RUNNING HEAD: CHILDREN'S PERFORMANCE IN COORDINATE
TASKS

The effect of horizontal versus vertical task presentation on children's
performance in coordinate tasks

Naomi Worsfold*
Alyson Davis
Bart De Bruyn

Department of Psychology
University of Surrey
Guildford, UK

* Correspondence: N.Worsfold@surrey.ac.uk

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Abstract

Empirical work on children's ability to understand spatial coordinates has focused on the factors that increase children's proficiency. When interpreting performance, it should be considered that presenting a coordinate task on a horizontal surface might constrain the responses that children make because some target positions are further away from the child than others. Vertical task presentation removes this constraint. Three- to nine-year-old children were presented with an interpretative coordinate task administered on a touchscreen, presented in an egocentric-vertical position or -horizontal position. The results show that for 5- to 7-year old children vertical presentation led to far more correct responses than horizontal presentation. Analysis of the children's errors suggested that this may arise due to the fact that vertical presentation suppresses children's bias towards responding in relation to one rather than both coordinates. Taken together these findings contribute to understanding why children's performance in xy coordination tasks is highly contextually sensitive.

There exists much debate over the age at which children are believed to possess the skills required to coordinate spatial dimensions, and the developmental acquisition of the necessary components of Euclidean awareness required for this. Piaget and Inhelder (1956) outline three levels in children's spatial development; topological, projective and Euclidean. Although proficiency in the coordination of dimensions does not develop until the Euclidean stage, concepts acquired at the preceding stages are prerequisites for the resolution of coordinate problems. A coordinate reference consists of two orthogonal dimensions, one horizontal and one vertical, that give reference to a point in space at their point of intersection. In order to accurately coordinate horizontal and vertical dimensions, a child is required to identify the horizontal and vertical axes, extrapolate straight lines from the orthogonal axes (a characteristic of the projective stage), and coordinate these two lines to find their point of intersection. Further task demands include aspects of working memory, in order to imagine where the two lines indicated by the orthogonal markers intersect.

A task administered by Piaget Inhelder and Szeminska (1960) indicated that children were unable to use a coordinate system to locate a point in space until the age of eight or nine years, once the stage of concrete operational thought had been reached. Children were presented with two rectangular pieces

of paper, differing in orientation, at opposite ends of a table. Children were required to reproduce a point (P^1) from sheet 1 (S^1) onto sheet 2 (S^2), being provided with a ruler and strips of paper, lengths of thread and a stick. It was not until the age of eight or nine years that children spontaneously used a coordinate system to make the transformation. However, this task was ambiguous in its requirement of the use of a coordinate system. In the task, children were required to recognise that using a coordinate system would provide a potential solution to the problem, which may be a possible explanation for why children did not succeed until the age of nine years. Whilst Piaget et al. may have been correct in asserting that spontaneous coordinate use does not develop until the age of eight or nine years, this initial study provides little insight into the age at which children can use a coordinate system if it is presented to them (Somerville & Bryant, 1985).

More recent research using a variety of methodologies and task contexts has demonstrated successful performance in coordinate tasks in much younger children, in some cases from the age of four years. Children's proficiency is increased in cases where the task is made less abstract (for example replacing letters and numbers as grid references with coloured circles as reported by Blades & Spencer, 1989). Children also perform well where the task makes more 'human sense', such as where the dimensions to be coordinated are the

imagined paths that two model people would walk (Bremner, Andreasen, Kendall & Adams, 1993). Children also demonstrate the ability to provide the coordinate references for a given point in space in 'construction' tasks (e.g. Cochran & Davis, 2005; Lidster & Bremner, 1999) and coordinate dimensions in arrays with up to 16 target positions (e.g. Blades & Spencer, 1989).

It has been proposed by many researchers (e.g. Blades and Spencer, 1989; Bryant and Somerville, 1986; Somerville & Bryant, 1985) that such adeptness in the utilisation of rectangular coordinate systems serves as an illustration of young children's understanding of Euclidean geometry. This understanding of Euclidean space can therefore be seen as a precursor for the development of further spatial awareness.

