanding of direction of fall as a function of (a) children's age (6, 8, or 10 years, *age* variable), (b) pre-fall motion (moving or stationary, *motion* variable), (c) type of ball (small light, small heavy, or large heavy, *ball* variable), and (d) medium of fall (air-only or air-plus-water, *medium* variable). Regarding prediction task hypotheses, Krist (2000) and Marioni (1989) suggested changes with age without being consistent about their nature. With the motion variable, research has focused on descent after pre-fall motion rather than comparing moving and stationary positions. Nevertheless, when substantial difficulties are reported at all ages and paths are often erroneously expected to be vertical, greater success can be expected with predicting vertical fall from rest than forward parabolas after motion. For type of ball, Anderson and colleagues (1992) indicated that difficulties with moving scenarios should be particularly marked with the two heavy balls. On the other hand, background research provides no grounds for anticipating effects from the medium. As noted, Kim and Spelke (1999) suggested that children sometimes recognize the veridicality of parabolic fall after pre-fall motion, but their work did not cover the full range of variables that Study 1 addressed. As a result, recognition task hypotheses were regarded as premature.

Method

Participants

Participants were recruited from state primary schools located in rural and predominantly middle-class areas of East Anglia in the United Kingdom. Government statistics suggest that the schools cover a wide ability range, with a mean that is slightly above the national average. All children in the relevant age groups received parental consent to participate. However, absence from school meant that 3 children completed only one of the two tasks, so their data were discounted. With these children excluded, the sample comprised 45 Year 2 children (15 girls and 30 boys, mean age = 6.69 years, *SD* = 0.47), 45 Year 4 children (21 girls and 24 boys, mean age = 8.82 years, *SD* = 0.39), and 47 Year 6 children (20 girls and 27 boys, mean age = 10.85 years, *SD* = 0.36).

Materials

The main materials were computer-presented scenarios (viewable at http://www.educ.cam.ac.uk/research/projects/objectmotion) that were programmed using Macromedia Director. The scenarios showed a girl in a hot air balloon holding and then dropping one of three balls. Real equivalents of the balls were available for handling during the study (small light = 10 g, 7 cm diameter; small heavy = 500 g, 7 cm diameter; large heavy = 500 g, 32 cm diameter). Besides varying the balls, the scenarios differed over whether the balloon was stationary or moving when the ball was dropped and whether the ball fell through air onto grass or into a swimming pool. The program recorded responses (detailed below) and latency to respond in milliseconds. However, for simplicity, latency is not considered further because its implications are identical to those stemming from responses.

A total of 12 scenarios was prepared for Study 1's prediction task, amounting to all possible combinations of ball, motion, and medium. Scenarios focusing on motion through air were placed together in a block, as were scenarios focusing on motion through air and water. Both blocks were preceded by one practice trial (randomly selected from the set of 12 and repeated later). Each time the task was presented, the order of blocks and of scenarios within blocks was randomly varied via the computer program. At the start of each scenario, the instruction "Notice which ball is being used in this trial" appeared to the right of a close-up of the girl and ball. Clicking a button labeled "Ready" in the bottom right corner of the screen caused the picture to zoom out so that the whole scenario was visible. The instruction "Notice if the balloon moves" was presented on-screen, and clicking a button labeled "Go" in the bottom right corner activated the scenario; that is, with stationary scenarios the ball was released, and with moving scenarios the balloon moved part-way across the screen before release.

At the moment of release, the action froze and three small white circles appeared: (a) directly under the ball, (b) behind the ball, and (c) in front of the ball. The "behind" and "in front" options were positioned to comply with parabolic paths, but because this set of circles was close to the balloon, they also looked compatible with diagonal paths (see Fig. 1A). The instruction to notice if the balloon moved was replaced with an instruction to select the next point of travel. Once a circle was chosen, this turned red and the other circles disappeared. At the same time, three further white circles appeared below the selected circle. If the selected circle was directly under the ball, the new circles were directly below, behind, and in front. If the selected circle was behind the ball, the new circles were directly below, parabolically behind, and diagonally behind. If the selected circle was in front of the ball, the new circles were directly below, parabolically in front, and diagonally in front. The instruction to select the next point also reappeared. Once a second circle was chosen, this too turned red and the other circles disappeared. The two red circles in Fig. 1B show the correct combination had the balloon been moving and one possible incorrect combination had the balloon been stationary. With the air-only scenarios, a third set of white circles appeared just above the grass in the same relative positions as the second set (see Fig. 1B). With the air-plus-water scenarios, this third set was below the water's surface (just below with the small light and large heavy balls because they float in water and on the pool's floor with the small heavy ball because it sinks). Although the circles were positioned as in the second set, the parabolic options were adjusted to take account of water resistance. After the final circle was selected, clicking "Next" at the bottom right of the screen initiated another scenario.

There were 24 scenarios in Study 1's recognition task, organized into two blocks according to medium, with each block preceded by a practice scenario. The order of blocks and of scenarios within blocks was randomly varied each time the task was presented. The recognition scenarios started in the same fashion as the prediction scenarios (with the same instructions) but continued rather than froze when the ball was released. In 12 cases continuation involved the ball falling with the correct trajectory, and in 12 cases it involved an incorrect trajectory. Speed of falling was always correct. Both correct and incorrect scenarios covered all possible combinations of ball, motion, and medium. With the stationary scenarios, incorrect motion involved six forward and six backward parabolas, whose distribution across the various combinations of medium and ball was randomly varied via the computer program for each task presentation. With the moving scenarios, incorrect motion involved six backward parabolas and six vertical fall, again distributed in a randomly varying fashion across the combinations. Just before an invitation to click "Go" to activate a scenario, an instruction to "Watch where the ball goes as it falls" was presented to the right of the picture. Once the ball had fallen, this instruction was replaced with "Did the ball fall correctly?" with two buttons appearing below the question labeled "Yes" and "No." After responding, selecting a button labeled "Next" initiated the next scenario.

