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ABSTRACT

Twenty-two children ranging in age from 2 to 3 years were tested on their abilities to apply weight and distance rules to the balance scale. This study was performed to test the prediction that 2-year-olds would be able to understand either a weight rule or a distance rule, but not be able to integrate the two. The sample group was instructed in the use of a simple beam balance with three pegs on each side. With a cut-out duck on one end of the beam and a cut-out rabbit on the other, the subjects were asked to predict which side of the beam would go down when the weights were placed or the pegs were moved. The results indicated that 2-year-olds can predict effects of both weights and distances on a beam balance where only one factor varies. When both factors vary, however, their performance is no better than chance. (Author/SW)

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# Performance on the Balance Scale by Two-Year Old Children

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# Abstract

The project tested a prediction from Halford that two-year old children would be able to apply weight and distance rules to the balance scale. The basis of the prediction is that comparing weights on two sides of a balance is a binary relation, and the same is true of comparing distances. There is evidence that binary relations are understood at two years of age. It is therefore predicted that, with suitable presentation, two year olds should be able to understand either a weight rule, or a distance rule, but should not be able to integrate the two. This prediction attributes understanding of these rules to children much earlier than competing theories and empirical work. More importantly it represents a case where earlier attainment has been predicted from an overarching theory.

A sample of two-year olds were instructed in the use of a simple beam balance with three, equally spaced pegs on each side, with a cutout duck at one end of the beam and a cutout rabbit at the other. For weight problems, the middle peg was always used on each side, and one- to three weights were placed on each side. Participants' task was to say whether "the bunny or the duckie would go down, or whether both would stay up". For distance problems two weights were placed on each side, on pegs 1, 2 or 3 steps out from the fulcrum, and the same question was asked. Children were pretested for each rule, then half were trained on the weight rule and half on the distance rule, and they were posttested on both rules. Performance was significantly better than chance on the weight pretest, but not on the distance pretest. However significant improvement was observed after distance training, and performance was significantly above chance on the distance posttest for the distance trained group.

The results indicate two-year olds came to the task with some understanding that balance depended on the weights on each side. They acquired an understanding that balance depended on distance from the fulcrum after training. The earlier acquisition of the weight rule reflects more experience with the downward pull exerted by weights. The importance of the results lies not so much in the demonstration of precocity relative to earlier findings, but in the demonstration that analyses based on relational complexity can make valid predictions of hitherto unobserved performance.

The purpose of the study was to test a prediction by Halford (1993) that from two years of age onwards children would be able to recognize the effect of weight or distance variables on the balance scale, but not both at once.

Basis of the prediction:

Weight effects and distance effects can be coded as binary relations.

Weight effect can be coded as a relation between weight on the left and weight on the right. Provided distances are equal, then whichever side has the heavier weight goes down. If weights are equal, the beam balances. This is a binary relation between weight on the left and weight on the right.

Distance effect can be coded as a relation between distance on the left and distance on the right. Provided weights are equal, then whichever side has the weights a greater distance from the fulcrum goes down. If distances are equal, the beam balances. This is a binary relation between distance on the left and distance on the right.

It is theorized that working memory limitations depend on the complexity of relations that are processed in parallel. Representation of relations imposes processing loads which depend on the complexity of the relations represented. Thus a unary relation (which binds one entity to a relation) is the least complex. A binary relation (which relates two entities: e.g. a horse is larger than a dog) is more complex. A ternary relation (which relates three entities: e.g. love-triangle) is more complex than a binary relation. A quaternary relation, which relates 4 entities (e.g. proportion, which relates 2 numerators and 2 denominators, $a/b = c/d$) is more complex than a ternary relation.

Normative data suggests that children typically process unary relations at a median age of one year, binary relations at a median age of two years, ternary relations at a median age of five years[1], and quaternary relations at a median age of eleven years. These norms suggest that two year old children should be able to understand weight effects or distance effects at two years, but should not be able to integrate these effects into higher level rules.