These findings have important educational implications. The principles involved in the coordination of dimensions are not introduced into the UK National Curriculum until the ages of seven to eight, and children are not expected to read and plot coordinates until the ages of nine to ten. The age at which these concepts are introduced is, not surprisingly, in line with the age at which Piaget suggested children possess the necessary understanding (Davis, 2003). However, more recent demonstrations of proficiency in much younger children have led to suggestions that the concepts underlying the use of

coordinates can be introduced at a very young age (e.g. Blades & Spencer, 1989; Lidster & Bremner, 1999).

However, it is important to consider that such successful performance in young children may well be because of their ability on certain types of trials. Lidster and Bremner (1999) found differences in children's ability to coordinate dimensions for different trial types, in particular superior performance on near-near trials, where the target is in the quadrant that is close to the horizontal and vertical pointers. Far-far trials, where the target quadrant is far from both pointers were the most difficult. Similar differences were also found by Cochran and Davis (2005) in a constructive coordinate task, where children were required to indicate the correct orthogonal pointers for a given target quadrant. The most plausible interpretation of these findings is that they serve as an illustration of children's difficulty in extrapolating the imaginary lines of intersection to targets in a distal position to the pointers (Bremner et al., 1993), with children having little difficulty in trials where target positions are proximal to the pointers.

Whilst above-chance performance in coordinate tasks has been demonstrated by young children, errors are still prevalent. Of interest are the types of error children make, and what this reveals about the strategies children employ in a coordinate task. Bremner et al. (1993) conducted an analysis of the

types of errors children make in an interpretative coordinate task with a 2x2 grid, suggesting that when children make an error they attend to only one of the two pointers (i.e. only one axis) and select a target position in relation to that pointer. Errors were classified as either next to one pointer in the near-far dimension, next to one pointer in the left-right dimension, far from one pointer in the near-far dimension, far from one pointer in the left-right dimension, or not in line with either pointer. They found that the dominant error type was selecting a position next to one of the pointers, suggesting this to be the strategy that children use in these tasks. Consistent application of a next-to-pointer strategy would lead to 100% success on near-near trials, 50% success on near-far and far-near trials, and 0% success on far-far trials. Bremner et al. observed that the performance of the 4-year-old children they tested closely approximated this pattern on a standard coordinate task. Here we see another possible explanation for the pattern of success in different trial types explained above. Although near-ceiling performance is often observed in near-near trials, this might not necessarily reflect children's ability to coordinate the two dimensions. Instead, success on these trials could arise simply by children applying a next-to-pointer strategy. Cochran (2006) found similar distributions of error types, with next-to-pointer errors being the most frequent type (72% of all errors). These two reports of error analyses, along with similar findings by

Blades and Spencer (1989), indicate that children's errors are far from random. This suggests that children might be consistently employing a strategy in such tasks, and that errors and correct responses might be the result of the application of the same strategy.

If this is indeed the case, task presentation factors could have an effect on the strategies children employ. Previous studies examining children's strategy use in a coordinate task, due to the use of table-top apparatus, have administered the task on a horizontal surface (e.g. Bremner et al., 1993; Cochran, 2006). With such horizontal presentation, irrespective of where the child is sitting or standing, and irrespective of the size of the array, some of the target positions will be further away from the child than others. For this reason, we suggest that presenting a task to children on a horizontal surface might constrain their responses and if so might influence their response strategy.

In the experiment presented here, we wanted to compare performance on an egocentric-horizontal presentation with an egocentric-vertical presentation where all target positions and pointers are equidistant from the child. We expect fewer errors to be made in the vertical condition when compared to the horizontal condition, and predict that condition might influence the strategies children use in order to complete the task.

