Young children's understanding of line of sight

Mark Morrison Boydell

Dedicated to my five grandparents.

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Declaration

I declare that the work undertaken and reported throughout this thesis was completed solely by the undersigned. This work has not been included in another thesis.

Mark M. Boydell

Sometimes the best map will not guide you

You can't see what's round the bend

Sometimes the road leads through dark places

Sometimes the darkness is your friend

Bruce Cockburn - "Pacing The Cage" from the *The Charity of Night* (Rykodisc, 1996)

Abstract

Previous research into children's understanding of line of sight has led to differing conclusions as to when and how children become able to appreciate that their view of an object will be different from another persons' view of the same object. This is probably due to the diversity of response methods required from the children as well as different types of tasks and settings being used between the experiments. The aim of the present thesis is to investigate systematically how children will fare across various settings and whether their comprehension of line of sight can be biased by the task's setting. The first experiment assessed children's understanding of line of sight through a tube that was bent to varying degrees of curvature and whether their response pattern would change when feedback was provided. Results showed that children have great difficulty performing correctly on this task, especially when the degree of curvature is small. The older children

corrected their response pattern when feedback was provided but the younger children tended to persevere in their response pattern regardless of contradictory feedback. The second experiment looked at children's performance when walls were used - half the walls were smooth gradual curves while the other half was walls made up of two segments that met to form an angle. Again the children were asked to predict if two dolls placed at opposite ends of each wall would be able to see each other. Results showed that though even young children have no trouble in performing correctly on the "angled" walls, performance on the curved walls was significantly poorer with the older children performing better than the younger children. The third experiment sought to quantify the point at which children deemed line of sight became possible. To do this we used a single "U" shaped trench with the children being asked if one doll could see another in various configurations. The results showed a strong bias towards *over*estimating visibility. The fourth experiment repeated the second experiment but used wooden trenches instead of walls but also sought to quantify the "switchover" point at which the children deem vision becomes possible between the two dolls. The difference between angles and curves was once again replicated as was the age difference. The fifth experiment compared children's appreciation of line of sight through/along tubes, trenches and walls.

This performance level varied strongly depending on the type of task the child was asked to perform upon with the tube proving to be the most difficult and the angled trench the easiest. The overall findings of the experiment pointed to a context-dependent performance, implying a piece-meal development of childrens' comprehension of line of sight.

Chapter 1

Children's knowledge of Seeing

Children display very early on in their lives a basic comprehension of the way the world is structured. The classic example of the visual cliff task (Gibson & Walk, 1960; Walk & Gibson, 1961) has demonstrated that very young children understand basic aspects of heights and perspective. This appreciation seems to develop quite rapidly throughout early childhood. Given the indubitable advantages offered by this skill, it is unsurprising it develops so rapidly. However, when it comes to appreciating the world from another person's point of view, many researchers have reported an "egocentric" slant in the children's responses (Peek-a-boo etc.). This led to Piaget's ascertaining that children's appreciation of the world was highly influenced by their own vision. In the current chapter, we shall be taking a critical look at the literature that has formed our understanding of children's visual egocentrism.

1.1 Piaget & Inhelder's (1963) mountains task

1.1.1 The experiment

Originally published in *The Child's Conception of Space*, the Mountains Task provided a compelling extension of Piaget's theory of egocentrism.

In this experiment, they used a small scale set of three mountains - each of the mountains was of a different colour, contained a distinctive feature on their peak (a red cross, a house and some snow) and varied in height. Other apparatus used was a set of ten pictures that showed different viewpoints of the mountains and a set of three pieces of cardboard that were the same shape and colour as the mountains. The mountains were placed on a 1 metre by 1 metre table with the child placed on one side of it.

In the first testing method they presented the child with pieces of cardboard and asked them first to recreate their own view of the mountains, then that of a doll which had been placed on another side of the table. The two reconstructions would therefore need to be different and take into account the difference in angle between the participant's and the doll's line of sight. The child was then moved to another side of the table and then asked to recreate their own view, followed by a reconstruction of a place they had previously occupied.

The second testing method abandoned the construction method and used the aforementioned pictures, asking the child to pick out which one of them would match the doll's view. The third testing method did exactly the opposite of the second method - the doll had to be placed so that it would have the same view as that shown in the picture.

The children used in this task ranged from 4 to 12 years of age[1] but though the results were discussed at length, they were not fully analysed due to Piaget's reliance on *La Méthode Clinique*. They did however subdivide the child's progress on this task across three separate stages with sufficient cognitive ability to complete the task successfully only emerging at Stage III.

- **Stage I**: the child does not have the cognitive abilities to appreciate the task and is therefore unable to succeed at it.
- **Stage II**: The child has no or little ability to distinguish

[1]The total number of children used was 100: 21 between 4 and 6;6, 30 between 6;7 and 8, 33 between 8 and 9;6 and 16 between 9;6 and 12

between the differing points of view but enough comprehension to attempt the task.

  - **Stage IIA**: In Method 1, the child creates a new construction but it is in fact their own view that is being created each time. In Method 2, the choice of image is either random or "egocentric". In Method 3, the doll is placed at random or left at the same place.
  - **Stage IIB**: At this stage, the child makes some clear attempts to solve the task and shows a certain level of appreciation of the problem at hand but inevitably fails to solve it.

- **Stage III**: Piaget and Inhelder argue that children only arrive at this stage around the age of 7 or 8. At this point, the children have sufficient ability to co-ordinate the differing points of views and discriminate between them. However, he also subdivides this stage into two substages:

  - **Stage IIIA**: The child understands relativity of viewpoint but this comprehension is "incomplete" (p.233) - some responses mix correct appreciation of the alternative point of view but some small aspects still reveal egocentrism[2]

[2] On p.233-234, they describe children tested on Method one who manage to appreciate the before-behind aspect of the point of view but fail on the left-right aspect.

- **Stage IIIB**: The mistakes from IIIA have disappeared and the child is able without too much difficulty to perform the various tasks correctly.

1.1.2 Criticism:

Though most of Piaget's assessments tended to be quite conservative, there is reason to believe that the findings from this experiment may have been excessively conservative and heavily underestimated the child's ability to appreciate another persons' point of view.

Complexity of the testing methods

Piaget's first method seems to be rather complex for a young child - asking a child to place cardboard mountains in a very precise fashion is possibly rather tedious and too painstaking a task to interest younger children. Interestingly, performance on Method 1 is noted by Piaget and Inhelder to be the first task to be performed correctly at stage IIIB though intuitively one would expect that the earliest task would be the photo task, since only selection is required.

Symbolic failure

The problem of symbolic representation remains in all three methods - in method one, the children have to appreciate that the smaller model represents the larger model and understand that they must not copy the model but recreate it from a different angle - in itself quite a complex thought process to accomplish. In method 2 and 3, they have to comprehend that the photo represents the mountains and that each photo represents the mountain from a different point of view.

Participants used

Though the total amount of children tested was quite large (N=100), it should be noted that the younger group had a large age span (ranging from 4 to $6\frac{1}{2}$) and a relatively small number of participants in it (21). Probably, very few young children were tested on this task.

1.2 Hughes' picture selection experiment (1978)

Hughes (1978) reported two experiments looking at whether the picture selection process from Piaget and Inhelder's task underestimated the child's inability to appreciate an alternative point of view. He argued that children's poor performance on Piaget & Inhelder's picture selection task could be due to two causes other than those advanced:

1. **The complexity of the task**

   Light (1979) argued that the task "requires complex spatial transformations which appear to be well beyond the congnitive capabilities of the preschool children" *(p. 18)* and this was confirmed in Flavell, Botkin, Fry, Wright & Jarvis (1968)'s experiment which demonstrated that young children can be successful on simple perspective-taking tasks, but tended to fail on more complex versions. It therefore seems that Piaget and Inhelder's task was too complicated to fully tap into young children's comprehension of point of view.

2. **A failure to notice the required salient features**

   Children's performance on picture selection may depend on their noticing salient features in the task. In Piaget's experiment, there was a wide range of features that could be used to solve the task. However, some more recent research has shown that when these features are pointed out to the children, their performance on the task improved (Fishbein, Lewis & Keiffer, 1972).

Hughes' experiment therefore sought to see whether either of these two explanations could account for young children's poor performance on picture selection tasks.

1.2.1 The experiments

The first experiment looked at whether children would appreciate the difference in point of view between the experimenter and their own in a simple context. Three dolls were placed on the three peaks of a flat triangle with each doll facing outwards. One peak would be facing the experimenter, another, the child. The three dolls differed in colour (either red, blue or yellow) but were otherwise identical. 40 four year olds were tested, with 20 being assigned to each condition group.

In the first condition (condition A), the children were asked a question about their own point of view ("Which picture shows what you see?") after which the triangle was rotated and the same procedure was carried out for the other two dolls. After this, the triangle was rotated again and the same procedure was carried out only this time the child was asked about the experimenter's point of view ("Which picture shows what I see?").

The other condition (condition B) featured the same testing phase but in this case it was preceded by three sets of three questions: the first set asked the child about their own point of view, followed by three questions about the experimenter's point of view and finally, three questions about the pictures[3] and each question from each set were for each different position of the triangle.

The results showed that children performed well on condition B's preliminary questions[4] which was followed by an above average performance on the picture selection questions[5]. However, condition A showed a very different picture: performance on the questions relating to their own point of view was similar to that of the children in condition B (12 out of 20), but when they were asked about the experimenters' point of view their performance collapsed, with only one child passing this section. More interestingly, on these questions 64% gave responses that were egocentric.

The statistical analysis of this experiment showed quite conclusively that although young children have the ability to evaluate another person's point of view, a picture selection task is a poor way to measure this knowledge.

[3]The verbatim version for each set was respectively "Which doll's face do you see?", "Which doll's face do I see?" and "Which doll's face do you see in this picture?"

[4]Respectively 20, 19 and 16 out of 20 children got at least two out of three correct responses on this task. Two out of three correct answers was deemed by Hughes to be a pass rate and will be used as such in the rest of this section.

[5]13 passed the questions relating to their own view and 13 also passed the questions relating to the experimenter's point of view.

1.2.2 Criticism

It could be argued that the differences found between the conditions, were due to the training received in condition B. Perhaps the two additional rotations of the triangle also helped the children to think about other views and enable them to perform the two step transfer necessary to solve the task[6]. However, Hughes' second experiment broke down the amount of pre-training into (a) none (b) only preliminary questions about the pictures (c) only preliminary questions about the two points of view and (d) all three sets of questions. Interestingly, condition (b) resulted in little improvement on correctly picking out the experimenters point of view over condition (a)[7]. Performance was not much better on condition (c) (6/20) but they improved dramatically on condition (d) (16/20). This seems to demonstrate that seeing extra rotations of the triangle only has a minor effect on their final performance, if any.