Besides the scenarios, we developed a questionnaire to assess experience with computers. Questions relating to computer *use* addressed how often computers were employed at home and school, with scores of 0 (*never using*) to 4 (*using many times per day*) allocated for each context. Questions relating to *variety* of use covered playing games, writing stories/letters, drawing pictures, listening

Fig. 1. Response options for Study 1 prediction task. (A) First set of options (white circles). (B) Third set of options (white circles) after two selections (red circles).

to music, using the internet, sending e-mail, and chatting with friends. Questions addressed whether each activity was performed in class, during playtime/lunch, or after school. Possible scores ranged from 0 (*not performed on a computer*) to 3 (*performed on a computer in all three contexts*).

Procedure

The prediction and recognition tasks were completed in private rooms at the schools and presented on Dell Latitude D820 laptops (screen = 22.25 cm height × 34.45 cm width). The children came one-by-one to perform the tasks, which were presented 2 weeks apart. For a randomly chosen 50% of each age group, the prediction task was the first task; for the other 50%, the recognition task was first. The first task began with a researcher providing an overview, inviting participation, and (with consent to continue, which was given in all cases) obtaining basic demographic information. Thereafter, the researcher directed the children to the computer, ensuring that they were seated approximately 60 cm from the screen. She produced the three balls in a randomly varying order, passing each one for handling and explaining how the balls would feature in the scenarios. The researcher then led the children through the first practice scenario, showing them how to respond using the computer mouse and noting which hand was used. With subsequent scenarios, she positioned the mouse to facilitate use with the preferred hand. The researcher was available throughout to offer procedural guidance, assist with reading (sometimes required with the youngest children), and ensure that the shift from air-only to air-plus-water or vice versa (and the accompanying practice scenario) was noticed. She presented the questionnaire relating to computer experience once the first task was completed, reading the questions aloud and recording oral responses on coding sheets. The second task was presented in the same way as the first, albeit with truncated introduction due to familiarity. Both tasks took between 10 and 15 min.

Results

We analyzed the data in two stages, the first examining overall accuracy and the second considering the trajectories that were chosen. Prediction task accuracy was assessed via the percentage of scenarios where all three selected circles were correct. Recognition task accuracy was assessed via the percentage of correct responses to "Did the ball fall correctly?" Accuracy on both tasks was independent of the order in which tasks were presented and children's gender, handedness, and computer use scores. Therefore, we ignored these factors for the main analyses. With the prediction task only, there was a significant correlation between accuracy and scores for computer variety, but when we explored the effects of the major variables via analysis of covariance (ANCOVA) with variety as the covariate, (a) results were equivalent to those obtained without the covariate and (b) covariate effects were nonsignificant. Therefore, we ignored variety in the analyses that are reported below. (Unreported analyses, including those of response latency, are available on request.) Analyses were performed using PASW Statistics (Version 18, SPSS, Chicago, IL, USA).

Prediction task

We explored accuracy on the prediction task via a 3 (Age: Year 2, Year 4, or Year 6) × 2 (Motion: stationary or moving) × 3 (Ball: small light, small heavy, or large heavy) × 2 (Medium: air-only or air-plus-water) mixed-model analysis of variance (ANOVA), with repeated measures on the last three factors. Of the significant effects, the strongest was the hypothesized effect of motion, $F(1,134) = 377.43$, $p < .001$, $\eta_p^2 = .74$. As expected, the children found scenarios where the ball was dropped from a stationary position much easier than scenarios where the ball was initially moving (see Table 1). Moreover, with the stationary scenarios performance improved with age and varied with ball, whereas with the moving scenarios it was poor regardless of age or ball. As Table 1 shows, it was the stationary scenarios that were responsible for the significant main effects of age, $F(2,134) = 4.27$, $p < .05$, $\eta_p^2 = .06$, and ball, $F(2,268) = 6.04$, $p < .001$, $\eta_p^2 = .04$, and for the significant Age × Motion interaction, $F(2,134) = 3.17$, $p < .05$, $\eta_p^2 = .05$, and Motion × Ball interaction, $F(2,268) = 7.33$, $p < .001$, $\eta_p^2 = .05$. Thus, the hypothesis that ball effects would be associated with the moving scenarios was not supported. A significant Age × Ball interaction, $F(4,268) = 3.59$, $p < .01$, $\eta_p^2 = .05$, resulted from the age-related improvements being restricted to the two heavy balls. The Age × Motion × Ball interaction was not statistically significant, nor was the main effect of medium or any interaction involving medium.

Acknowledging inconsistencies in the literature over age differences in the anticipation of backward, vertical, or forward trajectories, we classified the paths that were revealed through the selected circles as backward (first circle behind the ball), vertical then backward (first circle under the ball and

Table 1
Mean percentages accuracy on Study 1 prediction task as a function of age, motion, and ball.