Method

Participants

One hundred and twenty-six children from two primary schools (Dorset, United Kingdom) with predominantly white, middle class catchment areas were tested, in three age groups. The 3- to 5-year-old age group consisted of 36 children, with a mean age of 4 years, 1 month (range: 3 years 4 months to 5 years 10 months). There were 36 children in the 5- to 7-year-old age group, with a mean age of 6 years, 2 months (range: 5 years 11 months to 7 years, 9 months). Finally, the 7- to 9-year-old age group consisted of 54 children, with a mean age of 8 years, 3 months (range: 7 years 10 months to 9 years 8 months). These groupings were based on combinations of school classes (i.e. educational stages) in order to group together children with similar levels of experience in the concepts underlying coordinate use. The children were picked at random from the class register. The sample consisted of 60 boys and 66 girls, with roughly equal numbers in each age group.

Materials

An Apple Powerbook G4 laptop computer with a programme written in MatLab (Mac v. 5.2.1) generated the stimuli and coded the responses of the child; and controlled a touch sensitive LCD screen (Elo Intellitouch, size:

diagonal 38cm/ 15", 1024 x 768, 60 Hz, luminance: white 120 cd/m², black 3 cd/m², contrast 95%). The screen displayed an 18cm x 18cm grey square.

Within this square were four identical black circles with a diameter of 1.8cm, with the centre of the circle 4.5cm away from the edges of the square. Two red pointers were presented on the border of the square, on each trial being in line with the appropriate target quadrant (see Figure 1). For children tested in the vertical condition the touchscreen was mounted on a metal stand so that it was in a vertical position, whilst for the children tested in the horizontal condition the touchscreen was placed on the desk in front of the child in a horizontal position. The light conditions of the test situation were normal, and the participants viewed the stimuli binocularly.

Figure 1. The four stimulus types; shown for a top-left target position. The target position is indicated by the arrows; for the near-near stimulus type (nn) top-left and left-hand; for the near-far type (nf) top-left and right-hand for the far-near type (fn) bottom-left and left-hand; and for the far-far type (ff) bottom-left and right-hand.

Procedure

Each child was tested in one of two independent conditions of the task. Half of the children from each age group completed the trials with the touchscreen in a vertical position, and the remaining children completed the trials with the touchscreen in a horizontal position (3- to 5-year-olds: vertical N=18, horizontal N=18; 5- to 7-year-olds: vertical N=18, horizontal N=18; 7-to 9-year-olds: vertical N= 27, horizontal N=27). The child was seated comfortably in a position where they could see the touchscreen. In the horizontal condition, the touchscreen was placed on a table in front of the child, with the height of the seat adjusted so that the child could reach all target positions. In the vertical condition, the height of the screen was adjusted so that the child's eyes were level with the centre of the screen (see Figure 2).

Figure 2. The set-up of the equipment in the horizontal condition (left-hand photograph) and the vertical condition (right-hand photograph).

The child's attention was then directed to the touchscreen and the trials were explained:

“We can play a game on my screen. These two red triangles are two red racing cars. They drive straight ahead until they meet, and they always meet on one of these circles. This is a special screen because you can touch it. In this game you use your finger to touch the circle where you think the two racing cars will meet if they drive straight ahead. Make sure you look carefully at both red triangles”.

Children were given 4 practice trials in which the given problem type was demonstrated. If children did not understand, further explanation was given. Following this, each child was presented with 16 trials consisting of all the possible combinations of target position (top left, top right, bottom left, bottom right) and trial type (near-near, near-far, far-near, and far-far) in a random order (see Figure 1). The child was praised and thanked for his/her participation. Due to the quick administration of trials and novel response method afforded by the touchscreen, the task was extremely motivating for the children and all children completed all 16 experimental trials.

Results

Correct response analysis

The analysis consisted of establishing the number of trials in which the child gave a correct response. The touchscreen software codes a correct response as one with less than 30 pixel units of error on either axis, as measured from the centre of the target circle. The numbers of correct responses for each trial type are shown in Figure 3.

Figure 3. For the three age groups (3-5, 5-7, and 7-9 years), mean number of correct responses by trial type (near-near (nn), near-far (nf), far-near (fn), and far-far (ff)) and condition (vertical and horizontal presentation). Error bars indicate one standard error above and below the mean.