The second experiment also examined performance when the selection process was broken down into two components: they would first have to make a verbal response; after having made it, the pictures were shown to them and they were then asked to

[6] Step 1: calculate the experimenters' point of view; Step 2: select the picture corresponding to that point of view

[7] 4/20 passed the first task and 2/20 passed the control task

select the correct picture[8]. The success rate in this case was very high, especially when associated with condition (d), which yielded a perfect performance from the children.

It therefore seems plausible that Piaget and Inhelder's mountain task requires two steps from the child rather than one. The child has to start by calculating the doll's point of view, then match up their mental image of this new point of view with the pictures that are being shown to them. It is, however, curious that they tend towards an egocentric response when they fail in both Piaget and Inhelder's task and Hughes' task - it seems somewhat counterintuitive to go to the effort of calculating another person's point of view, which is different from your own, and then select a picture that shows your own point of view. Could it be that the egocentric choice is an easy option that the child knows is probably wrong but is readily available to them? It is also plausible that the children fail to understand what is expected from them or that maybe the mountains task is too complicated to be completed successfully at this age. The fact they seem to understand Hughes' task perfectly well seems, however, to imply the latter rather than the former. Another possibility is that the egocentric choice is some sort of default mode that the child

[8]The verbatim instructions were "Which doll's face do I/you see?" and then "So which picture shows what I/you see"

has to struggle to overcome. Given that appreciating another's point of view is not a skill that is frequently required at their age, it may just be that the ability is there but at times insufficiently powerful to override the egocentric view point.

Hughes' experiments also fail to clarify the reasons for failure. The first experiment seems to indicate that making them pay attention to the salient features helps them. But in the second experiment, these questions seem to be effective only if all of them are asked and show little effect individually. The condition in which the child is asked to make a verbal response before making a pictorial response also shows an increase from being asked preliminary questions about the pictures but no significant effect; however, the scores in this case may be too close to ceiling to yield a significant difference.

It also remains a much easier task for the child to perform — problematically, the children can answer correctly by simply having an understanding of proximity since the doll that is facing/visible to the experimenter is always the closest doll. Maybe the children are not really answering what the experimenter is seeing but rather which doll is closest to him.

1.3 Hughes & Donaldson (1979) - hiding from the policeman

1.3.1 The experiment

Since the picture selection task was at best a debatable way to measure a child's appreciation of point of view, Hughes & Donaldson (1979) attempted to use a slightly different response method. In the first experiment, they looked at 20 children aged between 3 and 4[9] and asked them to place a screen to block the experimenter's view of a toy. However, a successful response would also mean that the child would still be able to see the toy. The children were tested in three different positions - one where the correct response required them to place the wall perpendicular to their own line of sight, another parallel to their line of sight (i.e. a 90° rotation of the first response) and another diagonally (a 45° rotation of the first response).

The results showed that none of these were in the slightest bit problematic for the children - there was no difference between the age groups, nor were any egocentric responses made. The overall performance on the task was very high with around 90% of children in both groups getting all three tasks right.

The second experiment changed the response method and

[9] i.e. 10 children per group

required the child to place the toy out of sight from another toy. The first wall configuration used was of two intersecting walls in a + shape. In the first part of the experiment the doll — a policeman — was placed facing the edge of a wall so that he would be able to see into two of the quadrants. The second doll — a boy — was then placed in each quadrant consecutively and for each position the child was asked if the policeman could see the boy. After this the policeman changed sides and the child was then asked to place the boy where the policeman will not be able to see him[10]. In the final part of the experiment, a second policeman was introduced and placed so that only one quadrant is now unwatched by either policeman. The child is once again asked to place the boy where the policemen cannot see him - this was repeated 3 more times with the free quadrant changing for each question.

The children in this experiment were subdivided into two age groups and ranged between 3;6 and 4;11. The children were only measured on the final part of the experiment and no age difference was found in their responses; almost all the children were able to appreciate and co-ordinate the two different points of view with only three children failing 2 or more trials[11].

[10] If an error was made, the error was "pointed out" and the child was asked the question again. The error rate was of 8% overall

[11] 22/30 were correct on all three trials and 5/30 were correct on two of them

A further experiment looked at another 40 three and four year olds in two more complex versions of this task. The first version had five sectors and two policemen and the second had six sectors and three policeman with half the children from each age group being assigned to one or the other. The results this time showed a significant effect of age with the four year olds performing better than the three year olds on both tasks though no significant effect of task was found, although performance was noticeably better on the first version[12]. Again few of the errors produced by the three year olds were egocentric.

1.3.2 Criticism

Amount of training

In the second experiment, the children were given a lot of training before being tested. Although they are reported not to make many mistakes on the second phase of the experiment (8%), the figure is an overall statistic and does not state how many in each age group made a mistake. If a larger proportion of younger children were making that mistake it would not be unreasonable to wonder whether they were actually being taught how to solve the task before they were

[12]On the first version, 90% of the four year olds made no error whilst 60% of the three year olds made one or no errors. On the second version, 80% of the four year olds made no error and 70% of the three year olds making one or no errors.

being assessed. The same can be said for the third experiment - there's no clear description of the pre-testing phase but we are told the task is "introduced carefully and gradually" which does seem to imply some form of training too.

Intrinsic complexity

It is interesting that when Hughes & Donaldson (1979) increased the complexity of the task, there was a noticeable drop in performance in the younger group. This could indicate that Piaget's task is at least as complex as the more complex versions of Hughes & Donaldson (1979) task and possibly too complicated for the young children to complete correctly. When the child is being asked to recreate the view of the doll, they may have enough knowledge to comprehend that it is going to be different from theirs but are not able to compute the mental rotations necessary for producing a correct response.

Another reason for this could also be the nature of the required response in both Piaget and Inhelder's and Hughes and Donaldson's tasks: it seems sensible to assume that hiding a toy from another is probably more interesting and relevant to a child than painstakingly reconstructing the point of view of another doll. A more enticing or relevant task is more than likely going to keep the child interested for long enough to elicit a correct response.

Solving methods

Another possible explanation for the good performance on this task was advanced by Mark Blades (personal communication) who argued that the children could solve this task without necessarily appreciating the policeman's line of sight. The children could in fact succeed by using simple rules of hiding: If they placed the boy in the farthest away corner from the policemen they would end up being correct without actually understanding line of sight. This tallies with the criticism of Hughes' experiment in that they could solve it if they were to equate "seeing" to "being closest to".

1.4 Borke's (1975) replication of the mountain task.

1.4.1 The experiment

Given the potential problems with Piaget and Inhelder's response method and also the possible flaws in the experiments published by Hughes (1978) and Hughes & Donaldson (1979), it may be useful to return to Piaget's original experiment with a different response method. Borke (1975) included a condition in which this was tried.

Looking at a small number of three and four year olds[13], she used manipulation of models of a three-dimensional display as a response method. The child was first shown a display with a rotating copy of it to the child's left, after which they were asked to replicate a doll's view by rotating the replica. If the child made a mistake, they were shown the correct response and asked to repeat it and were given feedback. This initial trial block was then followed by three test blocks, each one consisting of a different display accompanied by a replica of that display. The displays varied in complexity: the first consisted of three objects (a lake, a house and a cow), the second was a copy of Piaget and Inhelder's three mountains and the final display was made up of a mix of"people and animals in natural setting" (p.241) (eight in total). For each display the doll was moved in turn to each of the three sides of the table (omitting the child's side) and the child was asked to recreate the doll's view by rotating the replica.

Statistical analysis showed a significant difference in performance between the three displays. Borke reported the children to be "highly accurate" on the first and third displays[14] but not on the three mountains display where 43% of the three year olds

[13]Eight three year olds and 14 four year olds

[14]The children were correct 80% of the time on the first display, the three year olds' were correct 79% of the time on display three and the four year olds' were correct 93% of the time.

responses were correct and 67% of the four year olds responses. Interestingly, when the overall errors were evaluated 31% were egocentric compared to 69% random.

Strangely, in this experiment the complexity of the display does not seem to affect performance with similar results on both the first and third displays, nor does there seem to be an excessive amount of egocentric responses when mistakes are made. The three mountains however seem to still remain complicated for the children whatever the response required. This could be due to the children's lack of attention to the salient features of the mountains, as hypothesised by Hughes, or a difficulty in engaging with them as they do not contain any character they may be able to relate to.

1.4.2 Criticism

The number of participants used in this study makes us cautious of the findings - Borke only tested 22 participants, only eight of which were three year-olds. The problem of training is also an issue here as they receive an extensive demonstration and feedback session before they attempt the tasks - this could account for a higher score on most of the tasks than one would expect without this pre-training. There was a lack of clarity over the scoring of the responses as it is not made clear what would constitute a pass. If a response was 5° away from the correct response would that be a fail or a pass? We do not know. Also the order of presentation of the tasks was not varied. There could have been a strong learning effect that occurred after the first two tasks that would account for their good performance on the more complex display. However it may also be the exact opposite - the more complex an array, the more salient features are made available to the child to use and therefore the better they would perform on it.

Flavell et al. (1968), however, showed that children's performance on their adapted version of Method 1 from Piaget and Inhelder's experiment was highly dependent on the complexity of the task - they asked children to copy a model from another point of view and tested children between 7 and 17 at this task. The more complicated versions of the task caused the 17 year olds sufficient difficulty in that the majority failed the task. The simplest versions of the task however were too complicated for the younger children. Though increased complexity does not necessarily mean an increase in the amount of salient cues, the research does seem to point to the idea that the high performance on the final display in Borke's experiment may be down to practise on the previous two displays.

Also, the experiment appears to show that children of that age understand symbolic representation and are able to make that transfer effectively to a rotating display. This would therefore mean that the poor performance on Piaget and Inhelder's mountains task is probably not due to a poor understanding of symbolic representation but rather to the response method or the overall difficulty of the task.

1.5 Young children's hiding ability - Flavell, Shipstead & Croft (1978)

As we have seen so far, the response required from the child seems to throw up different response patterns and may lead the experimenter to misinterpret the child's ability at appreciating line of sight. Flavell and colleagues looked at the ability of children between the ages of two and a half and three and a half to hide a toy by either moving the toy or by moving a screen. The participants were 48 children assigned to three age groups[15]

They were initially given a pre-training session in which the experimenter covered the doll with a scarf and said "My eyes are open and I'm looking. Do I see the puppet?". The same question was repeated again with the doll uncovered and half-covered. This was followed by the child being asked to hide the doll from the

[15] The age range in months for each group was 29-35 ($2\frac{1}{2}$), 36-41, (3) and 42-48 ($3\frac{1}{2}$). No mean age was reported.

experimenter who was placed either across the table or to 90° to the child's right or left. A screen was placed in front of the experimenter so the experimenter would always be looking at the wall face on. The presentation order was as follows: experimenter across the table from the participant, experimenter to their right, experimenter to their left and experimenter once again across the table from them. After the four positions were completed, the child was then asked to hide the toy from themselves. Following this, the toy was placed on the table and the child was asked to move *the screen* so the experimenter wouldn't be able to see the toy.