	Small light	Small heavy	Large heavy	All balls
Stationary scenarios				
Year 2	51.1 (44.6)	50.0_1 (44.0)	51.1_1 (44.6)	50.7_1 (36.9)
Year 4	52.2 (45.2)	65.6_{12} (42.4)	70.0_2 (37.5)	62.6_{12} (35.0)
Year 6	56.4 (45.0)	81.9_2 (32.0)	72.3_2 (37.3)	70.2_2 (29.5)
All children	53.3_a (44.6)	66.1_b (41.5)	64.6_b (40.7)	61.3 (34.6)
Moving scenarios				
Year 2	3.3 (12.6)	1.1 (7.5)	1.1 (7.5)	1.9 (5.3)
Year 4	4.4 (14.4)	1.1 (7.5)	3.3 (12.6)	3.0 (6.4)
Year 6	2.1 (10.2)	3.2 (12.4)	3.2 (12.4)	2.8 (8.7)
All children	3.3 (12.4)	1.8 (9.4)	2.6 (11.0)	2.6 (7.0)

Note: Standard deviations are in parentheses. When numeric subscripts within columns differ (across the first three rows), means are significantly different (Bonferroni, $p < .05$). When alphabetic subscripts in rows differ (across the first three columns), means are significantly different (Bonferroni, $p < .05$).

Table 2
Mean percentages frequency of trajectories used during Study 1 prediction task.

	Year 2	Year 4	Year 6	$F(2,134)$
Stationary scenarios				
Backward	11.5_b (9.7)	3.3_a (4.6)	2.5_a (3.6)	9.52 ($p < .001$)
Vertical then backward	9.7 (9.2)	9.3 (8.4)	11.3 (11.1)	0.22, *ns*
Vertical	50.7_a (22.2)	62.5_{ab} (21.0)	70.2_b (17.7)	3.84 ($p < .05$)
Vertical then forward	13.7 (11.3)	16.0 (9.6)	10.3 (6.2)	1.07, *ns*
Forward	14.5_b (11.4)	8.8_{ab} (8.1)	5.7_a (8.4)	3.66 ($p < .05$)
Moving scenarios				
Backward	12.2 (10.5)	18.9 (16.5)	24.5 (17.2)	2.74, *ns* ($p = .07$)
Vertical then backward	7.3_a (7.8)	19.7_{ab} (15.1)	33.0_b (19.8)	11.76 ($p < .001$)
Vertical	45.6 (22.9)	40.4 (22.4)	29.0 (17.9)	2.64, *ns* ($p = .07$)
Vertical then forward	13.4 (12.0)	11.9 (11.2)	5.7 (7.3)	2.58, *ns* ($p = .08$)
Forward	21.5_b (15.3)	9.2_a (6.6)	7.8_a (13.8)	5.89 ($p < .01$)

Note: Standard deviations are in parentheses. When alphabetic subscripts within rows differ, means are significantly different (Bonferroni, $p < .05$).

at least one subsequent circle behind the ball), vertical (all circles directly under the ball), vertical then forward (first circle under the ball and at least one subsequent circle in front of the ball), and forward (first circle in front of the ball). As can be inferred from Table 1, the modal response at all age levels with the stationary scenarios was correct vertical fall. However, errors occurred, and as Table 2 shows, they were oriented in both possible directions. The table also highlights a reduction with age in backward and forward errors with the stationary scenarios (but not vertical then backward or forward), indicating that this was the source of the age-related improvement identified above. With the moving scenarios, Table 2 confirms the prevalence of vertical paths that previous studies reported while also showing marked decreases with age in forward or vertical then forward paths (combined in Fig. 2) and marked increases in backward or vertical then backward paths (also combined in Fig. 2).

Recognition task

We examined accuracy on the recognition task via a 3 (Age: Year 2, Year 4, or Year 6) × 2 (Correctness: correct motion or incorrect motion) × 2 (Motion: stationary or moving) × 3 (Ball: small light, small heavy, or large heavy) × 2 (Medium: air-only or air-plus-water) mixed-model ANOVA, with repeated measures on the last four factors. As with the prediction task, there was a strong main effect of motion, $F(1,134) = 204.39$, $p < .001$, $\eta_p^2 = .60$. The stationary scenarios ($M = 87.2\%$, $SD = 18.3$) proved to be easier than the moving scenarios ($M = 55.2\%$, $SD = 20.6$). There was also a significant main effect of correctness, $F(1,134) = 6.57$, $p < .01$, $\eta_p^2 = .05$, albeit much weaker than the effect of motion. The scenarios that displayed correct motion ($M = 74.3\%$, $SD = 17.3$) were easier than the scenarios that

