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REPORT

Two-year-olds' naïve predictions for horizontal trajectories

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Abstract

Hood recently reported that preschool children overgeneralized the prediction that falling objects travel in a straight line in spite of extensive counter-evidence that the object had been deviated to a non-aligned box by a tube. This behaviour was interpreted as a naïve theory of gravity resulting from an overgeneralization derived from experience of falling objects. The current study set out to test whether there was also a significant tendency for 2-year-olds to predict that objects travel in a straight line in the horizontal plane. This was achieved by comparing search for an invisibly displaced object moving either vertically or horizontally. The findings confirmed a gravity bias for falling events but did not reveal a similar tendency in the horizontal condition. In the horizontal task, children were as likely to search at an incorrect non-aligned box as an aligned incorrect box. This supports the interpretation of a naïve gravity bias present from at least 2 years of age.

When presented with a task where an object falls down an opaque tube into one of three hiding boxes, preschool children make a 'gravity error'; they repeatedly search in the box directly below even though the tube is never connected to it (Hood, 1995). This perseveration is most marked around 2 years of age and led Hood (1995, 1998) to propose that the error reflects an inability to inhibit the prepotent assumption that objects travel in a straight line when falling. This inhibitory account is supported by a study of children with phenylketonuria (PKU) who are believed to have selective impairments on tasks that require inhibition (Diamond, Prevor, Callender & Druin, 1997). Although these children with early treated PKU had normal intelligence and could solve invisible displacements that did not involve gravity, they lagged behind normal children on the tubes task (Hood, Waisbren & Jarrold, 1999).

The origin of this gravity bias may reflect the extensive experience that children have had watching objects fall over the first years of life. There is some debate about when this capacity emerges (e.g. compare Baillargeon (1995) with Spelke, Breinlinger, Macomber and Jacobson (1992)), but in general, infants do not look down to anticipate the landing of a falling object before the age of 6 months (Piaget, 1954). However, the prepotency to assume that a falling object travels in a straight line does not apply to objects seen to move on an upward trajectory as 2-year-olds were less likely to choose the aligned box when the sequence was inverted (Hood, 1998). The interpretation of this finding was that upward events were relatively uncommon and so did not lead to the same degree of perseveration as that revealed in the falling sequences.

Another common object trajectory is movement in the horizontal plane. Many toys, such as balls or model vehicles, when rolled across a floor, tend to travel in a relatively straight line if the path is unobstructed. Such common experiences could lead to an object motion bias as observed with falling events. In a study of rule-based learning in 3- to 5-year-olds, Frye and his colleagues (Frye, Zelazo & Palfai, 1995) may have encountered this type of straight bias in the horizontal plane. In their physical causality task, a marble rolled down an inclined ramp. There was a gully on the left and another on the right side of the ramp. The marble was inserted into one of the gullies and travelled in a straight line until it reached a junction where a shunt could be activated. When a contingency light was illuminated, the shunt was open and the marble traversed diagonally across via another gully to exist on the opposite side of the ramp.

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When the light was extinguished, the shunt was closed and the marble continued in a straight line. During a training phase, the youngest children found it very difficult to predict the path that traversed diagonally across the ramp. Eventually they were able to overcome this bias. The pathways were then occluded by placing an opaque cover over the top and the children were asked to predict where the marble should end up on the basis of the light. Under these circumstances, 3-year-olds where unable to switch between the straight and diagonal trajectories, always choosing the straight path. However, 4- and 5-year-olds could readily predict the appropriate path based on the light. Frye *et al.* (1995) interpreted this finding as an inability of preschoolers to switch between different rules, but the bias to select the straight pathway is also consistent with the prepotent hypothesis for straight object trajectories. As with gravity, children assume that objects that move off horizontally down an incline tend to continue in a straight line and do not switch direction diagonally, though gravity is also involved when using an inclined ramp.

In spite of different methodologies and apparatus, the results of the two studies are consistent with the straight object motion bias. However, there are a number of reasons to question whether the horizontal motion bias is the same as that for falling events. One major difference between the two studies is that children were asked to make a contingent response in the Frye *et al.* (1995) study. Either box could be correct depending on whether the light was illuminated or not. This placed an additional attentional load on the child, which may have caused him or her to err by reverting to the straight motion solution. Without this contingency demand, the child may have been able to come up with the correct solution. A second major difference was that the path of the marble in the ramp task was entirely occluded after it had been inserted into the gully. In the tubes task, the conduit for the object is always visible, which adds to the bizarre nature of the error. Finally, the tubes task always had three possible boxes. Errors were significantly directed to the aligned box in comparison with the non-aligned box, which proves that search was biased to one location. However, as there were only two possible choices in the horizontal ramp study, choosing the aligned location did not necessarily mean a similar straight bias but could have also arisen from a bias against the other location. Only the addition of another distractor location could confirm a straight bias.