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1. Goswami (in press) claims that 3- and 4- year old children process ternary relations. In Experiment 1 she presented 3- and 4-year old children with two sets of three stacking cups. The experimenter indicated

a cup in one set (smallest, middle, or largest), and the child had to identify the corresponding cup in the other set (smallest, middle, or largest respectively). The high performance can be explained by absolute size discriminations (e.g. if the experimenter's set is 1,5,9, and the child's set is 2,6,10, and the Experimenter indicates (say) cup 5, the correct response is cup of size 6, but 6 is also the closest choice to 5 in absolute size). Halford and Wilson (submitted) calculated, using the reported cup-sizes, that the expected performance if children attended only to absolute size is 78 percent correct. Goswami used other techniques in Experiments 2 and 3, but the only evidence of processing ternary relations was by children with a mean age of 4 years 11 months, range 4.8-5.1. Overall, these experiments provide little evidence that ternary relations are processed by children below a median age of 5 years.

## Previous findings

Siegler (1981) found the weight rule (Rule I) was used by five year olds, but they could be taught to use the distance rule as well (Rule II). Surber & Gzesh (1984) found five year olds tended to favour the distance rule.

## Previous predictions

Case (1985) predicted that children would be unable to decide which side of a balance would go down by comparing weights until substage 0 of the dimensional stage, at 3.5 to 5 years (Case 1985, pp 101-102).

## Experiment 1

## Method

Apparatus comprised a balance scale with three pegs, equally spaced, on each side, with a bunny on one side and a duck ("duckie") on the other side, as shown in Figure 1. The balance was 54.5 cm long, and made of wood. Weights were circular plastic discs 3.5 cm in diameter and 0.5 cm thick with an 8 mm hold in the centre. A line was drawn around the edge of each weight so the number of weights on a peg was easily distinguishable. There were two chocks to hold the beam horizontal while weights were put in place and children made their judgments.

Participants were 22 children, 9 males and 13 females, aged 2 years 3 months to 3 years 6 months (mean = 2 years 8 months).

## Design

All children were given a pretest, followed by training, and a posttest. Both weight and distance effects were assessed on pre- and posttests. Half the participants were trained on weight and half on distance.

Each group served as the control for the other, but the purpose was to assess mastery of weight and distance rules, rather than to assess training per se.

## Procedure

### Pre- and posttests

Weight items always utilized the second peg. From one to three weights were placed on each side, and the child was asked: "Tell me if you think the duckie will go down or the bunny will go down or will they both stay up?" (Order of alternatives was randomised in all procedures). Six items were given.

Distance items were similar, except that two weights were always used, and were placed on pegs 1, 2 or 3.

### Training

Items were presented as for the pretest, but feedback and explanation was given to draw attention to the effects of different weights, or different distances. Training occupied approximately 25 minutes.

Weight training: The experimenter demonstrated and explained the effects of placing different combinations of weights on each side, using child-appropriate language (e.g. ". . if I put lots on this side, and only a little on this side . . the bunny/duckie goes down . . it's heavier this side). Then the child was asked to try to put weights on the beam to produce a given result (e.g. " . . put the rings/weights on so the bunny/duckie goes down . . . good boy/girl . . "). The second peg on each side was always used.

Distance training was similar except that attention was drawn to the effects of distance. The child was shown that the further the weights were from the middle (fulcrum), the more that side went down. Then they were asked to try to place weights on a peg on each side to produce a given result (e.g. " . . to make bunny/duckie go down . . "). Two weights were always used on each side.

## Results and Discussion

Pre- and posttest scores are shown in Table 1.

### Weight test performance

Pretest performance of the combined groups was better than chance, $t(21) = 4.99$, $p < .01$. ANOVA showed a significant improvement from pre- to posttest $F(1,20) = 15.25$, $p < .01$, but there was no interaction with type of training. It was concluded that 2-3 year olds can predict effects of weight on the balance at above-chance level, even before they are given specific experience in the experimental context.