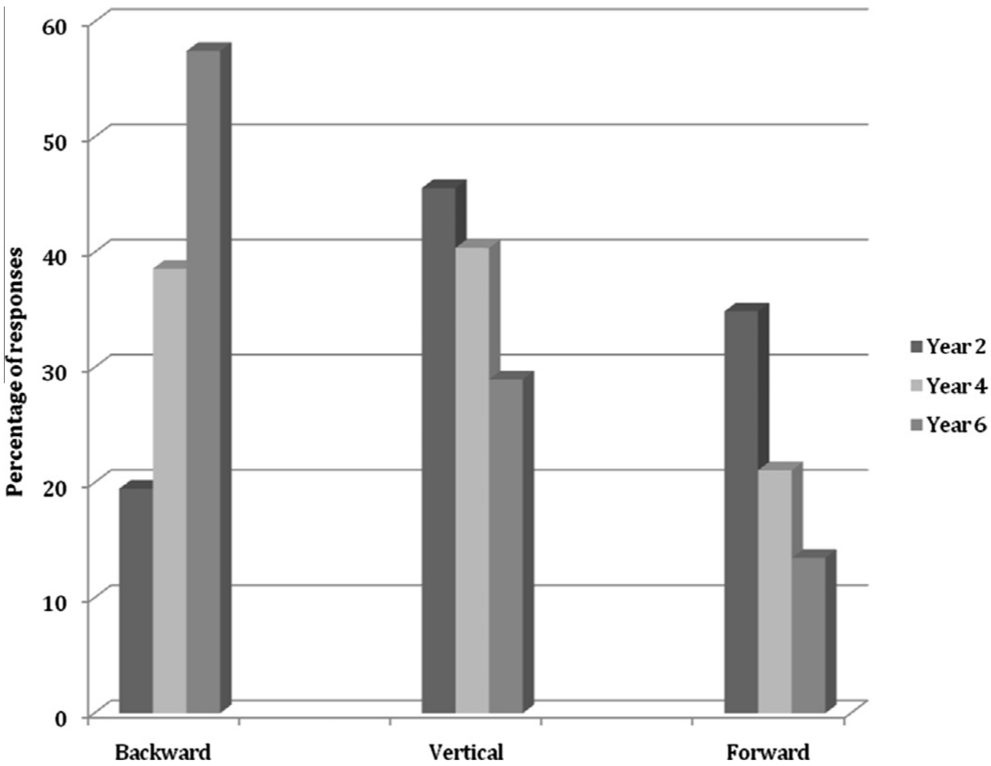

Fig. 2. Backward, vertical, and forward trajectories as a function of age group (Study 1 prediction task).

displayed incorrect motion (*M* = 68.2%, *SD* = 22.4). Of interest are responses to the moving scenarios that displayed incorrect motion because 50% of these involved backward fall and backward responses increased with age on the prediction task. In fact, 83.7% of errors with the incorrect moving scenarios resulted from vertical fall being erroneously accepted. Only 22.4% of backward scenarios were accepted, and this percentage did not vary significantly with age. The main effects of age, ball, and medium were not statistically significant with the recognition task, and there was only one significant interaction: Correctness × Medium × Ball, $F(2,268) = 3.95$, $p < .05$, $\eta_p^2 = .03$, for which post hoc follow-up revealed no significant effects.

Discussion

Our research stemmed from the hypothesis that gaps between prediction and recognition in the context of object fall result from omission at the explicit level of conceptions that are tacitly appreciated. Reviewing the results of Study 1, the most striking finding is that profiles were sharply differentiated depending on whether or not there was pre-fall motion. Nevertheless, with both the stationary and moving scenarios, the prediction task was considerably more challenging than the recognition task. In particular, with the stationary scenarios, there was a 61.3% success rate on the prediction task, whereas recognition task performance was close to ceiling. With the moving scenarios, success rates were 2.6% on the prediction task and 55.2% on the recognition task. Thus, there were marked gaps between prediction and recognition, meaning that the key issues are the conceptual understanding that can be inferred from the predictions and its consistency with the omission hypothesis.

With the stationary scenarios, backward and forward errors occurred at all age levels, even though the absolute frequency of both types decreased with age. Coupled with the fact that accurate responses outweighed errors, this suggests that, regardless of age, children believed that stationary objects normally fall vertically, but are sometimes deflected. Although the task instructions made no reference to wind, the children may have occasionally imputed this, expecting the balls to fall in whichever direction the wind was blowing. This interpretation is supported by the fact that the age-related improvement detected with the prediction task's stationary scenarios occurred with the two heavy balls given that children may come to believe that such balls are less likely to be buffeted about than light balls. However, if wind was imputed during the prediction task, there was no evidence for it playing a role during the recognition task. When backward and forward fall featured within the recognition task's incorrect stationary scenarios, children reliably rejected this as non-natural, performing at levels with these scenarios that were only marginally below the high levels achieved with correct stationary scenarios. Moreover, recognition task performance did not vary as a function of ball. Further research is needed, but if wind (or something similar) influenced prediction but not recognition, an element has been introduced at the explicit level, not omitted.

With the moving scenarios, response patterns with the prediction task provide no grounds for attributing underlying comprehension. Equally, however, they do not suggest that pre-fall motion was overlooked (due perhaps to the freezing at the point of prediction) or was noticed but treated as irrelevant. Had this happened, the patterns would have been indistinguishable from those obtained with the stationary scenarios, when they actually diverged. Although vertical fall was predicted on a substantial number of occasions, its frequency was considerably below that observed with the stationary scenarios and this time did not increase with age. Backward- and forward-oriented responses were prevalent with the moving scenarios during the prediction task, and in contrast to the stationary scenarios, the former increased with age and the latter decreased with age. As noted, age-related increases in backward-oriented responses were reported by Marioni (1989), and although Marioni did not indicate corresponding decreases in forward-oriented responses, this may be because his youngest participants were older than the Year 2 children. On the other hand, the current age trends are at variance with those reported in Krist (2000). Their significance in our research lies with the fact that they were not replicated during the recognition task, where children either displayed appreciation of forward parabolas (consistent with Kim & Spelke, 1999) or judged vertical fall as correct. They seldom accepted backward fall, and acceptance did not change with age. When children make prediction errors that differ qualitatively from what they recognize as correct and these errors increase with age, it is almost impossible to regard the errors as omissions at the explicit level of what is tacitly understood.