The results showed that all three age groups were very able at the toy-placing task with the three and a half group giving a perfect performance at this task. The two and a half year olds performed worst but still achieved a good performance, 13/16 children succeeding on each toy placement task[16]. On the screen placement task however performance was much worse, with significant improvement with age. Every age group's performance was also significantly worse on the *move screen* task than on the *move toy* task. Although on the toy placement task there was only one incorrect egocentric response, on the screen placement task

[16]On the final egocentric placement task, 50% failed. Perhaps this was due to having been asked to hide the toy from the experimenter four times in a row

around half the errors were egocentric.

A visual "diagnosis" task was also included at the end of the experiment - in this task the doll was not moved at all but a second experimenter was introduced and sat on the opposite side of the table from the child whilst the first experimenter sat alongside the child. The first experimenter then placed the screen in four different positions asking the child for each position whether the other experimenter would be able to see the toy. The four positions used were *All*, which completely blocked the child's view of the doll (but not the second experimenter's), *Top* and *Bottom* where respectively only the top and the bottom of the doll were visible to the second experimenter and finally *None*, where the second experimenter could not see the doll at all. The results for this set of tasks were quite interesting in that almost all the children performed correctly on the All or None tasks irrespective of their age group[17]

1.5.1 Criticism

These results once again seem to show that the response method can be crucial in determining how much children actually appreciate. Unlike previous experiments, the pre-training in this case is unlikely to have increased the children's performance given that the required

[17] The worst performance only had 3 out of 16 participants failing.

response was simultaneously egocentric and non-egocentric since if the seat was visible/invisible to the child, it was visible/invisible to the experimenter. The purpose of the pre-training task was to establish that the children would count an object visible if only part of it was visible and children seem to understand that partial visibility counts as visibility,

From this experiment it seems that young children have a basic comprehension of line of sight but are not always able to build upon this understanding to create the correct response required by the experiment. A strange result with the Flavell et al. (1978) task is that, though children have shown a good enough understanding of line of sight to be able to hide a toy appropriately, few of them are able to make a correct response when they are required to move the screen. The reasons for this are unclear and various explanations can be offered up to account for it:

Relevance of the response

The response that is required is not one that they are used to making. In hide and seek games they can understand they have to hide themselves from the other person but moving an object to obscure their visibility is a step further away from that context and therefore less readily available to the child to solve this problem.

Solving method unrelated to line of sight

Blades' proposal that the children were solving Hughes and Donaldson's task by using simple rules of proximity (see page 37), may have some credibility here, since the youngest children were able to perform the hiding task by using a simple rule which may have been to hide it as far away from the experimenter possible in a unexposed place. That would account for their good performance on the diagnosis task and also account for their poor performance on the screen moving task as that rule could no longer work in that context. Given that no understanding of line of sight is required to execute Blades' proposed rule, it therefore seems debatable whether the overall ability of two and a half year olds as well as three year olds on these tasks is actually related to line of sight.

Contextual dependency

It could also be argued that the youngest children's understanding of line of sight is highly context dependent. They can appreciate line of sight but are only able to apply this understanding within certain contexts. They can understand that certaing places are excluded from a line of sight but maybe not fully understand that a line of sight can be curtailed by moving a screen into its trajectory.

However, by the age of three and a half, most children are able to perform well on the screen moving task which seems to imply that they have understood line of sight in this context as well. This also shows again the Piaget and Inhelder's task was probably not testing children's appreciation of line of sight or point of view, but instead either (a) their ability to make complex calculations of a point of view at an early age or (b) - if we accept the response methods as valid measurements of the children's ability- the child's understanding of line of sight and point of view *within the particular context of a mountain landscape.*

1.6 Appreciation of the nature of lines of sight - Flavell, Green, Herrera & Flavell (1991)

1.6.1 The experiments

This experiments of Flavell et al. (1991) give an interesting insight into the quality and the contextual nature of young children's understanding of line of sight and point of view. The first experiment looked at three and five year olds' predictive ability when asked whether they would be able to see through a curved tube. After a short training phase, the children were shown a straight tube side on[18] and asked, if they were to look in one end, whether they would be able to see the toy affixed at the other end of the tube[19]. The tube was then bent to a curvature of 140°, a similar curvature to a banana, and the same question was asked again. The same transformation - question system continued for 2 other degrees of curvature (90° (L-shape) and 0° (U-shape) after which the tube was returned to straight and the child was asked the question again. No feedback was given in this experiment until the final question where the child was allowed to inspect the tube. Visibility was in fact impossible for all of the degrees of curvature except the straight condition. This block of questions was followed by what they referred to as the feedback block in which the experimenter used a different tube, then bent it to 140° and asked the child to predict visibility. This time the child was allowed to look down the tube after this prediction and was asked if they could see the toy or not, after which the tube was turned back to a side-on view and they were asked to once again predict whether or not they would be able to see through it. Finally the child was given a third block

[18]i.e. the axis of the tube was orthogonal to their line of sight so they were unable to see into it.

[19]The toy was placed just inside the tube and was therefore invisible to the child though the training session made them aware of the presence and placement of this toy.

of testing that was identical to the first block but another tube was used.

The results on this first experiment were quite surprising - the first block of testing found significant differences between the age groups and significant differences between the varying degrees of curvature[20]. Interestingly, the five year olds' performance on the 140° task improved significantly after the feedback block but the three year olds did not, nor did their performance improve on any of the tasks pre to post-feedback. The results from this experiment are summarised in table 1.1

[20]The difficulty increased thus: $0° < 90° < 140°$

	Pre-feedback			Feedback		Post-feedback		
				Before	After			
	140°	90°	0°	140°	140°	140°	90°	0°
Three year olds	16	26	32	16	26	21	32	32
Five year olds	47	47	68	26	79	84	84	89

Table 1.1: Percentage of participants making a correct visual evaluation (taken from Flavell et al. (1991))

These findings seemed to demonstrate that children as old as five may not necessarily have a good understanding of the basic constraints of line of sight. They may understand how to hide from someone in certain contexts but from this experiment they do not seem to understand that line of sight is straight, which one would assume would be a basic piece of knowledge needed to correctly solve tasks such as Hughes and Donaldson's. However, there are some obvious limitations to this experiment. Firstly, the children may have been acting conservatively in this experiment: they were after all shown that they could see through the tubes in the training session and may believe that since they were able to see through it originally, the physical deformation should not affect it - if they are thinking in that manner, maybe this task is underestimating their abilities to understand line of sight as they are being incorrectly cued into making the incorrect response due to the experiment's manipulations of the same tube in each block. Secondly, this may be a contextual effect as we have previously hypothesised. Evaluating visibility through tubes is not something children would tend to often do whereas if it were to take a form of hiding they may be much better at evaluating line of sight. One of the undeniable advantages of this experiment however is that the response required from the child is simple and is unlikely to cause the child any problems.

A second experiment dealt with these issues. The general outlook was the same (i.e. prediction of vision between two dolls) but this time they looked at only one degree of curvature (90°) in varying viewing conditions. The four conditions they used were:

Through Tube

In this task, the children were once again asked if a toy would be able to see through a curved tube.

Along Tube

Here the child's attention was drawn to the outside of the tube as a possible line of sight and asked if the dolls would be able to see each other along that route.

Around Barrier

A barrier was set up between the two dolls but they were placed on the outline of a 90° curve traced on the floor and the child was asked if they would be able to see each other along the 90° route.

Right Angle

The dolls were placed on the outer sides of a rectangular box so that their line of sight must also bend 90° if vision were to be possible.

Once again, they looked at the performance of three year olds and five year olds on these tasks[21] and found a a significant difference in performance between the age groups with the five year olds consistently performing better on each task. Significant differences were also found between the conditions with the order of difficulty from easiest to most difficult: Right Angle, Around Barrier, Along Tube and Through Tube. Again the performance on the Through Tube task was poor in three year olds as was the performance on the Along Tube task, with respectively 28% and 39% responding correctly to these two tasks but this was in direct contrast to their performance on the Around Barrier and Right Angle tasks where 67% and 89% respectively were correct[22] (see table 1.2 for a summmary of the data).

Age group	Through tube	Along Tube	Around Barrier	Right Angle
Three year olds	28	39	67	89
Five year olds	61	78	83	94

Table 1.2: Percentage of participants correctly predicting non-visibilty in different viewing conditions. Adapted from Flavell et al. (1991)

[21] 18 participants in each age group

[22] When grouping the tube tasks and the barrier tasks together, the difference yielded was statistically significant

In the third experiment, prediction of vision through tubes was examined. In this task three tubes were pointed at a toy zebra - one that was straight, another curved at 90° and another that was coiled up on itself (like a snail shell). Another straight tube not pointing at the toy was also included. A toy doll was inserted at the opposite end of each tube and the children were asked if that toy would be able to see the zebra. Again the results (see table 1.3) showed poor performances from both three year olds and four year olds on the 90° task but good performances on the other three tubes with significant differences between each one of them and the 90° task, thus replicating the findings and seemingly demonstrating a crucial quality of young children's comprehension of line of sight: though they understand that their point of view is not universally held, they do not fully appreciate that lines of sight are straight.

Age group	Correct straight	Wrong Straight	Coil	90°
Three year olds	78	83	83	22
Four year olds	100	94	78	39

Table 1.3: Percentage of participants correctly predicting non-visibilty in different viewing conditions. Adapted from Flavell et al. (1991)

1.6.2 Criticism

Much of the criticism that could have been levelled at Flavell's experiments were in fact dealt within the paper such as the possible cuing of the child to believe that curved vision is in fact possible. The coil condition used within the third experiment could arguably be seen as proof that children do not think that line of sight can bend but we must appreciate that the coil was (A) of a very extreme curvature and (B) in many ways qualitatively similar to a barrier given the fact it makes a full loop upon itself.

In the second experiment, it would seem that their acceptable performance on the easier two tasks (Around Barrier and the Right Angle) may explain their good performances on Hughes and Donaldson's experiment. A barrier offers a more salient encroachment on vision whereas a tube does not seem to do so. It would be interesting to see how many of the responses made in the Hughes and Donaldson task were within an area that could have been seen by "curving" one's vision - the findings from the current experiment would imply that very few children would have responded in that way.

