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Children’s Developing Theories of Motion: Subjectivity and Shift

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**Abstract**

Research with primary school children indicates while younger children believe a light ball will roll down an incline faster than a heavy ball – matching their beliefs about horizontal motion – older children believe the heavy ball will roll down faster – matching their conceptions about fall. The present research evaluated why this age shift occurs. Two studies were carried out with children aged 5-11. Study 1 (*N* = 210) investigated the subjectivity of predictions by addressing age-related changes in disparity between a heavy and a light ball. The study indicates predictions about fall are relatively stable across age groups but both horizontal and incline motion predictions change with age, suggesting the horizontal element in incline motion reasoning loses salience. Study 2 (*N* = 144) examined the role of the incline height in predictions. The results show the incline height at which both balls are predicted to have the same speed reduces with increasing age, suggesting an increased salience of the vertical element in incline motion reasoning. Together, both studies illustrate while horizontal motion and fall are reasoned about differently their importance in incline motion reasoning shifts with age, with the horizontal element’s salience decreasing and the vertical’s increasing.

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1. **Introduction**

Various investigations have for some time shown that, in line with theoretical approaches whereby events involving horizontal motion are psychologically distinguished from those involving fall (Hayes, 1979; Howe, 1998), children reason differently about fall than they do about motion along horizontals (Bliss & Ogborn, 1988; Bliss, Ogborn, & Whitelock, 1989; Ogborn, 1985). More recent work has expanded on this, addressing the particular role that reasoning about motion down inclines might play in the development of children’s commonsense theories of motion (Hast & Howe, 2013a, b). This work suggests incline motion is not reasoned about in a third, different, way but children seem to draw on information from both horizontal and vertical dimensions to inform predictions. Notably, the research indicates while predictions about horizontal and vertical motion appear to be stable across age groups there is a clear shift with age in incline motion predictions.

The objective of the present research was to clarify the development of children’s theories of motion. Particular attention was given to two constituents of these theories: incline motion and the role of object mass. The importance of mass in relation to an object’s motion arises from the critical role it plays in reasoning about the physical world (Galili, 2001). Several studies illustrate while children anticipate heavier objects to fall faster than lighter ones (Baker, Murray, & Hood, 2009; Chinn & Malhotra, 2002; Hast & Howe, 2012, 2013a, b; Nachtigall, 1982; Sequeira & Leite, 1991; van Hise, 1988) they also predict lighter objects to move faster along a horizontal than heavier objects (Hast & Howe, 2012, 2013a, b; Howe, 1991, as cited in Howe, 1998; Inhelder & Piaget, 1958). Such predictions appear to be quite stable across age groups. Hast and Howe (2013a, b) have added to this, demonstrating while 5-year-olds are more likely to predict a light ball will roll down an incline faster than a heavy ball, 11-year-olds will predict the heavy ball to roll down faster. However, while the authors suggest incline motion reasoning is based on an integration of horizontal and vertical motion dimensions, they do not offer enough insight into why this age-related shift might occur.

To further the understanding of how incline motion fits into the development of theories of motion, subjectivity of predictions may help clarify this understanding. While the 5-year-olds and the 11-year-olds may both believe a heavy ball will fall faster than a light ball, this is not an indication as to how much faster it is expected to be. Disparities could be expected to change with age. In a study by Wilkening (1981) 5-year-olds, 10-year-olds and adults were asked to make predictions about motion for a set of animals. While all were able to correctly apply the time-distance interaction, the disparity for predicted speeds between the animals became greater with increasing age. This indication of disparity reduction may be integrated into overall theories of motion and could clarify how the relationship between motion dimensions is understood throughout childhood.

A further aspect contributing to subjective decisions is the role of incline height. Previous studies on modifications of incline height only approached this matter by comparing speeds of individual objects before and after height changes (Hast & Howe, 2013a; Howe, Tolmie, & Rodgers, 1992; Inhelder & Piaget, 1958). Children were usually successful in determining that increasing an incline’s height increases the ball’s speed, and that lowering the height decreases it. No simultaneous consideration of two objects was required in these studies, so no insight into the age-related shift for incline motion predictions is given. Research by Ferretti, Butterfield, Cahn and Kerkman (1985) comes closest to addressing this shortcoming. Here, 5- to 11-year-olds were required to consider balls rolling down two inclined planes placed next to each other, whose heights could be individually adjusted. However, the focus was not the speeds of the balls along the planes, but how far the balls would roll or fly after leaving the plane.

Overall, while research on incline motion is indicating a shift in conceptions across the primary school age range this shift is currently unclear. Two studies outlined below aimed to answer the following questions: Firstly, how subjective are the predictions of motion trajectories that children make? And secondly, why does the age-related shift observed in incline motion predictions occur?