### Distance test performance

Pretest performance was not significantly better than chance. There was a significant improvement from pre- to postest $F(1,20) = 5.76$, $p < .05$, and this was modified by an interaction with type of training $F(1,20) = 11.76$, $p < .01$. Posttest performance was significantly better than chance for the distance trained group, $t(10) = 3.27$, $p < .01$. It was concluded that 2-3 year old children cannot predict effects of distance on the balance before training, but can learn to make above-chance predictions when given specific experience.

## Experiment 2

The purpose of Experiment 2 was to replicate and extend Experiment 1, then assess performance when weight and distance were in conflict (i.e. when the greater weight was on one side but the greater distance was on the other).

Apparatus was as for Experiment 1.

Participants were 20 children with a mean age of 3 years 1 month, range 2:3 to 3:6.

### Design and procedure

Weight and distance effects only: All children were pretested, then half were trained on weight and half on distance. This was followed by a posttest. All were then trained on the alternate factor, then a second posttest was given. Pre- and posttests comprised 3 weight and 3 distance items, given as for Experiment 1. The training procedure was also the same as in Experiment 1.

Conflicting weight/distance: Following the second posttest for weight and distance effects alone, there was a pretest on weight-distance conflict items. This was followed by training on conflict items, followed by a posttest. Pre- and posttests comprised four items, one in which weight prevailed (side with greater weight went down), one in which distance prevailed (side with greater distance went down), and two in which the beam balanced. For example:

Weight prevailing: 3 weights on peg 1 on the left/right side, 1 weight on peg 2 on right/left.

Distance prevailing: 1 weight on peg 3 on the left/right, 2 weights on peg 1 on right/left.

Balance: 3 weights on peg 2 on the left, 2 weights on peg 3 on the right.

## Results and discussion

Pre- and posttest scores are shown in Table 2.

Weight test performance was significantly better than chance on all three tests, smallest $t(19) = 3.54$ for combined groups. ANOVA showed a significant effect of pretest/postest $F(2,36) = 29.93$ $p < .001$, reflecting improvement over time.

Distance test performance was no better than chance on the pretest or the first posttest, but was better than chance on the second posttest, t(9) = 10.06, p < .001. ANOVA showed a significant effect of pretest/postest F(2,36) = 29.93 p < .001, reflecting improvement over time.

Conflict test performance was no better than chance on either the pretest or the posttest, and there were no significant changes between tests.

## General Discussion

Both experiments show that 2-4 year old children can predict effects of both weights and distances on a beam balance, where small numbers of weights, and small distances are used, and where only one factor varies at a time. However when both factors vary, as in the conflict items, performance is no better than chance.

Weight prediction was better than chance even before training, but success was achieved with distance after modest training. This confirms that weight is acquired first, probably because there are more opportunities to learn about the downward pull of weights. In terms of complexity weight and distance rules are equivalent, because both can be coded as binary relations. The earlier acquisition of weight therefore presumably reflects environmental factors.

It might be suggested that children did not really discriminate weights, but might have responded to correlated factors, such as number of rings, size of the object on each side, etc. However above-chance performance without prior training makes this interpretation unlikely, because it is hard to see how such a discrimination would have been acquired pre-experimentally. It is more likely that children were applying their knowledge that weights exert a downward pull. An artifact might be more likely in distance discriminations, because these were acquired experimentally. Perhaps children might have picked up accidental correlated factors indicated by the words used, but such explanations cannot extend to weight, nor do they negate the finding that 2-3 year old children are utilizing a binary relation of some sort.

The study demonstrates earlier recognition of weight and distance effects on the balance than appears to have been observed, or predicted, previously. This successful performance was however predicted from the complexity metric produced by Halford (1993). Rather than interpreting the study as demonstrating that previous work underestimated children's performance, it seems more constructive to see it as demonstrating the benefits of a sound complexity analysis. These successful predictions were made because a means was developed for analysing task complexity which is generally valid, and for which age norms, albeit approximate ones, have been obtained.