Chapter 2

Line of Sight and other sorts of Visual Knowledge

Although the body of work dealing with understanding of line of sight is relatively small, the topic connects with several other research fields. In this chapter, we look at some research on three related topics: basic cosmology, gaze following, and photography.

Basic cosmology. A grasp of the relation between the land, the horizon, the sky and the heavenly bodies should bear some relation to developing visual knowledge. Perhaps such knowledge assists that grasp, but it might also be thought to hinder it, since the land looks flat, and the sky looks like a roof or dome in which the stars are set and across which the sun and moon travel. At any rate, study of the development of basic knowledge of the cosmos may tell us something useful about knowledge of line of sight.

Gaze following. Children must learn to co-ordinate their gaze with the gaze of others in order to achieve joint attention to an object. Knowing what another person is looking at involves knowledge of line of sight. So research on the development of gaze following should provide complementary insights.

Photography. Understanding of the concepts inherent to photography implies a good understanding of line of sight since a camera must be pointed at the object it is about to photograph. Research in this area has been spasmodic and had most often focused on issues of theory of mind more than line of sight but there remains useful insights into a child's understanding of such concepts.

We shall end the chapter by surveying the literature of children's understanding of vision when related to barrier-tasks. Although the tube experiments were not exactly barriers, it seems that the curvature could be seen as a barrier of sorts and therefore that area needs to be explored along with the discussion by Flavell (1978) of the development of visual understanding in children.

2.1 Basic Knowledge of the World

A point of some interest is the way in which a child's theory of the world develops (see Piaget (1929) for the earliest attempt to explore this). The research we have reviewed leave the impression that there is piecemeal development of understanding of line of sight: the child may be able to understand that two dolls can't see one another in a given context (such as the barrier task in the Flavell et al. (1991) experiment) but this knowledge does not carry through to more complex environments (such as the tubes in the same paper).

Some research has looked at how children can develop theories of phenomena for which they have no direct feedback. One would expect a child to learn eventually that gravity affects all unimpeded objects as they will have experienced it on a very regular daily basis. However, when it comes to more complex and counter-intuitive science such as the curvature of the earth, they will have very few experiences that would encourage them to accept that theory (after all, it was not until the work of Drake (1967) that the world at large started to take note of this shift in theory).

Michael Siegal, Gavin Nobes and Stella Vosniadou have looked at how children develop their understanding of scientific phenomena. Their research focused on children's comprehension of cosmology.

In effect it mostly looked at very basic aspects of cosmology such as the curvature of the earth, the positioning of the sky and the effects of gravity. Most of the tests related to how children were able to deal with contradictory information. For example, how did they deal with the flat earth illusion while being taught that the earth is round? The importance of cultural information in the growth of knowledge is also a key concept of their work. When/if a child arrives at a scientifically correct concept, there is a series of phases they will have gone through to arrive at this point. This concept could have been derived from what (Nobes, Moore, Martin, Clifford, Butterworth, Panagiotaki & Siegal, 2003, p. 72) call "intuitions, presuppositions or naive theories". However, if this were to be the case, Nobes et al. argue, cultural information would therefore be unimportant compared to direct observations of the phenomena. This is the standpoint of Vosniadou and colleagues (Vosniadou, Skopeliti & Ikospentaki, 2004; Vosniadou & Brewer, 1994, 1992, 1987) who base their work on Carey's theory of domain-specific *restructuring* (1985) in which children increase their knowledge by constantly restructuring it. Vosniadous research measured children's understanding non-verbally - the children were asked to either draw or form a plasticine model of what they felt was a correct representation of the planet. There are obvious issues with this type of methodology because the external representation may not fully portray the child's internal representation. As a result of this criticism, more recent research (Nobes, Martin & Pangiotaki, 2005) has moved beyond the drawing-based methodology of Vosniadou et al. (2004), Vosniadou & Brewer (1994) and Vosniadou & Brewer (1992) and the 3-D modelling used by Siegal, Butterworth & Newcombe (2004) and Nobes et al. (2003). Nobes et al. (2005) used an image rating task instead. They asked children of different ages to rate which images they thought best represented their understanding of cosmology. They felt that, when presented with a choice, the child will most likely choose the image that was closest to their internal representation.

On this task, even 5 year olds exhibited a good knowledge of the spherical nature of the earth, whereas in Vosniadou's research, they tended to exhibit a naive and scientifically incorrect understanding - Nobes et al. (2005) argue that their evidence demonstrates fragmented and incoherent knowledge, rather than the coherent naive mental models implied by Vosniadou's research. Moreover, Nobes et al. (2005) argue that it is cultural information that is crucial to the child's developing scientific theory and the information gleaned from their day to day experience is not necessarily incorporated into a coherent mental model but remains fragmented and can contradict culturally-acquired understanding. It should be noted that the above debate over models and fragmentation is based solely on one area of knowledge - Nobes et al. (2005) accept that in areas of knowledge where children are more likely to experience contradictory events (e.g. gravity in physics), the influence of cultural information will be far less important and the children's theories will be more closely based on their own experiences of the phenomena.

2.2 Gaze Following and Joint Attention

Research by Butterworth & Cochran (1980) and Butterworth & Jarrett (1991) looked at infants' understanding of gaze in a series of tasks. In these experiments the baby was initially placed facing the mother. The mother would then establish eye contact and turn to look at an object placed at the side of the room (to left or right). The results showed that babies as young as six months of age would follow the mother's eye-gaze towards an object provided that it was within the same visual field as the mother. If the object was placed behind the baby (so that they could not see both the mother and the object at the same time), they tended to fail to find the object. Around the age of 18 months of age, they were found to improve at this task and start to be able to follow gaze so as to find these "hidden" objects. Flom, Deák, Phill & Pick (2004) extended the initial setup to see how 9 month olds would respond to clearer signals such as pointing or vocalisations. By and large, their results showed a marginal improvement in searching patterns in that babies would find objects that were in the periphery of their vision, but their performance on the "hidden" objects was still poor. Deák, Flom & Pick (2000) found that placing the parent at a 90° angle from 12 month old children allowed them to visually find the objects that were placed behind themselves. However, 9 month old infants (Flom et al., 2004) did not show this ability.

2.3 Young children's comprehension of photography

It seems that a child's understanding of photography should also be related to ability to understand line of sight. For a camera to take a photo of an object, the following conditions must be fulfilled A: it must be pointing at the object, and B: no barrier must interrupt the line between the object and the lens. Zaitchik (1990) looked at how children understand what can be seen in photographs. Zaitchik sought to compare children's understanding of photography with their performance on a false belief task similar to that developed by Wimmer & Perner (1983). Wimmer & Perner devised a task in which a child sees an actor A hide a toy in a given hidden location, then leave the room. Subsequently, actor B moves the object to another hidden location unbeknownst to actor A. The child is then asked where actor A would look for their toy. It was not until a few months before their fourth birthday that children would be able to assign to actor A a false belief (see also Perner, Leekam & Wimmer (1987) for a variation on this task). In Zaitchik's experiments, a Polaroid photograph was taken of an object in a given location. The photo was then set aside and the location of the object was then changed to a different location. The child was then asked "In the picture, where is the object?". The results showed that the photograph task was at least as difficult for children as the false belief task. Despite changing various aspects of the experiment to improve the children's performance on the photograph task, the younger children continued to perform poorly on it. Moreover, their performance on the photograph tasks was consistently poorer than their performance on the standard False Belief task. Perner (1991) has wondered whether the poor performance on the photograph task is not due to children having no experience of comparing photographs to reality and therefore failing due to this lack of experience. However, in a series of experiments, Perner, Leekam, Myers, Davis & Odgers (1998) noted that the child's overall performance on the photograph task could be improved by making the child gaze at the back of the developing photograph which seems to contradict the theory that lack of experience is the reason for their poor performance. The experiments also replicated Zaitchik's main findings and found that children performed better when the representational aspect was removed from the photograph task. They did this by introducing to the child a machine which would make glossy paper change to the colour of whatever it was pointing at when operated.

Liben (2003) investigated a different area of children's comprehension of photography. In one experiment, she showed children two photographs of the same object side by side, then asked the child whether the photos were the same or not. If they were different, the child would then have to explain what had caused the change. The differences in one of the experiments was a change in the distance from which the photograph had been taken - one photo was a closeup whereas the other was taken from the same angle but further back. A majority (75%) of the three year olds were unable to explain the change that had occurred. The five year olds performed comparatively better with half of them being able to explain the difference correctly on all or all but one of the pairs. By seven years of age, the children were able to perform almost at ceiling level. The adults tested were almost always able to explain the difference between the two photographs.

2.4 Barrier tasks in infancy

From an early age, babies attend to faces and take cues from gaze. Brooks & Meltzoff (2005) sought to establish at what age a child began to follow an adult's gaze towards a given target that was outside the child's immediate visual field and found that on average, children become able to do this somewhere between their 10th and 11th month which is in line with the findings of Butterworth & Cochran (1980) (see section 2.2). Children are also able to distinguish verbally between "seeing" and "looking" around their second birthday (Bretherton & Beeghly, 1982) but this verbal ability does not necessarily transfer to the children's ability to distinguish between seeing and looking in non-verbal tasks. Research by Butler, Caron & Brooks (2000) looked at the ability of 14- and 18-month old children to appreciate obstruction of line of sight. In their task, the experimenter gazed in the direction of an object. Sometimes a barrier would prevent the experimenter from seeing the object.

At other times there would be no barrier, so the experimenter would be able to see the object. They also used a barrier with a window in it which allowed the experimenter to see the object through the window. They measured whether the children followed the experimenter's gaze across the conditions. They found that 18 month old children seemed to appreciate that a barrier would impair the looker's vision, whereas a window or no barrier would not, but the 14 month old children did not show this clear difference in appreciation. They would look at the target object more frequently than the 18 month olds. However, there was a decrease in their performance on the no barrier task, indicating that there may be some understanding of the effects that a barrier has on vision. Butler et al. (2000) argued that the experimenter's face was less salient as her face was surrounded by two barriers in this task and so the children found eye-gaze cues more complicated to use. Bridges & Rowles (1985) looked at 3 to 7 year olds in a series of barrier-like tasks where the child was asked to predict whether a monster would be able to see *over* a barrier when a toy was placed in various positions. The research found a steady increase in performance from the children. Their appreciation how a barrier affected line of sight increased with age.

Perner (1991) reports a task in which 18 month old children were asked to let another person see a picture glued to the bottom of a plastic cup. The children tended to use an unusual technique of holding the cup low, then tilting it back and forward between the other person and themselves. This method meant that they could see it and the other person could also see it in turns. It also shows a low-level understanding that another person's line of sight is different from their own and that this line of sight can be obscured by barriers of sorts - the sides of the cup. Perner (1991) argues that this task may show that children appreciate that the process of seeing is an *inner experience* and are creating the experience of seeing the picture for themselves to make sure the other person can also appreciate the same experience.