Another reason to question whether there was a bias for straight motion in the horizontal plane is that recent animal studies addressing similar questions have found a different pattern of results from vertical motion. Cotton-top tamarins (*Saguinus oedipus oedipus*), a small New World monkey species, also exhibited marked perseverative gravity errors for falling events when tested with a scaled-down version of the tubes apparatus (Hood, Hauser, Anderson & Santos, 1999). This was interpreted as demonstrating comparable cross-species behaviour on a cognitive task and hence the universality of naïve physical reasoning for gravity. However, in a recent follow-up study, these same animals were found to be significantly better on a horizontal version of the task (Hauser, Williams, Kralik & Moscovitz, 1999). This would suggest that the universality of common object motions may not apply to horizontal motion. Therefore, the current study set out to directly compare search behaviour for objects travelling in both horizontal and vertical versions of the tubes task with the same child. This will determine to what extent any biases are shared for these two trajectories.

Methods

Subjects

Thirty 2-year-olds were initially recruited. This age was chosen based on the subjects in the original study who reliably made errors (Hood, 1995) and the sample who were shown to dissociate downwards from upwards invisible displacements (Hood, 1998). Testing continued until five trials in each condition were obtained or the subject became distracted or lost concentration on the task. The target of five trials in each condition was chosen as this corresponds to the procedure used in the original study. Only 20 two-year-olds (11 girls, nine boys; mean age 24.5 months; SD = 1.0 month; range 23–26 moths) completed at least five trials of both horizontal and vertical conditions.

Apparatus

A diagram of the apparatus is shown in Figure 1. It was made of a Plexiglas rectangular frame with three opaque chimneys on the top section and three opaque containers directly below. These could be connected by an opaque plastic tube. The separation between the containers was 13 cm and the distance between chimneys and containers was 40 cm. The tube was made of gray flexible plastic which was ribbed for rigidity. The diameter of the tube, chimneys and container sections was approximately 5 cm and the connections were maintained by friction. The hiding boxes were 6 cm × 6 cm × 4 cm, had a circular hole in the top and were also held in place by friction. In the horizontal condition, this apparatus

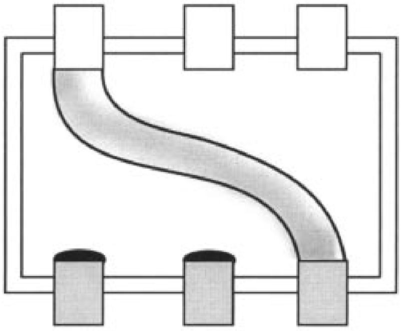

Figure 1 *Schematic diagram of the tubes apparatus. The tube could be connected from any chimney to a non-aligned hiding container.*

was rotated by 90° so that the chimneys and hiding containers were level.

Procedure

Prior to testing, subjects were familiarized with the different pieces of apparatus. The subject was given one end of the tube to hold and the experimenter dropped the ball down the tube which was inclined at approximately 45°. This was repeated three times. The purpose of this was to ensure that the subject had been shown that the opaque tube was hollow. The experimenter then removed the tube and presented the Plexiglas frame in the vertical position. The hiding boxes were attached to the frame and a ball was placed directly in one of the boxes. The subject was asked to locate this ball in each box on three trials. The experimenter then demonstrated a hiding retrieval sequence in both the vertical and horizontal positions. In this demonstration, the experimenter connected a chimney to a non-aligned container with a tube, and either dropped the ball down the chimney in the vertical position or patted the ball into the end of the tube in the horizontal position. The experimenter then pulled off the correct container to show the subject the location of the ball. Following this demonstration, the child was tested on five trials in both the horizontal and vertical conditions. These were chosen from the six tube arrangements that are possible which do not include any aligned chimneys and boxes. These were presented in pseudo-random sequence which had been determined beforehand.