In previous analyses of children's correct responses in coordinate tasks (e.g. Bremner et al., 1993; Somerville & Bryant, 1985) children's performance is compared to chance based on a strategy of only taking one pointer into account, where chance is taken to be 0.5. Using the same criterion, we

compared the number of children's correct responses to a binomial distribution based on the probability of 0.5 of giving a correct response. In the 3- to 5-year-old age group, only one child out of 18 in the vertical condition and no children out of 18 in the horizontal condition scored 12 out of 16 or better ($p < .05$). In the 5- to 7-year-old age group 10 out of 18 and 5 out of 18 children scored 12 or better in the vertical and horizontal conditions, respectively ($p < .05$). In the 7- to 9-year-old age group 22 out of 27 children in the vertical condition and 24 out of 27 children in the horizontal condition scored 12 or more out of a total of 16 ($p < .05$).

The data were analysed using a 3 (age) x 4 (trial type) x 2 (condition) mixed ANOVA with trial type as the repeated measure. The analysis revealed a main effect of condition: $F(1, 120) = 5.75, p < .05, \eta^2 = .05$. As Figure 3 shows, the overall pattern suggests vertical presentation to be superior to horizontal presentation; however a slight advantage for horizontal presentation is evident in the 7- to 9-year-old age group. There was also a significant main effect of trial type: $F(3, 309) = 142.28, p < .001, \eta^2 = .54$. Pairwise comparisons revealed that performance on near-near trials was significantly superior to all other trial types (Bonferroni $p < .001$), and that performance on far-far trials was significantly inferior to all other trial types (Bonferroni $p < .001$). There was no significant difference between performance on near-far and far-near trials

(Bonferroni $p > .05$). The main effect of age was also significant: $F(2, 120) = 77.78, p < .001, \eta^2 = .57$. All age groups were significantly different from one another (Games-Howell $p < .001$ on all comparisons, with an increase in correct responses with age).

The main effects were qualified by a significant trial type x age interaction: $F(5, 309) = 27.54, p < .001, \eta^2 = .32$; and a significant age x condition interaction: $F(2, 120) = 4.00, p < .05, \eta^2 = .06$. Further analysis of the trial type x age interaction revealed significant age differences on near-far trials: $F(2, 123) = 47.15, p < .001$, with significant differences between all three age groups (Games-Howell $p < .001$ on all comparisons). There were also significant age differences on far-near trials: $F(2, 123) = 48.38, p < .001$, with significant differences between all three age groups (Games-Howell $p < .001$ on all comparisons). Age differences were also evident on far-far trials: $F(2, 123) = 62.01, p < .001$, with significant differences between all three age groups (Games-Howell $p < .001$ on all comparisons). In all cases, there was an increase in correct responses with age. There were no significant differences between age groups on near-near trials: $F(2, 123) = 2.00, p > .05$.

Analysis of the age x condition interaction suggests that there are significant differences between the performance of children in the vertical condition versus the horizontal condition for the 5- to 7-year-olds, $t(34) = 2.21$,

$p < .05$, with this difference being marginal for the 3-to 5-year-olds, $t(34) = 1.83$, $p < .1$. In both cases, performance was superior in the vertical condition. However, there was no significant difference between the performance of children in the vertical versus horizontal conditions for the 7- to 9-year-old group, $t(52) = -0.91$, $p > .1$.

Strategy analysis

In order to try to explain the reasons for the different effect of condition across age groups, we examined children's use of a next-to-pointer strategy. Far-far trials are the only trial type where strategy use can be dissociated, since in a near-near trial, a correct response could be reached either through the use of a next-to-pointer strategy, or a Euclidean-based strategy. In a similar way, a correct response on a near-far or a far-near trial can be either next-to-pointer, or in line with a pointer. However, far-far trials are the only trial type where a next-to-pointer strategy will *always* lead to an incorrect response.

We analysed children's responses on all four far-far trials they were presented with. A trial where a next-to-pointer strategy was used was one where the target position chosen was either next to the pointer in the near-far dimension, or next to the pointer in the left-right dimension. The percentage of far-far trials in which a next-to-pointer strategy was used is shown in Figure 4.