John Flavell has expounded a two-level development of early understanding of vision in early childhood (Lempers, Flavell & Flavell 1977, Flavell 1978, and see also Flavell 2004 for a more recent exposition of his theory). The two stages are as follows:

- **Stage I**: The child is able to appreciate that another person will not see the same *object* as them - they can correctly predict whether another person can see or not the same object as them, but at this stage, they cannot fully appreciate that when the other person sees the same object as them, they will have a qualitatively different experience from them (Flavell, 2004).

- **Stage II**: As in Stage I, the child can appreciate that even though the other person sees the *same* object as them, they will have a different perspective and experience of that object to what the child is experiencing. If an image is orientated right side up for the child, they will understand that someone sitting across from them will see this image upside down.(Flavell, 1992)

Further research (Flavell, Flavell, Green & Wilcox, 1980; Masangkay, McCluskey, McIntyre, Sims-Knight, Vaughn & Flavell, 1974; Hughes & Donaldson, 1979; Cox, 1980; Gopnik, Slaughter & Meltzoff, 1994; McGuigan & Doherty, 2002) has further validated Flavell's two-level theory. The development of the various stages has also been relatively well pinpointed in the same literature. Children around the age of two and a half to three are at least capable of Stage I thinking. Flavell further argues that around this same age children understand that for another person to see a target four conditions must be fulfilled (Flavell, Shipstead & Croft, 1980):

- *a*: At least one of the person's eyes must be open
- *b*: The person's line of sight must be aiming towards the target
- *c*: Their line of sight must be unimpeded (i.e. no barriers in

the way)

- *d*: What the child can see has no influence over what the other person can see

Around this same age, children are able to move an object behind a barrier in order to hide it from a viewer, but have some difficulty in being able to move a barrier to hide an object (Lempers et al., 1977; McGuigan & Doherty, 2002). The experiments by McGuigan & Doherty showed that the move-barrier task was considerably more difficult for young children. However, the gap in performance became smaller around the age of three and almost entirely disappeared just before their fourth birthday. Anderson & Doherty (1997) have also found that a child comprehends what a person is looking at around the age of three and McGuigan & Doherty found this to be positively correlated with performance on the move-barrier task.

A paper by O'Neill, Astington & Flavell (1992) looked at how children understand the information that a given modality will be able to impart in a specific experience. They used four pairs of objects - two pairs looked differently but felt the same, and the other two pairs looked identical but felt different. After hiding one member of each pair down a tunnel, the child was asked what modality they would have to use to determine which object was down the tunnel: “Will you have to look inside or feel inside?”. A strong modal difference was found: three and four year olds were more likely to (incorrectly) believe that by feeling the object they would be able to evaluate a difference that could only be determined visually. Five year olds, however, did not show this modal difference.

Chapter 3

Experiment One: Tubes and feedback

3.1 Introduction

Based upon research undertaken by Flavell et al. (1991) we aimed to replicate their findings regarding children's understanding of line of sight. Since Flavell et al. had studied three year olds and five year olds, it was thought that the performance of four year olds on this task might offer a better insight into this skill's development. We also sought to make the experiment slightly easier for the children to solve. Since the least bent tube (140°) in Flavell's first experiment seemed to be rather difficult for the children and since a pilot study showed that adults also have some difficulty solving it, we decided to increase the curvature slightly to make it marginally easier. The increase was of 10° taking it to 130° on Flavell's measurement method. However, from this point on, we will no longer use Flavell's method of measuring curvature but a more intuitive method. A straight tube will be referred to as a 0° curve (i.e. no deviation from a straight line), the U-shaped tube will be referred to as a 180° tube, the L-shaped tube as a 90° tube and the banana curved tube as a 50° tube. Hopefully, this new method of referring to the curvature will make things easier for the reader to imagine.

Due to this slight increase in curvature, we expected improved performance on the 50° task. Since the four year old group was on average seven months older than Flavell et al.'s three year old group, there was also a possibility that they would perform a lot better than the three year olds and maybe perform as well as the five year olds. Despite that possibility, we predicted that the four year olds would perform better than the three year olds in Flavell et al.'s experiments but probably not as well as the five year olds.

We added a method to ensure consistent curvature throughout the experiment. Flavell didn't make clear how the experimenters made sure that the degree of curvature was the same in the pre-feedback, feedback and post-feedback blocks. To fix the curvatures, we used different outlines of the tube at each level. Each time the tube was bent, it was matched to this outline, so that (a) the child knew it was being bent to the same degree as previously, and (b) the tube's curvature would not vary between trials or across participants. To make sure the child could identify the different outlines, each one was drawn on a different coloured piece of cardboard.

This further change to Flavell's task may have had the effect of improving the children's overall performance, though in this case it should improve their performance across curved trials, whereas the increase in the tube's curvature should only improve performance on the trials in which it is used. The effect of each change should thus be relatively easy to distinguish.

3.2 Method

3.2.1 Participants

The participants were 18 four year olds (10 female and 8 male; mean age: 4;0 range: 3;4-4;5; sd=2.73) and 19 five year olds (10 female and 9 male; mean age: 5;2 range: 4;11-5;6; sd=2.37). They all attended a local nursery/primary school. All were tested individually in one sitting and none refused to respond.

3.2.2 Procedure

Three aluminium bendable tubes were used. The tubes all measured 60 cm in length and had an interior diameter of 75 mm. The tubes, which were originally designed to evacuate gas from household machines, would stay in any position they were bent to. Three different Playmobil dolls (which were fixed at the end of each tube) were used. Their height was 50 mm. Three cardboard outlines of the tube at three different angles were used: these featured marked outlines of the tube's shape - they were used to make certain that the child realised that the tube was being bent to the same degree of curvature each time. Therefore, we felt we would be able to accurately compare performances on a given degree of curvature across the trial blocks.

In the first stage each child was told "I have 3 tubes here. At the end of each one is a lady". Each tube was then presented individually unbent and the child was asked if they could see the doll at the end of the tube. This was to make sure that they understood that they could see through a straight tube. If a child were to fail on this task, their results would not have been included. Three blocks of trials then followed this introductory test.

For the first block the experimenter chose one of the three tubes

Figure 3.1: Tube curved at 180°

at random. In front of the child, a large piece of cardboard was placed on the floor. The outline the tube was about to take was drawn on the cardboard - three different cardboard outlines that were changed by the experimenter between each trial. The outlines all had the "viewing" end of the tube[1] at a 90° rotation to the left of the child's line of sight. The experimenter would then say "look I'm going to make this tube like this [pointing to the outline]" and then bent the tube so that the outline would match the curvature of the tube. The bending procedure aimed to be as rapid and accurate as possible, making sure the tube had a smooth gradual bend. The

[1] i.e. the end which did not have the doll affixed in it

time it took to bend each bend was approximately five seconds. After the tube was in the correct shape, the experimenter held it up in front of the child, orthogonal to the child's line of sight with the "viewing" end still at a 90° rotation to the left of the child's line of sight and the other end pointing upwards. The child was then asked: "If you look in here (pointing to the end of the tube without the doll in it) would you see the lady that's here? (pointing to the opposite end)".

This whole procedure was repeated for all the degrees of curvature (50°, 90°, 180° and 0°). The correct responses to the questioning were respectively no, no, no and yes. The child was given no indication whether she/he had given the correct response. After the final trial of this block, the child was invited to look through the tube so they could make sure that the previous transformations did not impede vision when the tube was made straight again.

For the second block, the experimenter chose one of the two remaining tubes at random and proceeded in the same manner. using the appropriate cardboard outlines to demonstrate the change. The experimenter again told the child they were going to bend the tube (i.e. "look I'm going to make this tube like this [pointing to the correct outline]") and then asked the child "If you look in here (pointing at the end of the tube without the doll in it) would you see the lady that's here? (pointing to the opposite end)" For the first task in this block the tube was first bent to 50°. After the child had made their prediction, they were asked to look through the tube and say whether they could see the person at the end of the tube ("Do you see the lady?"). If they gave an incorrect response, the experimenter looked into it, gave the correct response and asked the child to look again[2] - this was repeated until the child responded correctly. After the feedback, the tube was bent back to 0° and the child was again asked the same prediction question and was then asked to look down the tube and was asked the same feedback question. After this the tube was bent back to 50° and the same prediction and feedback questions were asked.

The third block was an exact re-run of the first block with the third unused tube.

3.3 Results

Frequencies of correct responses for the tested angles were as shown in table 3.1.

Performance on the first block was generally poor: none of the the four year olds were correct on the 50° or the 90° tube tasks.

[2]The verbatim instructions were "Let me have a look [experimenter looks through the tube]. I can't see the lady. Do you see the lady?"

Performance improved marginally for the 180° tube task but was still poor. The five year olds performed better than the four year olds on this block but not above chance as more than half the children failed to predict visibility correctly in the 50° and 90° tube tasks. Their performance on the 180° tube task was much better with around 3 in 4 of them passing it. An improvement in performance related to the degree of curvature can be observed in both the four year olds and the five year olds between the 90° and the 180° tube tasks.

In the feedback block, both groups showed similar amounts of correct responses for the first 50° tube task compared with their pre-feedback performance on the 50° but after having been shown visibility was impossible through the tube, the four year olds showed only a small improvement, with almost 4 in 5 still failing the task. The five year olds, on the other hand, improved dramatically with almost all the children predicting correctly on the second trial of the block. This pattern remained in the final block, with the four year olds showing an improvement from the first block but with around 2 in 3 of them still failing the tasks. The five year olds' performance was almost perfect, with only two children failing the 50° and 90° tube tasks and one failing the 180° tube task. The improvement in performance related to degree of curvature is no longer apparent with an overall even performance across all degrees of curvature in both groups. It should also be noted that all of the children correctly predicted that they would see through the tube whenever they were asked if they would be able to see through it in the 0° position. This implies that they understand the tubes continue to permit visibility even after they have been through a series of transformations.

	Pre-feedback			Feedback		Post-feedback		
	50°	90°	180°	50°	50°	50°	90°	180°
Four year olds	0	0	3	0	4	6	7	6
(n=18)	(0%)	(0%)	(17%)	(0%)	(22%)	(33%)	(39%)	(33%)
Five year olds	8	8	14	9	17	17	17	18
(n=19)	(42%)	(42%)	(74%)	(47%)	(90%)	(90%)	(90%)	(95%)
Overall	8	8	17	9	21	23	24	24
(n=37)	(22%)	(22%)	(46%)	(24%)	(57%)	(62%)	(65%)	(65%)

Table 3.1: Frequencies of participants making a correct visual evaluation (group percentage in brackets).