Results

All children completed five trials in the horizontal condition and five trials in the vertical condition which were counterbalanced. On a three-choice binomial test, four or five correct choices out of five trials is significant and so individual children who made only one or no errors were judged to have passed the condition. Four children passed the horizontal condition and, of this group, one child also passed the vertical condition. This was the only child to pass the vertical condition with the rest of the sample making at least two errors. Therefore, on this criterion, the children were poor on both the horizontal and vertical versions of the task. However, a comparison of the two conditions in terms of error rates revealed that the children performed significantly better on horizontal compared to vertical trials. The overall mean number of errors in the horizontal condition was 2.79 ($SD = 1.55$) or 56%, and the mean number of errors in the vertical condition was 3.7 ($SD = 1.38$) or 74%. A non-parametric Wilcoxon ranked test revealed that children made significantly more errors in the vertical condition in comparison to the horizontal condition ($z = 2.2$, $p < 0.05$; two-tailed). The nature of the errors also differed between the two conditions. In the horizontal condition, the percentage of searches at the aligned box was 33%, which did not differ significantly from the mean percentage of searches at 23% directed to the non-aligned but incorrect box (Wilcoxon paired rank test: $z = 1.1$, $p = 0.26$; two-tailed). However, in the vertical condition, the mean percentage of searches at the aligned box was 46%, which was significantly greater than the mean percentage of errors at 28% directed to the non-aligned incorrect box (Wilcoxon paired test: $z = 2.37$, $p < 0.05$; two-tailed). An analysis of the first two trials, where there was a switch from one condition to the other (horizontal to vertical or the reverse), indicated that there was a non-significant trend to perform better if the horizontal condition was presented first, with 88% correct. Only 44% of children passed the first vertical trial, and success on the second trials did not differ at 20% for the horizontal condition following the first vertical trial and 25% for the vertical condition following the first horizontal trial. This distribution failed to reach significance on a χ^2 analysis ($\chi^2(3, N = 17) = 4.71$, $p > 0.1$) though further studies with larger samples may reveal an effect.

Discussion

The majority of children failed on both the horizontal and vertical versions of the tubes apparatus using the four out of five criterion for successful search. However, the two conditions were not equivalent as individual comparisons revealed that there were significantly more errors in the vertical condition. Also, combining the horizontal and vertical conditions in the same testing session with the same child may have contributed to a task order effect as there was a non-significant trend for children to do well on the horizontal task if it was presented first than if it was presented after a vertical trial. Therefore, overall performance on the horizontal condition may have been impaired by interleaving the vertical condition. This should be addressed by testing the two conditions in separate populations. Furthermore, the nature of the errors was different as these were more likely to be directed to the box directly below in the vertical condition whereas errors in the horizontal condition were equally likely to be directed to the aligned and non-aligned boxes. These results are consistent with the interpretation that inferring invisible displacement of an object moving in either the vertical or horizontal plane is difficult for 2-year-olds. In the vertical version of the task, the problem is compounded by an object motion bias for the aligned box which does not appear to be operating in the horizontal version. Therefore, on the basis of fewer errors and the absence of a bias, one would predict that children will go on to solve the horizontal invisible displacement before the vertical one. This should be verified by further longitudinal studies.

It is worth noting that the results from this study are exactly the same as those found in the comparative study with cotton-top tamarins who were tested on vertical and horizontal versions of the tubes (Hauser *et al.*, 1999). They also generally failed on the horizontal motion but produced fewer errors and straight biases than with the vertical arrangement. Although caution should always be exercised when drawing comparisons between human and non-human performance, there are several additional findings from the cotton-top studies that shed light on the nature of the gravity error. For one thing, the error does not occur simply as a result of not understanding how tubes work. Tamarins also produced gravity errors when the displacement was produced by an occluded ramp which could be adjusted to direct the ball to the non-aligned container. Although occluded ramps have not yet been tested in humans, the finding that children could predict how the tube directed the ball when the motion was reversed also supports the idea that the conduit was not critical (Hood, 1998).

The comparative work also presents some intriguing findings that are worth pursuing in future studies with children. Hauser and colleagues (Hauser, MacNeilage & Ware, 1996; Hauser, 1998; Hauser & Carey, 1998) have demonstrated that the violation of expectancy paradigm borrowed directly from the infant cognition field (e.g. see Baillargeon, 1995, or Spelke *et al.*, 1992) can be successfully applied to non-humans to investigate cognitive processes. Like human infants, adult monkeys will look longer at impossible outcomes that violate physical laws or expectancies. In the gravity task, when either a tube or ramp was used, tamarins looked significantly longer at the outcome of seeing the object in the gravity defined location compared to the correct non-aligned container (Hauser *et al.*, 1999). However, on the search measure, these very same animals searched at this location. Therefore, on a looking time version, non-human primates appeared to know that the gravity response was impossible but continued to search at this location. Although a looking time version of the gravity displacement has yet to be conducted in humans, 2-year-olds fail search versions of invisible displacements that are readily discriminatable by much younger human infants (Berthier, DeBlois, Poirier, Novak & Clifton, 1999; Hood, Carey & Prasada, 1999). This dissociation is not yet fully explained but adds to the controversy as to how best to interpret performance based on search and looking time measures (Bremner, 1998).

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