Figure 4. For the three age groups (3-5, 5-7, and 7-9 years), mean percentage of far-far trials where a next to pointer strategy was used by condition (vertical and horizontal presentation). Error bars indicate one standard error above and below the mean.

The mean percentage of next-to-pointer responses was compared to chance (50%) using 1-sample t-tests (one-tailed). The 3- to 5-year-old children in both the vertical and horizontal conditions were using a next-to-pointer strategy significantly more often than expected by chance (vertical: $t(17) = 6.34, p < .001$; horizontal: $t(17) = 9.80, p < .001$). The use of a next-to-pointer strategy in the 5- to 7-year-old age group was not significantly different to chance in the horizontal condition; $t(17) = .579, p > .05$. The 5- to 7-year-old

children in the vertical condition were using a next-to-pointer strategy less than expected by chance at a marginal level of significance; $t(17) = -1.68, p = .06$. In the 7- to 9-year-old age group, children in both the vertical and horizontal conditions were using a next-to-pointer strategy with significantly lower frequency than expected by chance (vertical: $t(26) = -4.85, p < .001$; horizontal: $t(26) = -8.09, p < .001$).

We also analysed whether children were biased to select a target position nearer to them ('near-to-child' positions; bottom left and bottom right quadrants) more often than further away from them ('far-from-child' positions; top left and top right quadrants) in the horizontal condition compared to the vertical condition. The percentage of trials (all trial types) in which children selected near-to-child positions is shown in Figure 5.

Figure 5. For the three age groups (3-5, 5-7, and 7-9 years), mean percentage of trials where a ‘near-to-child’ target position was selected (bottom-left and bottom-right quadrants by condition (vertical and horizontal presentation). Error bars indicate one standard error above and below the mean.

The percentage of trials in which children selected near-to-child positions was compared to chance (50%) using 1-sample t-tests. The 3- to 5-year-olds in the vertical condition did not differ to chance, $t(17) = 1.37, p > .05$, however children of this age in the horizontal condition did select positions in quadrants near to them significantly more often than expected by chance, $t(17) = 4.61, p < .001$. Neither the 5- to 7-year-olds in the vertical condition nor the horizontal condition differed to chance (vertical: $t(17) = -.42, p > .05$;

horizontal: $t(17) = 1.13, p > .05$); the same was true of the 7- to 9-year-old group (vertical: $t(26) = 1.00, p > .05$; horizontal: $t(26) = -.37, p > .05$).

Discussion

The primary aim of the present study was to investigate whether vertical presentation of a coordinate task, where all target positions are the same distance from the child, results in superior performance to horizontal presentation, where some target positions are further away from the child than others.

The results showed that only the 5- to 7-year-old children in the vertical condition were significantly more accurate than children of the same age in the horizontal condition regardless of trial type. When the use of a next-to-pointer strategy was examined, it was found that plane of presentation only affected strategy use for this age group. It is evident that in the younger children (3 to 5 years of age), a next-to-pointer strategy dominates their responses so strongly that plane of presentation cannot influence their strategy use. Similarly, the employment of a next-to-pointer strategy in the older children (7 to 9 years of age) is so infrequent, that again plane of presentation is not able to exert an effect on strategy use. When this finding is combined with the near-ceiling performance across trial types for the oldest children as shown in Figure 3, it

suggests that the older children are using a Euclidean strategy to correctly solve each individual trial.

When the use of a next-to-pointer strategy in the middle age group (5 to 7 years) is examined, it is evident that there are fewer children using a next-to-pointer strategy in the vertical condition when compared to the horizontal condition. It appears that between the ages of five and seven children are making the transition from the consistent use of a next-to-pointer strategy to a strategy based on a degree of Euclidean understanding. During this period of transition, vertical presentation leads to fewer children using a next-to-pointer strategy, explaining the superior performance in the vertical condition for this age group. This is likely to be because the use of a Euclidean strategy is facilitated by being able to process the whole array simultaneously. At a time when the use of a Euclidean strategy is developing, processing the whole array at once is much easier to achieve when the task is presented vertically and all target positions are equidistant from the child. It appears to be the case that vertical task presentation affords easier progression from the use of a next-to-pointer strategy to the use of a Euclidean strategy. Horizontal presentation makes it harder to achieve simultaneous processing of the whole array, which can explain the greater prevalence of children using a next-to-pointer strategy in this condition. The present results show that vertical presentation is most

beneficial for the age band when there is transition between two equally salient strategies; one strategy used by the younger child and the other strategy used by the older child.