Pre-feedback block

A loglinear analysis of the data showed a significant effect of age ($\chi^2(1)$=36.043; p<.001) and degree of curvature ($\chi^2(2)$=9.759; p =.007). *Post Hoc* Tukey tests (p < .05) revealed the 180° task to be easier overall than the 90° and 50° tasks. The effect is smaller for the four year olds, but they are at floor level on the 50° and 90° tasks. Independent samples t-tests were carried out and showed significant differences in performance between both age groups on all of the pre-feedback tasks.

Feedback block

The four year olds performed at floor level on the first feedback task and showed a moderate improvement on the second task. Around half the five year olds were responding correctly on the first task but on the second task this had reached ceiling levels.

Neither the five year olds nor the four year olds significantly improved their performance between the pre-feedback 50° task and the first feedback 50° task. However, the five year olds performed significantly better on the second 50° task in the feedback block than on the pre-feedback 50° task ($t(18) = 4.025, p = 0.001$) and also better than on the first 50° task ($t(18) = 3.618, p = 0.002$). The four year olds showed significant improvement between the pre-feedback 50° task and the second feedback 50° task ($t(17) = 2.204, p = 0.042$)

Post-feedback block

A loglinear analysis of the data showed a significant effect of age ($\chi^2(1)$=41.214 p<.001) but the effect of degree of curvature had dissapeared. Independent sample t-tests showed that the four year olds had performed significantly better on the 50° and the 90° post-feedback trials than they had on the identical pre-feedback versions (50°: $t(17) = 2.915, p = 0.01$; 90°: $t(17) = 3.289, p = 0.004$). Their improvement in performance on the 180° task marginally failed to achieve significance ($t(17) = 1.844, p = 0.083$). The five year olds showed a significant improvement on all three tasks pre- to post-feedback (50°: $t(18) = 3.375, p = 0.003$; 90°: $t(18) = 4.025, p = 0.001$; 180°: $t(18) = 2.191, p = 0.042$)

Response patterns

Looking at the children's response patterns gave us a more detailed insight into the data. In the pre-feedback block (table 3.2), the 4 year olds give only two types of response patterns - ⓒ (all wrong bar the 180° task) and ⓓ. The 5 year olds exhibit the same two patterns along with ⓐ (all responses correct).

The effect of curvature completely disapears in the post-feedback block, suggesting a "saltatory" development: either the child will fully comprehend or s/he will not.

	Pattern			Group		
	50°	90°	180°	4 year olds	5 year olds	Overall
ⓐ	✓	✓	✓	0	8	8
ⓑ	✗	✓	✓	0	0	0
ⓒ	✗	✗	✓	3	6	9
ⓓ	✗	✗	✗	15	5	20

Table 3.2: Frequencies of response patterns on the pre-feedback block.

	Pattern			Group		
	50°	90°	180°	4 year olds	5 year olds	Overall
ⓐ	✓	✓	✓	6	16	22
ⓑ	✗	✓	✓	0	1	1
ⓒ	✗	✗	✓	0	0	0
ⓓ	✗	✗	✗	11	1	12
ⓔ	✗	✓	✗	1	0	1
ⓕ	✓	✗	✓	0	1	1

Table 3.3: Frequencies of response patterns on the post-feedback block.

Errors in reporting visibility

The children's judgements when allowed to look in the feedback block were surprisingly inconsistent, since many children claimed to be able to see the doll through the tube when they actually could not. The response patterns are summarised in tables 3.4 and 3.5. As stated in the Methods section, an erroneous response was corrected by the experimenter and the child was asked again to perform the task until they were correct.

Eight out of 18 of the four year olds claimed to be able to see the doll on the first task. This type of error was not replicated in the five year olds group - only one out of the 19 children claimed to be able to see the doll but this was after having made a correct prediction that they wouldn't be able to see the doll.

On the second trial, the children who had made an incorrect assessment on the first test would have been corrected until they gave a correct response (none of the children persisted in claiming they could see it immediately after being corrected). Probably due to this, the amount of four year olds dropped sharply to only two out of 18.

	Predict see?: No See?: No	Predict see?: Yes See?: No	Predict see?: No See?: Yes	Predict see?:Yes See?:Yes
Four year olds	0	10	0	8
Five year olds	8	10	1	0

Table 3.4: Frequencies of response patterns on the first 50° predict-feedback task.

	Predict see?: No See?: No	Predict see?: Yes See?: No	Predict see?: No See?: Yes	Predict see?:Yes See?:Yes
Four year olds	4	12	0	2
Five year olds	17	2	0	0

Table 3.5: Frequency of response patterns on the second 50° predict-feedback task.

3.4 Discussion:

The experiment confirmed and extended Flavell et al. findings and in part confirmed our own predictions.

Age of comprehension

The mean age of our younger group was seven months older than Flavell et al.'s young group, but performance is very similar. Indeed, our group performed consistently worse on the pre-feedback and feedback blocks despite the advantage of age. However, Flavell et al. found no significant improvement for their young group pre-to-post-feedback, whereas we found some.

The possible reasons for this are numerous: as previously noted we made some parts of the task easier by making the bending process clearer to the children and by increasing the curvature of the first tube by 10° (cf. section 3.1). The older group seemed to be generally better at predicting lines of sight than the younger group, but their performance was however not perfect either: in the first block, more than half of them failed the 50° and 90° tasks whereas no child in the younger group passed either of these. In the 180° condition in the pre-feedback block, there was a marked difference between the young and old group with respectively 17% and 74% of each group passing this task.

Experience/familiarity

The ability to predict visibility through curved tubes seems to be unrelated to the ability to predict what can be seen in different situations (as discussed in chapter 1). Children have little experience of looking through tubes in their daily life and the few examples we can imagine are counter-intuitive (e.g. periscopes). It should also be noted that children are not usually required to do predictions in the up/down axis but rather in the left/right axis - this lack of familiarity with the task probably affects their results also. A useful extension to this experiment would be to look at children's ability to predict vision on a series of walls curved at similar angles to the tubes and gauge whether the poor performance on this task was mainly due to the use of tubes or rather to an intrinsic difficulty evaluating vision with curved surfaces.

Errors in reporting visibility

As shown in table 3.4, 8 out of 18 four year olds made errors - not of prediction, but of actual reported visibility - when they were given the first feedback task. Since all the four year olds had predicted that visibility would be possible through the tube, accurate reports of visibility would have contradicted some of their predictions and/or would have violated the rules that seemed to govern these predictions. These are two distinct processes since it could be argued that they are not using a rule-based theory for solving this task but are just answering at random and therefore have no real method for predicting vision. All the children did however pass the simple training task at the beginning of the experiment so it seems more than likely that in at least certain settings, there is a theory in place that allows them to evaluate line of sight. Therefore, it seems probable that the children are attempting to answer to the best of their current understanding.

Conservatism

The issue of erroneous reporting of visibility brings us to the issue of conservatism: children have been found to deviate very little from their first efforts, persevering with a certain response despite contrary feedback (cf. chapter 1). The children who mistakenly reported visibility may have done so out of a form of conservatism: they had been suddenly confronted with clear evidence that their prediction was incorrect but they decided to knowingly deny this evidence. Almost all the children when confronted with this inconsistency admitted, often without having to look again, that in fact they could not see the doll - a bit like a child caught red-handed but hoping denial would alter reality. The lack of clear improvement after the feedback in the four year olds seems to indicate that most of the children do not allow this feedback experience to affect their pre-defined theories or solving methods. There are many possible reasons for this:

- they understand the feedback implies they had previously been wrong so denial would cover up their failure

- they were unable to draw conclusions from the feedback and therefore stuck to their original solving methods
- they were able to draw conclusions from the feedback but as it only occurred once, there was insufficient evidence to change their theory.

3.5 Conclusion

This initial experiment provided us with some interesting problems pertaining to children's understanding of line of sight and how they dealt with solving various tasks. It is interesting that many younger children chose not to use the feedback effectively to alter their solving method. The general lack of familiarity of the task does however bring up the issue whether children would perform better in a situation that was much more similar to what they see daily. Also the curved nature of the tube may be encouraging the children to make incorrect predictions as opposed to a normal angle - a useful extension of this experiment would be to compare and contrast how children perform on a curve versus an angle.

Chapter 4

Experiment Two: From Tubes to Walls

4.1 Introduction

In an attempt to make the task more relevant for the children, we changed our stimuli to accommodate the issue of familiarity. Since children have been shown to appreciate the structure and visibility ofered by walls (Hughes & Donaldson, 1979), cardboard walls should offer us a good set of stimuli to use in the following experiment.

To look further into what may have caused many of the children to fail on the previous experiment, we decided to use the same degrees of curvature but build two different versions of each one - one wall would mimic the curvature of the tube and the other wall would be in fact two (or three in one case) straight walls joined together to the same degree of curvature. For example, the 90° task would have two versions, one that is a wall curved as a shallow U and another made out of two walls forming an L-shape.

As the "angled" walls will be more salient to the child (since more similar to their "real-life" experiences), we expected the children to perform well on this part of the task.

For the "curved" walls, we were unsure whether the children's performance would be any different from the angled versions as it was also a wall, so there would probably be a crossover effect between the two versions of each angle i.e. the child would perform very much in the same way on the "angled" version as s/he had on the "curved" version given that the degree of curvature was exactly the same. We expected evaluating lines of sight through a tube to be intrinsically linked to the child's lack of familiarity with tubes and the problem should therefore not be found to the same extent when looking at curved walls.

4.2 Referring to the tasks

To clarify each reference made to the various tasks we will be using in this experiment and the following experiments, we have opted for a simplified shorthand system. Each task will be made up of two groups of letters and one group of numbers; The first group of letters represents the type of object used: Tu stands for Tube, Tr stands for Trench, W stands for Wall. The second and third group refer to the state of the object - first whether the object is curved in a gradual fashion (like a U shape) (C) or is angled (A), which means there is a clear point at which two lines meet and form the angle (such as a V or an L shape). The number refers to the degree of curvature of the object which will be 0, 50, 90 or 180. For example, TrC90 would mean a task where the child is being asked to evaluate visibility in a Trench which is curved to a degree of 90°. An “angled” version of that task would therefore be TrA90.

4.3 Method

4.3.1 Participants

The participants were 29 children (15 male and 14 female). Their ages ranged from 2;7 to 5;2. (Mean age: 4;0). The children were from a local nursery school. All were tested individually in one sitting and none refused to respond. For the purpose of analysis we later subdivided them into two groups: a three year old group (n=15; range: 2;7 - 3;10; mean: 3;5; sd: 0;4) and a four-year old group (n=14; range: 3;11 to 5;3; mean: 4;8; sd: 0;5).