Study 2

Study 2 replicated Study l's procedures, with speed as the topic, specifically acceleration during fall through air and deceleration on impact with water. Regarding the prediction task, previous research (e.g., Hast & Howe, 2009; Nachtigall, 1982) warrants the hypothesis that children seldom anticipate acceleration through air but provides no guidance about whether deceleration or constant speed is expected or about what happens on impact with water. Also uncertain are the effects of ball. As noted, many children believe that heavy objects fall faster than light objects (e.g., Chinn & Malhotra, 2002; Hast & Howe, 2009; Howe, 1998; Nachtigall, 1982; van Hise, 1988). Some believe the reverse, and the prevalence of the two perspectives may change with age (although this is controversial). Object size is also thought to be relevant. What is unclear is how object properties are used when questions pinpoint speed change rather than undifferentiated "fastness." Even less certain are the implications of moving or being stationary prior to fall, so apart from testing one hypothesis around medium, analyses relating to Study 2's prediction task were exploratory. Similarly, we did not regard hypotheses as feasible with the recognition task. Shanon's (1976) work was restricted to adult samples, so the good understanding that was reported (for acceleration through air) cannot be presumed with children.

Method

Participants

Participants were recruited from state primary schools, not the Study 1 schools but from the same region and of equivalent ability range. All children in the relevant age bands received parental consent to participate, but absence from school meant that 5 children did not complete one of the tasks. Excluding these children, the sample amounted to 37 Year 2 children (23 girls and 14 boys, mean age = 6.84 years, *SD* = 0.37), 49 Year 4 children (23 girls and 26 boys, mean age = 8.88 years, *SD* = 0.33), and 47 Year 6 children (26 girls and 21 boys, mean age = 10.8 years, *SD* = 0.41).

Materials

The materials included the computer-presented hot air balloon scenarios and computer experience questionnaire used in Study 1. Following Study 1, the scenarios for both the prediction and recognition tasks were arranged in two blocks (air-only and air-plus-water) preceded by practice scenarios. The order of blocks and of scenarios within blocks was randomly varied via the computer program each time the tasks were presented. Responses and latency to respond were recorded (although, as with Study 1, equivalent results mean that latency data are not reported).

Study 2's prediction task used the same 12 scenarios as Study 1, with scenario presentation identical to Study 1 up to ball release and action freezing. Thereafter, two questions appeared in sequence, with response options (corresponding to the words that are capitalized below) presented under the question and selected by clicking with the computer mouse. The order of options was randomly varied each time the task was presented. With air-only scenarios, the first question was, "As the ball falls through the air, will the speed CHANGE or stay the SAME?" If the first question was answered correctly via CHANGE, the second question was, "As the ball falls, will its speed get SLOWER or FASTER?" If the first question was answered incorrectly via SAME, two arrows ("1" and "2") appeared below the hot air balloon, with randomization of whether 1 was above 2 or 2 was above 1. Here the second question, included to ensure two questions regardless of how the first question was answered, was, "As the ball falls, will it pass POINT 1 first or POINT 2?" With air-plus-water scenarios, the first question was, "Will the ball fall at the SAME speed through the air and the water or at DIFFERENT speeds?" The second question after correct selection of DIFFERENT was, "Will the ball travel slower/faster through the AIR or the WATER?" with use of "slower" or "faster" determined randomly each time a scenario was presented. The second question after incorrect selection of SAME was, "Will the ball be nearer/further from the balloon in the AIR or in the WATER?" with selection of "nearer" or "further" determined randomly.

The recognition task used 24 scenarios, with 12 showing the balls falling with correct speed and 12 showing them falling with incorrect speed. Direction of motion was always correct. Both correct and incorrect scenarios covered all possible combinations of ball, motion, and medium. When the medium was air alone, correct motion meant appropriate acceleration and incorrect motion meant deceleration. With air-plus-water, correct motion meant slower fall through water compared with air and incorrect motion meant slower fall through air; here the balls always accelerated correctly when traveling through air. Scenario presentation was identical to that in Study 1 apart from the appearance of "Did the SPEED of the ball look correct?" beside the balloon rather than a question about direction.

Procedure

The procedure was identical to that followed in Study 1.

Results

As with Study 1, the analysis was in two stages, the first addressing overall accuracy and the second examining specific profiles. Prediction task responses were considered as accurate only if both questions were answered correctly. Recognition task responses were straightforwardly accurate or inaccurate. Percentage accuracy on both tasks was independent of the order of task presentation and children's gender, handedness, and computer use scores. However, as in Study 1, there was a significant correlation between prediction task accuracy and scores for computer variety. Conducting the main analyses with variety ignored or included (as the covariate in an ANCOVA) produced equivalent results. Therefore, reported data are restricted, for simplicity, to what emerged when variety was ignored. (Unreported analyses, including latency effects, are available on request.) All analyses employed the same software as Study 1.

Prediction task

We analyzed accuracy on the prediction task via a 3 (Age: Year 2, Year 4, or Year 6) × 2 (Motion: stationary or moving) × 3 (Ball: small light, small heavy, or large heavy) × 2 (Medium: air-only or air-plus-water) mixed-model ANOVA, with repeated measures on the last three factors. Only one main effect was statistically significant, namely the effect of medium, $F(1,130) = 39.80$, $p < .001$, $\eta_p^2 = .23$. As hypothesized, children performed very poorly with the air-only scenarios ($M = 31.0\%$, $SD = 26.8$). They performed much better with the air-plus-water combination ($M = 50.3\%$, $SD = 28.6$). Furthermore, virtually all errors with the air-only scenarios occurred on the second question, whereas errors with the air-plus-water scenarios were more evenly balanced. In particular, only 3.3% of responses to the first question with the air-only scenarios indicated expectations of constant speed. However, of responses to the second question when the first one was correct, 65.4% indicated expectations of speed *decrease.* One-third (33.3%) of responses to the first question with the air-plus-water scenarios predicted no change in speed on impact with water, and 24.7% of responses to the second question after correct answers to the first one predicted speed increase. None of these values changed significantly with age.