We have replicated previous findings (e.g. Cochran & Davis, 2005; Lidster & Bremner, 1999) that have demonstrated superior performance on near-near trials and inferior performance on far-far trials when compared to all other trial types. However, whilst the trial type effect has been replicated, our results also indicate that children may not fully understand how to coordinate dimensions in a way that previous interpretations have assumed. It is difficult to attribute near-ceiling performance in near-near trials to an understanding of Euclidean geometry when successful performance could be produced by the same strategy which causes errors in other trial types. These results highlight the importance of remembering that near-ceiling performance in some trials may be incorrectly interpreted as a display of proficiency in coordinating dimensions, rather than an artefact of the application of a strategy which incidentally leads to 100% accuracy in near-near trials. Performance on near-near trials appears to be superior simply because the dominant strategy used in this type of task happens to lead to success in these trials. Similarly, it needs to be considered that our age effect, with developmental improvements in proficiency across all trial types, may in part be the result of a decline in the

application of a next-to-pointer strategy, and a shift towards a Euclidean-based strategy where both pointers are taken into account.

From a theoretical point of view, it is important to note that children might be getting near-near trials right for the wrong reason. Similarly, poor performance in far-far trials has often been explained in terms of difficulty in extrapolating the lines of intersection from the pointers to distal target positions. This may well be the case, but there is an alternative explanation. If children simply apply a next-to-pointer strategy, this strategy would lead to 0% accuracy on these trials. Therefore, concluding that children as young as 4 years of age have some understanding of Euclidean geometry may be inappropriate. Crucially, whilst Piaget has been criticised for underestimating children's understanding of coordinates, more recent interpretations may have overestimated them (a similar argument is made by Cochran, 2006).

It is important to note that the utility of a next-to-pointer strategy is specific to a 2x2 grid. Further research is needed to investigate whether children continue to use this simple strategy even in cases where it does not consistently lead to success, or whether they demonstrate flexibility in their strategy use depending on the size of the array they are presented with. For example, in a given task children might select one from a range of different strategies that give the highest chance of success. It would also be interesting to analyse

children's strategies in a free-search coordinate task where the target location is not constrained by quadrant, and whether the advantage for vertical task presentation extends to other domains of spatial development.

The analysis of children's selection of near-to-child positions indicates that children are only biased towards near-to-child target positions, or biased away from far-from-child target positions, in the 3- to 5-year-old age group. This may be due to motor constraints, or due to a perceptual bias to process only those target positions in close proximity to the child. Either way, it is clear that vertical task presentation reduces this bias.

The findings of the present study have potentially important implications for education. Demonstrations of proficiency in young children have previously been used as evidence for the proposition that the concepts underlying coordinate use can be introduced into the mathematics curriculum at a much younger age than in current practice. Whilst we too demonstrate performance by very young children that, on the surface, might support this view, it is important to consider the extra information that is provided by examining children's strategies. Our results highlight that it is important to go beyond seeing a child's correct response as a demonstration of some level of understanding, but to consider how the child reaches this correct answer. For example, whilst the performance of children in all age groups was very similar

on near-near trials, it is plausible to suppose that the youngest children achieved their responses through the consistent application of a simple strategy across all trials. However, the older children appear to have reached a solution for each individual problem based upon their ability to coordinate dimensions.

To conclude, the present study has demonstrated that presenting a coordinate task to young children on a vertical surface results in fewer errors than the same task when presented horizontally, at least for 5- to 7- year-old children. An interesting direction for future empirical work is to investigate whether this result generalises to more complex coordinate problems and indeed to other types of spatial tasks.

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