4.3.2 Procedure

Six different settings were built out of cardboard - each setting consisted of a cardboard base onto which a cardboard "wall" had been built (see figure 4.1 and 4.2 for an example). The base measured 50 × 38 cm and the overall angles of the walls were 50°, 90° and 180°. For each degree of curvature, there were two alternative versions - one curved and one "angled" (i.e. like two walls meeting together).

The walls were all 10 cm tall. Two different Playmobil dolls measuring 5 cm were used. The child's line of sight was always orthogonal to the centre of the wall so they could see both dolls at the same time. The child was sat on a chair and the walls were placed on the floor: this was so they would be able to appreciate the curves and the angles from a higher vantage point than from a face on approach.

The two dolls were first placed facing each other. The child was then asked if the toys could see each other or not[1]. We then placed a cardboard barrier between the two dolls (so they were unable to

[1] The verbatim instructions were "This doll is Tommy and this doll is Susan. I will place them like this [places them facing each other]. Now can Tommy [Experimenter touches Tommy's head] see Susan [E. touches Susan's head]?"

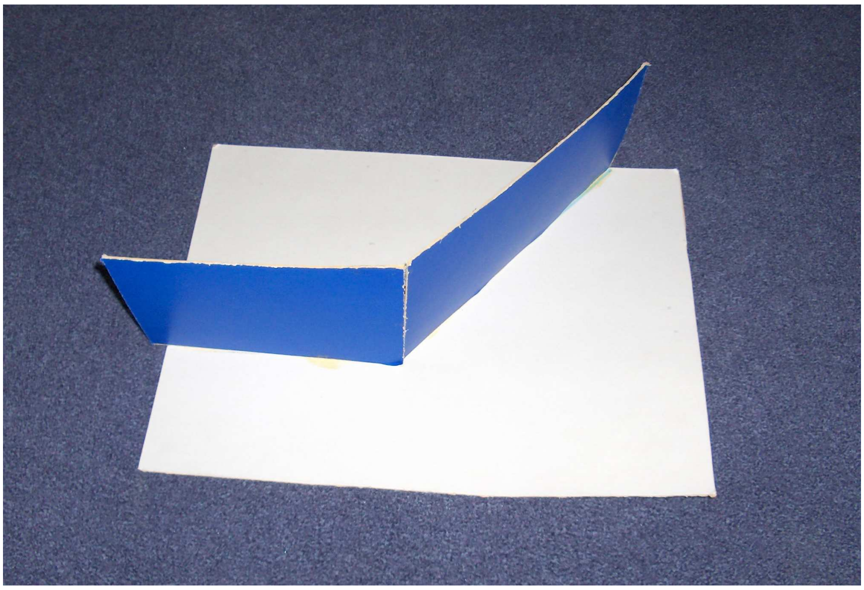

Figure 4.1: Example of an angled wall

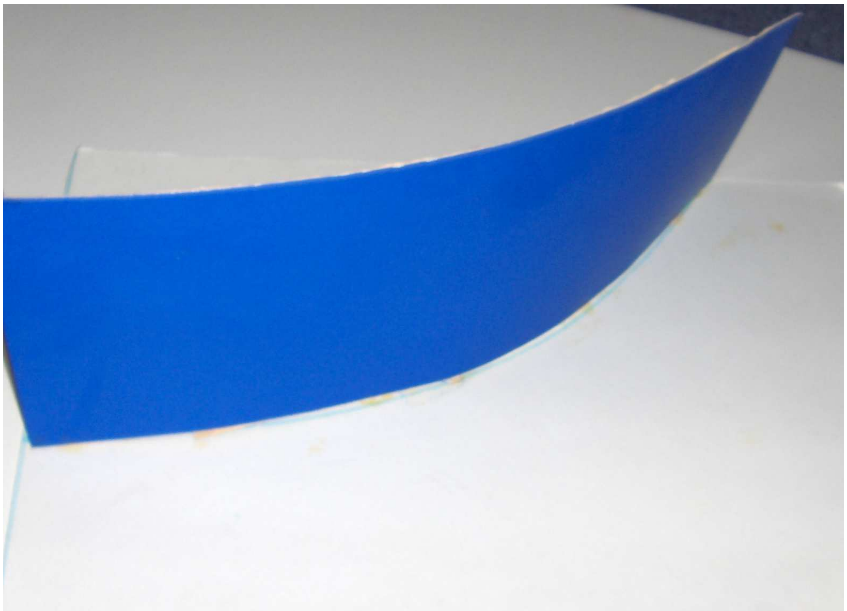

Figure 4.2: Example of a curved wall

see each other) and the same question was repeated. The order of these two questions was randomised between children. This task firstly aimed to check if the child could appreciate basic notions of vision and line of sight and secondly to make them feel that it was all right to respond negatively to the questions they were going to be asked.

The following test phase involved eight trials. In six of these trials the toys were placed at opposing extremities of one of the six walls and the child was asked "Will Tommy be able to see Susan here [pointing at each doll in turn]". The correct answer in these six trials was "no" but, to avoid a pattern forming in the children's answering, we introduced two conditions where the two toys were able to "see" each other. For this the dolls were placed on the concave side of one the walls. The order of presentation of the eight trials was randomised for each child and the children were never given any indication whether the response they made was correct or not.

4.4 Results

None of the children tested failed the introductory task, nor did any fail any of the tasks where the two dolls could effectively see each other which was consistent with our predictions.

In table 4.1, we can see the frequency of correct predictions on each given task and for each age group.

	Angles			*Curves*		
	50°	90°	180°	50°	90°	180°
3 year-olds	12	13	14	1	8	13
(n=15)	(80%)	(86.7%)	(93.3%)	(6.7%)	(53.3%)	(86.7%)
4 year-olds	12	14	14	9	12	14
(n=14)	(85.7%)	(100%)	(100%)	(64.3%)	(85.7%)	(100%)
Total	24	27	28	10	20	27
(n=29)	(82.8%)	(93.1%)	(96.6%)	(34.5%)	(69%)	(93.1%)

Table 4.1: Frequency of subjects predicting visibility correctly.

From looking at the data in table 4.1 we can see that the children perfrom well on the angled trials but their performance is poorer on the curved trials especially on the smaller angles.

4.4.1 Age Differences

We ran a one-tailed Independent Sample t-tests on the various tasks and have summed them up in table 4.2.

There is little or no difference between the two groups' performance in the angles task, but the curves task shows clearer differences between the ages. Although only the curved 50° task shows a significant difference (on the .05 level), table 4.1 shows a difference of more than 30% between the two groups on the curved

	Wall Angle	t-value and p-value
	50°	$t = .39; p = .697$
Angles	90°	$t = 1.42; p = .168$
	180°	$t = .96; p = .343$
	50°	$t = 3.96; p < .001$
Curves	90°	$t = 1.94; p = .063$
	180°	$t = 1.42; p = .168$

Table 4.2: Results of Independent Sample t-tests comparing three year olds and four year olds (All Dfs are 27).

Angle compared between angled and curved walls	*three year olds (df: 14)*	*four year olds (df: 13)*	*Overall (df: 28)*
50°	$t = 6.2$; $p < .001$	$t = 1.88$; $p = 0.082$	$t = 5.11$; $p =< .001$
90°	$t = 2.65$; $p = .019$	$t = 1.47$; $p = 0.165$	$t = 2.98$; $p = .006$
180°	$t = 1$; $p = .334$	n/a[1]	$t = 1$; $p = .326$

[1] This is due to all the children in this group making no mistakes on either the angle or the curve task.

Table 4.3: t (mean angled walls - mean curved walls) for three levels of angle.

90° task.

4.4.2 Comparing angles with curves

We ran paired sample t-tests on each age group looking at whether there was any difference between the curve and angle trials at each given angle. These results are summed up in table 4.3.

The results demonstrate that the curved tasks are more difficult than the angled tasks:: the young group performed significantly better on the angled version of the 50° and the 90° than they did on their respective curved versions. This significant difference in

Angle compared between angled and curved walls	*three year olds (df: 15)*	*four year olds (df: 14)*
50°	$r = .314$; $p = .635$	$r = .548$; $p = .043$
90°	$r = .419$; $p = .12$	n/a[1]
180°	$r = .681$; $p = .005$	n/a[1]

[1] This is due to all the children in this group making no mistakes on either the angle or the curve task.

Table 4.4: Correlations (at each angle) between angled and curved walls.

difficulty disappears with the older group, although they do perform less well on the curved versions of 50° and 90° than on their angled equivalents. Pooling the two groups, the effect of wall type at both 50° and 90° was highly significant.

The 180° task reveals no significant difference in either group nor when looking at them as a pooled group. The older group had no difficulty whatsoever with either the curved version or the angled one with no-one in the group failing either (hence making a paired sample t-test incalculable).

4.4.3 Correlations

Correlations for both age groups are summarised in table 4.4.

Other significant correlations were:

- for the four year olds, the curved 50° task correlated positively with the curved 90° task ($r = .548$; $p = .043$); however, when partialling age out this failed to reach significance (r = .472; p = .103)

- for the three year olds, all the angled tasks correlated positively with each other (see table 4.5) and with the exception of the correlation of the angled 90° with the angled 180° task, they remained significant after the partialling out of age.

	Correlation scores (df: 15)	*Correlation scores partialling out age (df: 12)*
50° - 90°	$r = .784$; $p = .001$	$r = .7793$; $p = .001$
90° - 180°	$r = .681$; $p = .005$	$r = .6772$; $p = .008$
50° - 180°	$r = .535$; $p = .04$	$r = .5277$; $p = .05$

Table 4.5: Correlations for the young group on the angled trials.

4.4.4 Scoring system

After looking at the tasks individually, we decided to look at the tasks overall. We scored responses one point per correct response and none for an incorrect one. As the two conditions where the toys could see each other were only introduced as an attention test we did not add them to the total (besides, all the children passed them). This gave us an overall score out of 6, with subscores out of three for the set of curved and angled walls. The mean score for the curved walls was 1.97 (s.d. = .9433) whereas the mean score for the angled walls was 2.72 (s.d. = .7019). Through running a paired samples t-test, we found a significant difference between these results ($t = 4.683$, $df = 28$; $p < .001$), demonstrating that the curved walls are more difficult for the children to evaluate correctly then the angled walls.

The mean score on the angled walls were 2.6 (s.d.: 0.91) and 2.86 (s.d.: 0.36) for the young and the old group respectively whilst their mean scores on the curved walls were respectively 1.46 (s.d.: 0.83) and 2.5 (s.d.: 0.76) (also out of 3) (see fig. 1). An independent samples t-test revealed the difference between groups to be highly significant on the curved walls task ($t = 3.841$; $df = 27$; $p = 0.002$) and no significant difference was found between the groups on the angled walls task.