1. **Study 1**

The purpose of this study was to address the subjectivity of children’s predictions of object motion trajectories for a heavy and a light ball. Specifically, it sought to investigate *1)* how predictions compare across three motion dimensions, i.e. horizontal motion, motion in fall and motion down inclines and *2)* how subjective predictions compare within and across age groups.

* 1. *Participants, materials and procedure*

A total of 210 children aged 5 to 11 years participated in this study, with approximately equal distributions across the age groups Year 1 (5-6 years), Year 2 (6-7 years), Year 4 (8-9 years) and Year 6 (10-11 years). For the three older age groups the task was carried out with whole classes of around 30 students each. For the Year 1 children the task was broken down into smaller groups of six or seven.

The materials consisted of an A5 booklet and two balls, a white table tennis ball and a dark glass marble. Both balls were approximately 4 cm in diameter, but the table tennis ball weighed approximately 3 g while the marble weighed approximately 75 g. The booklet was divided into three sections, one for each of three motion dimensions (horizontal, fall, incline). Each section’s first page had a brief written description of the task. This was followed by five diagrams. In Diagram 1, two balls were shown, and in the case of fall and incline motion two hands were shown holding the balls. One ball was black, the other was white – the first represented the glass marble, the second represented the table tennis ball. The anticipated trajectories for the two balls were indicated by a dotted line. In Diagram 2, only one ball was shown as being one quarter along the trajectory; the second ball was missing. In Diagram 3 the ball was shown as being halfway along the trajectory, in Diagram 4 as three quarters along, and in Diagram 5 just before the end of the trajectory. For half of the overall sample, the dark ball was shown, for the other half the white ball was shown. Tasks were arranged such that one half of groups worked on fall first and the other half on incline motion first. Horizontal motion was a direct result of preceding incline motion and therefore not subject to task order changes.

The researcher first asked the children to look at the first diagram in the booklet. The researcher presented both balls to the whole class or group, making it clear that the black ball in the diagram represented the marble and the white ball in the diagram represented the table tennis ball. The researcher passed the balls around so that each child had opportunity to handle both. The children were then taken through the instructions on the second page of the booklet and were asked to complete the first section’s diagrams by drawing in the missing ball. For each of the four diagrams that had one ball missing the children were required to draw the second ball where, at the same point in time as the shown ball, they anticipated the missing ball might be if both balls had been released at the same time. Once all children had completed the first section the researcher took them through the second and third instructions in the same manner. The task lasted approximately 20 minutes per class or group.

* 1. *Results*

No significant effects of dimension or age on *absolute* disparity were noted. The mean difference between the shown ball and the drawn ball – regardless of direction of difference – did not significantly vary across any of the three dimensions or across the four age groups. For *relative* disparity, on the other hand, significant main effects of dimension, *F*(2,412) = 96.41, *p* < .001, *η*2p = .32, and age, *F*(3,206) = 5.61, *p* < .05, *η*2p = .08, were noted, as well as a significant dimension x age interaction, *F*(6,412) = 3.08, *p* < .05, *η*2p = .04.

There was significant variation among mean relative disparities across age groups for horizontal motion, *F*(3,206) = 5.13, *p* < .05, *η*2p = .08. Mean relative disparity became smaller with increasing age, with a significant change between Year 1 (*M* = -1.79 cm, *SD* = 2.00) and Year 6 (*M* = -0.44 cm, *SD* = 2.63), *t*(99) = 2.91, *p* < .05, *r* = .08. There was also significant variation among mean relative disparity across age groups for incline motion, *F*(3,206) = 5.57, *p* < .05, *η*2p = .07. Mean relative disparity changed from a negative value (light-faster) to a positive value (heavy-faster), with a significant change between Year 1 (*M* = -0.76 cm, *SD* = 2.96) and Year 6 (*M* = 1.20 cm, *SD* = 2.68), *t*(99)= 3.42, *p* < .05, *r* = .11. No significant variation was noted for fall, indicating stability in predictions across the age groups.

1. **Study 2**

The purpose of this study was to address why the age-related shift observed in incline motion predictions occurs. Specifically, it sought to outline *1)* whether the incline height is relevant to making predictions, *2)* whether a heavy and a light ball ever assumed to have the same speed when rolling down an incline, and *3)* whether the incline height where speeds are predicted to be the same varies with age.

* 1. *Participants, materials and procedure*

A total of 144 children aged 5 to 11 years participated in this study, with 36 children from Year 1 (5-6 years), Year 2 (6-7 years), Year 4 (8-9 years) and Year 6 (10-11 years) respectively. The children were from the same school as above but had not taken part in Study 1.

The materials consisted of an apparatus and three balls, based on Hast and Howe (2013a). The apparatus consisted of a plastic channel of 100 cm length, 5 cm height and 10.5 cm internal width. The channel was attached to a metal frame of 125 cm height. The channel could be moved along the metal frame to modify the height of incline of the channel, allowing to place the tube or plane at an angle range of close to 0 degrees (practically horizontal) to close to 90 degrees (practically vertical). The same two balls as in Study 1 were used as test balls. In addition, a squash ball similar in size to the two test balls was used as a practice ball.