There were two significant interactions involving medium: Medium × Ball, $F(2,260) = 6.62$, $p < .01$, $\eta_p^2 = .04$, and Medium × Ball × Age, $F(4,260) = 2.64$, $p < .05$, $\eta_p^2 = .04$. When the balls fell through air alone, the Year 6 children ($M = 52.1\%$, $SD = 40.3$) performed significantly better (Bonferroni, $p < .01$) with the small heavy ball than the Year 2 children ($M = 25.7\%$, $SD = 36.6\%$). The Year 4 children ($M = 34.7\%$, $SD = 35.7$) did not differ significantly from the other groups. The only other statistically significant interaction on the prediction task was between motion and age, $F(2,130) = 3.56$, $p < .05$, $\eta_p^2 = .05$. This resulted from a significant difference (Bonferroni, $p < .01$), with the moving scenarios only between the Year 6 children ($M = 48.2\%$, $SD = 22.6$) and the Year 2 children ($M = 30.6\%$, $SD = 22.1$). The Year 4 children ($M = 39.1\%$, $SD = 26.5$) did not differ significantly from the other groups.

Recognition task

We analyzed accuracy with the recognition task via a 3 (Age: Year 2, Year 4, or Year 6) × 2 (Correctness: correct motion or incorrect motion) × 2 (Motion: stationary or moving) × 3 (Ball: small light, small heavy, or large heavy) × 2 (Medium: air-only or air-plus-water) mixed-model ANOVA, with repeated measures on the last four factors. As with the prediction task, there was a significant main effect of medium, $F(1,130) = 12.32$, $p = .001$, $\eta_p^2 = .09$. This time, however, performance was better with the air-only scenarios than with the air-plus-water scenarios, and it was tempered by two significant interactions: Medium × Correctness, $F(1,130) = 20.60$, $p < .001$, $\eta_p^2 = .18$, and Medium × Motion, $F(1,130) = 7.95$, $p < .01$, $\eta_p^2 = .06$. Both the main effect and the interactions stem from very poor performance with the incorrect air-plus-water scenarios that depicted pre-fall motion (see Table 3). Indeed, these scenarios contributed to (a) the significant main effect of correctness, $F(1,130) = 26.70$, $p < .001$, $\eta_p^2 = .17$, where performance with the incorrect scenarios ($M = 51.1\%$, $SD = 22.1$) fell below performance with the correct scenarios ($M = 64.0\%$, $SD = 18.2$); and (b) the significant Correctness × Motion interaction, $F(1,130) = 7.34$, $p < .01$, $\eta_p^2 = .05$, where performance with the incorrect scenarios that de-

Table 3
Mean percentages accuracy on Study 2 recognition task as a function of medium, motion, and correctness.

	Stationary	Moving	Both motion
Air-only scenarios			
Correct	58.4 (33.4)	69.4 (28.7)	63.9_2 (22.7)
Incorrect	59.6 (32.6)	56.4 (34.4)	58.0_2 (27.6)
Correct and incorrect	59.0_b (21.5)	62.9_b (23.6)	61.0 (17.5)
Air-plus-water scenarios			
Correct	64.9 (30.2)	63.2 (29.1)	64.0_2 (22.4)
Incorrect	50.4 (35.2)	38.1 (31.0)	44.2_1 (24.9)
Correct and incorrect	57.6_b (22.0)	50.6_a (19.9)	54.1 (16.5)

Note: Standard deviations are in parentheses. When numeric subscripts in the "both motion" column differ (across the first, second, fourth, and fifth rows), means are significantly different (Bonferroni, $p < .001$). When alphabetic subscripts in the "Correct and incorrect" rows differ (across the first two columns), means are significantly different (Bonferroni, $p < .05$).

Table 4
Mean percentages accuracy on Study 2 recognition task as a function of age and correctness.

	Correct scenarios	Incorrect scenarios	All scenarios
Year 2	64.6 (19.4)	41.7_{1} (18.9)	53.2_{1} (10.4)
Year 4	63.9 (16.8)	52.0_{2} (20.0)	58.0_{12} (12.6)
Year 6	63.5 (19.1)	57.6_{2} (24.3)	60.5_{2} (15.2)
All children	64.0 (18.2)	51.1 (22.1)	57.6 (13.3)

Note: Standard deviations are in parentheses. When numeric subscripts in columns differ (across the first three rows), means are significantly different (Bonferroni, $p < .001$).

picted pre-fall motion fell below that of the other combinations (Bonferroni, $p < .05$). The Medium × Motion × Correctness interaction was not statistically significant.