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Table 1. Means (and sds) out of 6 in Experiment 1.

|  | Pretest | Posttest |
|---|---|---|
|  | **Weight predictions** |  |
| Weight trained | 3.73 (1.19) | 5.27 (1.19) |
| Distance trained | 3.27 (1.62) | 4.27 (1.27) |
| Both groups | 3.50 (1.41) | 4.77 (1.31) |
|  | Chance = 2.00 |  |
|  | **Distance predictions** |  |
| Weight trained | 1.64 (1.86) | 1.36 (1.63) |
| Distance trained | 2.00 (1.00) | 3.55 (1.57) |
| Both groups | 1.82 (1.47) | 2.46 (1.92) |
|  | Chance = 2.00 |  |

Table 2. Means (and sds) out of 3 in Experiment 2.

Weight predictions

| Pretest | Posttest 1 | Posttest 2 |
|---|---|---|
| 1.80 (1.01) | 2.70 (0.73) | 2.95 (0.22) |

Chance = 1.00

Distance predictions

| Pretest | Posttest 1 | Posttest 2 |
|---|---|---|
| 0.85 (0.99) | 1.35 (1.27) | 2.75 (0.55) |

Chance = 1.00

Conflict item predictions

| Prestest | Posttest |
|---|---|
| 0.55 (0.51) | 0.40 (0.60) |

chance = 1.33

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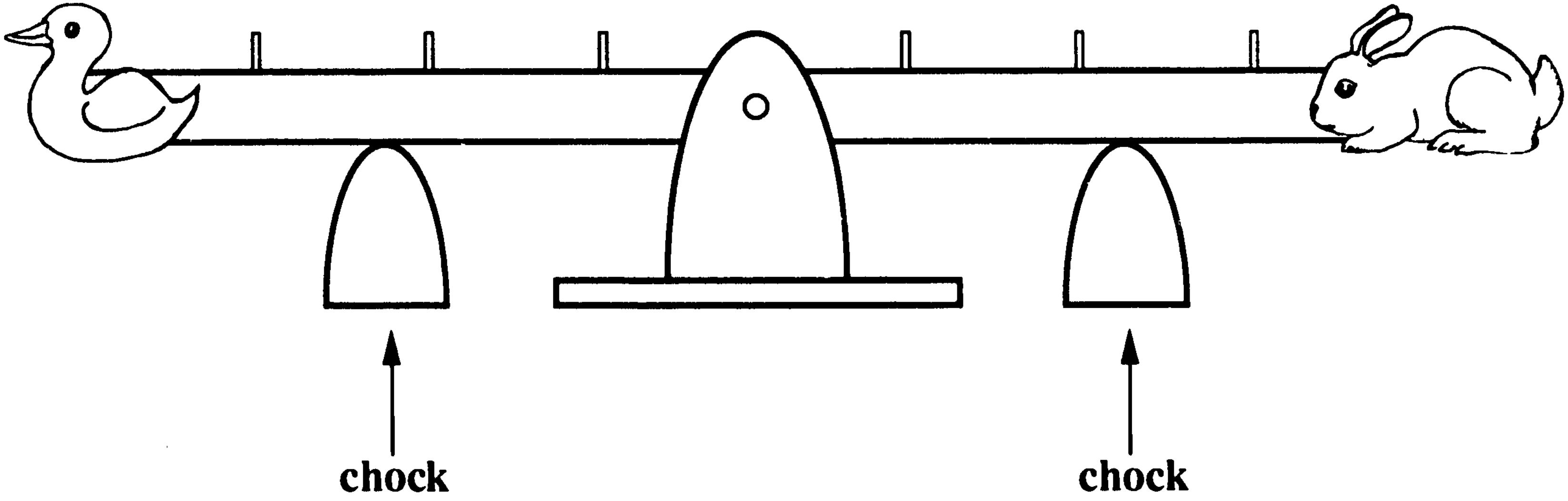
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