Children were worked with individually. The researcher presented the practice ball and asked the child to explain what would happen if the ball were let go from the top of the channel. The child was then shown that the channel’s height could be adjusted and was asked to explain what would happen to the ball if the height was changed. The researcher then removed the practice ball and introduced the two test balls. Both were given to the child who was then asked to state whether, if rolling down the channel, one ball would be faster or whether they would be as fast as each other. If different, the child was asked to give reasons and was asked whether the incline could be changed so that the two balls would be as fast as each other. If so, the child was invited to adjust the height. If the child had initially said the two balls would be of the same speed the child was asked whether there was a height when one of the balls would be faster than the other and, if so, to indicate this height as well as which of the two balls would then be faster and why. Heights were recorded by the researcher after completion of the task. The task lasted approximately 15 minutes per child.

* 1. *Results*

There was significant variation among mean scores for overall faster motion response options, whether the heavy ball or the light ball would be faster, or whether the two would be the same, *χ2*(2,144) = 68.67, *p* < .001. The light ball (*M* = 0.58, *SD* = 0.49) was predicted significantly more often to roll down faster than the heavy ball (*M* = 0.39, *SD* = 0.49), *T* = 2, *r* = -.14. The heavy ball rolling down faster was predicted more frequently than making a same-speed prediction (*M* = 0.03, *SD* = 0.16), *T* = 7, *r* = -.40. Significant changes with age were noted as to which ball would initially roll down faster. There was a significant age-related variation for the heavy ball rolling down faster, *H*(3) = 34.36, *p* < .001, with scores increasing with age, *J* = 5256, *z* = 5.79, *r* = .48. There was also a significant age-related variation for the light ball, *H*(3) = 32.91, *p* < .001, with scores decreasing with age, *J* = 2556, *z* = -5.57, *r* = -.46. No age effects were noted for same-speed predictions.

Regarding the possible manipulation of the incline height to bring about a change in the relationship between the two balls’ speeds, that is, changing from different speeds to the same speed, there was significant change with age whether the incline can be manipulated, *H*(3) = 12.43, *p* < .05. Older children were more likely than younger children to indicate no possible adjusting of the incline height, *J* = 2884, *z* = -3.42, *r* = -.29. Where the light ball had initially been predicted to be faster there was a significant age-related variation for the angle of incline, *H*(3) = 28.06, *p* < .001. Mean angles decreased with age from 63.8 degrees for Year 1 children to 37.3 degrees for Year 6 children, *J* = 216, *z* = -5.03, *r* = -.68. However, where the heavy ball had initially been predicted to be faster there was no significant age-related variation for the angle of incline.

1. **Discussion**

This research aimed to further the understanding of how commonsense theories of motion develop throughout childhood, focusing on the age-related shift in incline motion reasoning. As in previous work the shift in understanding was evident. The previous work suggested a combined role of horizontal and vertical elements in incline motion reasoning but could not provide clear support for this notion. The current results, on the other hand, indicate there are several key aspects of motion that appear to contribute to the shift in reasoning.

Study 1 illustrates while absolute disparities between the heavy and the light ball do not appear to change with age, indicating some sense of stability in reasoning, relative disparities do change, at least for horizontal and incline motion predictions. Fall predictions are again seen to be stable, and this seems to concur with findings that ideas about fall in particular are well established at an early age. On the other hand, it was clear that disparities changed significantly both for horizontal and incline motion scenarios, and both changed in the same direction. The older children still predicted, overall, that the light ball would be faster when rolling along the horizontal, but only minimally. Study 2 shows the incline height or angle itself is also a contributory factor in reasoning about incline motion. Again, children’s predictions showed the shift pattern, changing from light-faster in younger children to heavy-faster in older children. Older children were also more likely to state that the incline could not be adjusted to allow for same speeds, indicating that the heavy ball would always be faster than the light ball. The age-reduced incline angle for initial light-faster predictions seems to suggest that with increasing age it becomes easier for the heavy ball to catch up with the light ball, again emphasising a heightened role of the vertical element in incline motion reasoning.

Together, the findings from these two studies make an important contribution towards a clearer understanding of how commonsense theories of motion develop in childhood. Both horizontal and vertical elements appear to play a role in making predictions about incline motion across all age groups, but the role of each dimension changes. There is a clear shift from close association of the incline with its horizontal element (the actual slope possibly being linked to the horizontal aspects of surface friction) to close association of the incline with its vertical element (the role of gravity potentially gaining more salience). Given that reasoning for fall is quite stable the shift is due to a reduced importance of the horizontal element in the incline motion reasoning process.

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