In addition, there was a significant main effect of age, $F(2,130) = 3.37$, $p < .05$, $\eta_p^2 = .05$, and a significant Age × Correctness interaction, $F(2,130) = 3.40$, $p < .05$, $\eta_p^2 = .05$. Although the three age groups performed equally well with the correct scenarios, there was improvement with age with the incorrect scenarios (see Table 4). The main effects of motion and ball were not statistically significant. However, there were four additional significant interactions: (a) Ball × Correctness, $F(2,260) = 3.32$, $p < .05$, $\eta_p^2 = .03$; (b) Ball × Correctness × Medium, $F(2,260) = 3.55$, $p < .05$, $\eta_p^2 = .03$; (c) Ball × Correctness × Motion, $F(2,260) = 9.25$, $p < .001$, $\eta_p^2 = .07$; and (d) Ball × Medium × Age, $F(4,260) = 2.46$, $p < .05$, $\eta_p^2 = .04$. With the first three, post hoc follow-up simply confirmed the effects of medium, correctness, and motion reported already. The fourth was due to age differences across the four air-only scenarios depicting the small heavy ball. Here the performance of the Year 2 children ($M = 48.0\%$, $SD = 20.7$) was significantly below that of the Year 4 children ($M = 62.2\%$, $SD = 24.0$) and the Year 6 children ($M = 63.8\%$, $SD = 23.2$) (Bonferroni, $p < .05$).

Discussion

In Study 2, medium proved to be the main determinant of performance. With the air-only scenarios, the children averaged just 31% accurate responses with the prediction task. There was modest improvement with age on the moving scenarios and the scenarios that used the small heavy ball, the latter concurring with object effects that other studies have found. Nevertheless, the general picture was low prediction accuracy with the air-only scenarios at all age levels, and with every age group virtually all errors involved predicting deceleration. Although poor performance was hypothesized given the difficulties that undergraduates experience with comparable tasks (e.g., Champagne et al., 1980; Shanon, 1976), constant speed, not deceleration, is the modal error among undergraduates. The implication is developmental change (albeit not improvement) after 10 years of age.

Yet while the children in our research were inaccurately predicting deceleration with the air-only scenarios, many were accurately judging accelerating motion as correct on the recognition task and judging decelerating motion as incorrect; at an average of 61%, success rates with the recognition scenarios relating to fall through air were much higher than those with their prediction counterparts. Thus, prediction task responses display conceptions that are the *reverse* of those displayed during recognition. The underlying research question is whether errors when predicting are interpretable as omissions at the explicit level of what is tacitly understood. When data relating to the air-only scenarios point toward reversal, an explanation that relies solely on omission seems hard to sustain.

With the air-plus-water scenarios, the children averaged 50.3% accurate responses on the prediction task, well above their performance with the air-only scenarios and this time with errors more or less evenly spread between anticipating no change in speed and anticipating acceleration on impact with water. The frequency with which acceleration was predicted corresponds closely to the frequency with which Howe (1998) found equivalently aged children claiming that water sucks objects down, supporting the suggested association. In any event, prediction accuracy with the air-plus-water scenarios was largely independent of the contextual variables; the only statistically significant interaction that applied with these scenarios was the one indicating modest improvement with age when there was pre-fall motion.

With an average success rate of 54.1%, performance on the air-plus-water recognition task looks surprisingly poor. However, errors were concentrated on incorrect scenarios that depicted pre-fall motion, and this may reflect a specific problem. In particular, pre-fall motion may have been distracting, directing attention to what happened in air rather than at the air–water interface. If so, the focus would have been on veridical displays because the balls always accelerated correctly through air with the air-plus-water scenarios. Data from the air-only scenarios indicate that acceleration through air is typically seen as correct. Therefore, an "air focus" due to motion distraction would have resulted in relevant air-plus-water scenarios being judged as correct. This would lead to systematic error when speed change on entry to water was not in fact correct, that is, with incorrect scenarios depicting pre-fall motion. Apart from these scenarios, recognition task performance with air-plus-water scenarios was comparable to that with air-only scenarios, suggesting that despite the low average, the children did generally appreciate that balls decelerate on impact with water.

General discussion

The starting point for our studies was evidence that undergraduates make erroneous predictions about object fall despite recognizing whether observed fall is veridical. It was noted that although prediction requires explicit engagement with conceptual knowledge, recognition is achievable through tacit processing. Following Kim and Spelke (1999), it seemed possible that the greater challenge imposed by explicit engagement leads to elements being omitted, and research with children was viewed as potentially helpful in exploring this omission hypothesis further. Like undergraduates, the children who participated in our studies made predictions that were frequently erroneous, whereas their ability to differentiate between correct and incorrect motion was usually satisfactory. In particular, prediction task accuracy with stationary and moving scenarios in Study 1 and with air-only scenarios in Study 2 was inferior to recognition task accuracy (respective accuracies: 61.3%, 2.6%, and 31.0% for prediction; 87.3%, 55.2%, and 61.0% for recognition). Moreover, accuracy with these scenarios (and so the extent of the prediction–recognition gap) was largely independent of task variables. Predictions improved somewhat with age when the two heavy balls were featured in Study 1's stationary scenarios and when the small heavy ball or pre-fall motion was featured in Study 2's air-only scenarios. Recognition was marginally better when displayed motion was correct than when it was incorrect. Otherwise, task variables made little difference. Results from Study 2's air-plus-water scenarios are less clear-cut; however, as noted, misdirected attention may have compromised recognition with some of these scenarios.

The discrepancy between prediction and recognition is not straightforwardly attributed to specific features of the methodology. For one thing, the scenarios used in the prediction task were identical to those used in the recognition task up to the freezing prior to fall. Thus, the fact that the recognition task's correct scenarios were generally judged as correct attests to scenario verisimilitude that actually applies with both tasks. Assuming, then, that the prediction–recognition gap is genuine, the key issue is whether the omission hypothesis provides an adequate interpretation, and findings that suggest a negative answer have been highlighted already. To recap, with the moving scenarios in Study 1, recognition task performance at all age levels involved correctly accepting forward parabolas or erroneously accepting vertical fall. Prediction task performance involved sharp increases with age in use of backward trajectories, such that in Year 6 these paths were twice as frequent as vertical fall and three times as frequent as in Year 2. With the air-only scenarios in Study 2, accelerating fall was characteristically recognized as correct. Decelerating fall was recognized as incorrect, yet the modal prediction at all ages was deceleration. In both cases, conceptual elements were guiding predictions that appear not to have been used in recognition, implying inclusion at the explicit level, not omission. Moreover, although the evidence is less clear-cut, inclusion may also have occurred with the remaining scenarios. Imputed wind may have influenced the predictions made with the stationary scenarios in Study 1, when it could not have influenced recognition. With the air-plus-water scenarios in Study 2, the belief that water sucks objects down may have underpinned anticipation of acceleration on impact with water when there were no grounds for attributing this belief during recognition.

Earlier, we pointed out that the omission hypothesis implies straightforward models of task performance and conceptual development. This raises the question of what alternative models are required if the hypothesis is rejected. Regarding task performance, Hogarth (2001) and Plessner and Czenna (2008) would undoubtedly call on two independent knowledge systems (see also Fodor, 1985), one covering explicit understanding (including prediction) and the other addressing tacit understanding (including recognition). Data from split-brain adults (Roser, Fugelsang, Dunbar, Corballis, & Gazzaniga, 2005) suggest potential relevance for motion; hemispheric differences were detected over "causal perception" of motion (albeit horizontal, not vertical) and "causal inference," equivalent to tacit and explicit processing, respectively. Yet although a "separate systems approach" cannot be rejected, it is rather implausible. First, as noted, both prediction and recognition depend on scenarios being related to underlying conceptions, suggesting partially integrated processes. Second, there were parallels between performance on our prediction and recognition tasks as well as differences. Vertical fall was frequently predicted with the Study 1 scenarios and judged to be correct during the recognition task. With the air-only scenarios in Study 2, age-related improvement on both the prediction and recognition tasks was associated primarily with the small heavy ball. With the air-plus-water scenarios, deceleration on impact with water was often predicted and judged to be correct.

Lying between the omission hypothesis and the separate systems approach are hybrid models (e.g., Carey, 2009) that interpret prediction as involving (a) relation of scenarios to tacit conceptions that are used in recognition and (b) use of alternative (perhaps overlapping) conceptions when inferring how scenarios unfold, that is, when engaging in genuinely explicit activity. On such models, requests to predict direction after pre-fall motion trigger conceptions that include forward parabolas because tacit understanding of forward parabolas has been demonstrated in Kim and Spelke (1999) and now the current Study 1. While defining scenarios as recognizable (and tasks as solvable), these conceptions would not necessarily decide what is actually predicted. Rather, elements in the scenarios would be linked with elements in the conceptual system as a whole that, *on reflection*, appear to be relevant, and these linkages determine predictions. Linked elements may derive from sociocultural representations rather than from tacit knowledge. Thus, media images are a likely candidate for explaining why backward fall is frequently predicted after pre-fall motion given that films and the like often depict fall (e.g., of bombs) from inside moving carriers, and here the illusion is backward descent. Indeed, media influence provides a straightforward account of why prediction of backward trajectories increases with age.

More generally, the developmental consequences of such hybrid models are that when very young children formulate predictions they will have little knowledge to call on apart from tacit conceptions. Thus, predictions will reflect whatever subset of these conceptions can be elevated through reflection and inference. With age, tacit conceptions will be increasingly subject to sociocultural influences, which no doubt sometimes confirm tacit constructs but at other times embellish these or transform them altogether. One implication is that predictions made by young children are more likely than predictions made subsequently to concur with the omission hypothesis. Thus, it may be critical that Kim and Spelke's (1999) research, which underpins the hypothesis, was conducted with children who were no older than 6 years. A second implication is that when tacit understanding is good (and sociocultural experiences are antipathetic), prediction accuracy may decrease with age. From this perspective, it is significant that the Year 2 children in Study 1 were more likely than the Year 6 children to predict correctly that balls fall forward after pre-fall motion, albeit without anticipating parabolas. In addition, "U-shaped development" (Strauss, 1981) has sometimes been reported on tasks that, although not addressing predicted motion, nevertheless require explicit engagement with conceptual knowledge. In other words, initial understanding is more precocious than later understanding. This said, tacit correlates of U-shaped development remain to be explored, suggesting an avenue for future research rather than conclusive evidence.

Thus, although a hybrid model, such as the one sketched above, concurs with our results, much more research is needed. In particular, descriptive research that covers aspects of motion other than fall, areas of physics other than motion, and domains of knowledge other than physics is required. One implication from the above is that the research should be conducted with as broad an age range as possible. For now, the key message lies with our studies' answer to their background question. The discrepancies observed in adults between prediction and recognition of object fall are also found with children, but these discrepancies cannot be fully interpreted as omission at the explicit level of what is tacitly understood. Therefore, for object fall at least, a model of task performance and conceptual development that does not rely exclusively on the degree to which tacitly appreciated constructs are omitted or included is required. Detailed understanding of this model depends on future research.

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