4.5 Discussion

From the descriptive statistics of the present sample, it appears evident that there is a considerable difference between the children's appreciation of vision around angles and curves.

As the previous experiment - which looked at children's evaluation of vision through tubes - showed us, children's understanding of vision seems to be highly related to the kind of task that the children are being asked to perform. As this research indicates, children's appreciation of vision with angled walls is of little use to them when it comes to appreciating the vision that curved walls allow. This contextual understanding of vision seems to also be responsible for the poor results.

However, the difficulty that children had building on their experience of not being able to see through the bent tube, seems to point to a relatively conservative approach to their views of the world: they seem to hold on to their views whatever experience proves to them. However, how is it that their understanding of angled walls is so good? In this study, we found little difference between the three year olds and the four year olds on the angled task but, as the angle was the same, we could have expected them to stick with their response from the curved task for the angled version of that degree of curvature. This was not the case, so it seems unlikely that children may view a curved wall and an angled wall as two completely separate entities.

It is not clear whether the children are misinterpreting the question or not. The problems could be due to their answering the question as if they were being asked "Can you see them both?". However, the clear differences in the scores of the younger group on the 50°tasks and the 180° tasks seem to indicate that they were able to comprehend the question correctly but, have some difficulty evaluating the curves correctly.

The difficulty of the curves may be due to the way they seem to "offer" vision: the children sometimes see objects transiting along curved planes - for example, roads, railway tracks, playground slides; these curves are designed to give movement to an object so that an object can transit along it. Now when this is applied on a vertical plane, they could be holding on to this belief that these curves will help the line of sight "slide" along, hence causing their overestimation of vision.

It can also be argued that the better quality of prediction on the walls with angles over the curves could be due to the salience of the angle over the curve: the angle is one clear focal point for the child to use to evaluate vision or not, whereas the curve has to be appreciated over quite a long distance. This is, of course, impossible to control for but may be a valid reason for the found differences too.

Another point that can be raised is the positioning of the toys: the child is required to make quite a large mental rotation in order to place themselves in the position of the toy. Although this applies to both condition blocks, it can still influence their ability with the curves over the angles if, as we have discussed previously, the angled walls are qualitatively easier tasks and may not need as much "roleplaying" in solving them accurately. Therefore, the positioning of the toys could be influencing their ability to resolve the task, whilst a different positioning (maybe with the "looking" toy positioned facing them or back to them) would have yielded slightly better results.

Our reason for changing from the vertical plane to the horizontal plane was to hopefully make the task simpler for the children. It seems that this change may have slightly reduced the task's difficulty but, even on the horizontal plane, there still are some evident difficulties as this experiment showed.

4.6 Conclusion

This experiment offers us some answers but mostly raises more questions about children's performance as we have just discussed. In the next experiments, we shall attempt to tease apart the effect we are finding and hopefully get a clearer image as to what is happening.

Chapter 5

Experiment three: vision in trenches

5.1 Introduction

From the last two experiments, we drew the following conclusions:

- At a same degree of turn, children's performance is generally poorer on curved tasks than on angled tasks . The smaller the degree of turn, the greater the discrepancy between their performance on angles and curves.

- Their performance improves with age. The gap in performance between angles and curves becomes smaller the older they become.

To give more precision to our evaluations, we sought to quantify the point of the "switchover" - the point at which the child deems line of sight between the two dolls becomes possible.

In this experiment, we tried to make the task as easy to solve as possible: children may have had some difficulty gleaning information from the walls in the previous experiment, therefore we replaced them with a corridor dug into a block of wood. These stimuli gave the children a clearer impression of the shape of the curve as there were two walls from which they could glean information.

An extra complexity pertaining to the two initial experiments was the positioning of the dolls: one of the dolls was always placed at 90° to the child's left. This meant the doll's line of sight was perpendicular to the child's so, to correctly appreciate the doll's line of sight, the child had to perform a mental rotation. Though this added complexity did not seem to affect children's performance on the angled tasks, we decided all the same to place the "looking" toy so that the child would be just behind the doll. Some mental rotation would be required to solve the task as we placed them looking at the tunnel from above at approximately 60° from the horizontal, but the lines of sight should be much easier to establish, as both the child's line of sight and that of the doll would be parallel to each other.

5.2 Method

5.2.1 Participants

The participants were 31 children (13 male and 18 female). Their age ranged from 2;6 to 5;1. (Mean age: 3;10). The children were from a university playgroup and a local nursery school. All were tested individually in one sitting and none refused to respond.

The children were subdivided into two age groups: 16 were in the three year old group (mean: 3;3 s.d: 4.1 min: 2;6 max: 3;8) and 15 in the four year old group (mean: 4;6. s.d.: 5.4 min: 3;9 max: 5;1).

Two other children were tested but gave inconsistent responses - they both alternated between saying yes and no without paying attention to the task. Their results were therefore discarded from the analysis but are discussed in the discussion section.

5.2.2 Procedure:

We used a wooden block that had a 180° curved trench built into it (see photo 5.1) The depth of the trench was 78 mm. We used two different Playmobil dolls: one male, the other female. Their height was 50 mm. A small carriage that could travel along the length of the trench was also used.

Pre-testing phase

The two dolls were first placed facing each other. The child was then asked if the toys could see each other or not[1]. We then placed a cardboard barrier between the two dolls (so they were unable to see each other) and the same question was repeated. The order of these two questions was randomised. This task aimed to firstly check if the child could appreciate basic notions of vision and line of sight and, secondly, to make them feel that it was acceptable to respond negatively to the questions they were going to be asked.

Testing phase

The experimenter then sat one doll on the carriage and placed it at one extremity of the tunnel (A) and fixed the other doll at the opposite end (B) (see figure 5.1). The child was sat on a chair giving them an angle of vision approximately 60° from the horizontal. This allowed them to see the entire trench and both toys at all times.

The experimenter started the testing phase of the experiment by asking the child "Can Tommy see Susan from here?". The child's response was noted and the carriage was moved forward by a point (see figure 5.2) the same question was then repeated for all 17 points.

[1]The verbatim instructions were "This doll is Tommy and this doll is Susan. I will place them like this [Experimenter places them facing each other]. Now can Tommy [Experimenter touches Tommy's head] see Susan [E. touches Susan's head]?"

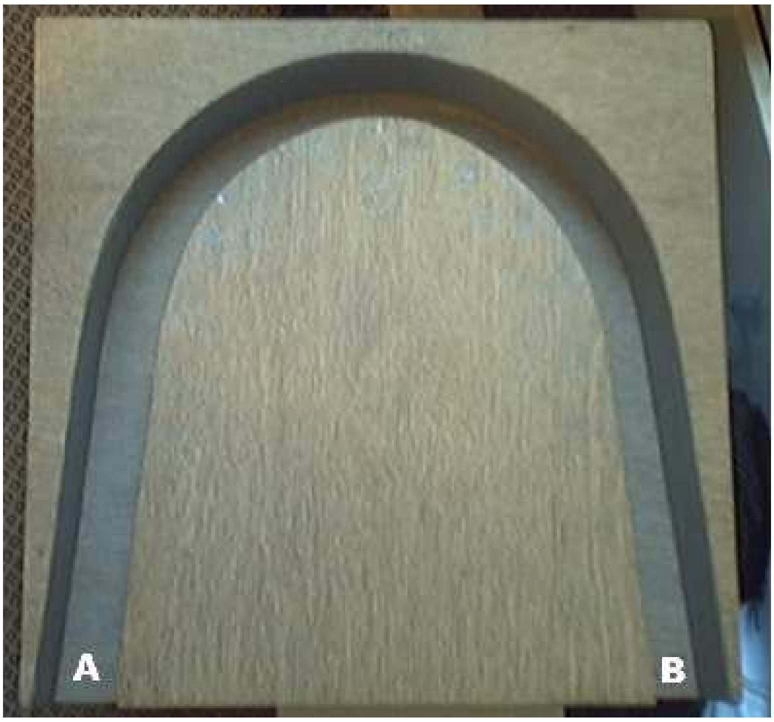

Figure 5.1: Dolls' initial positioning in the trench

The point from which the 2 dolls were able to see each other was point 10. The children were given no feedback during this phase and did not know if the response they made was correct or incorrect.

5.3 Results:

As expected, all the children passed the introductory task. For the testing phase, we elected to classify the children into 3 groups of response: Risky appreciation, Correct Appreciation and Cautious appreciation depending on where their switchover occurred. The frequencies for these different response patterns are summarised in

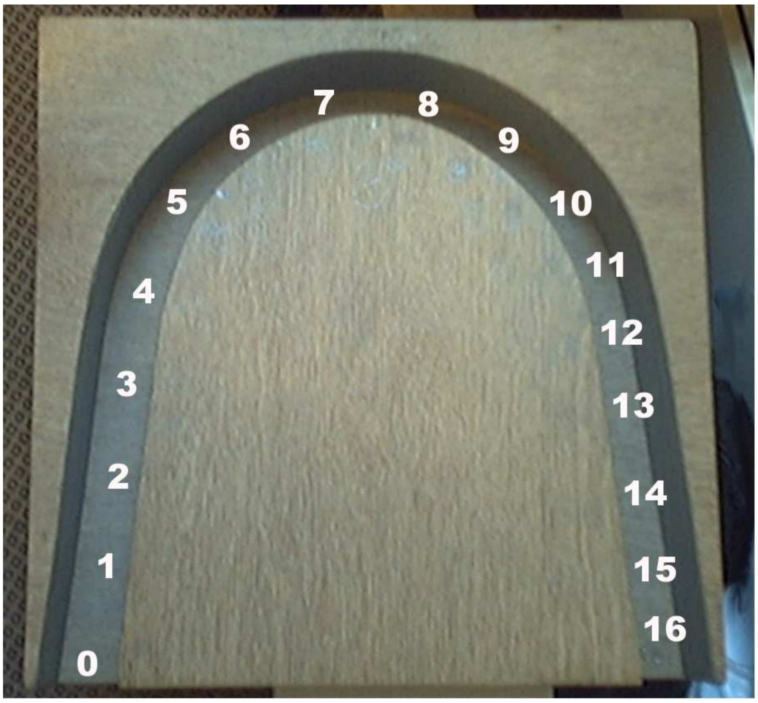

Figure 5.2: Trench positions

table 5.1 .

Appreciation	All (n=31)	Three year olds (n=16)	Four year olds (n=15)
Risky	10 (32.3%)	10 (62.5%)	0
Correct	11 (35.5%)	4 (25%)	7 (46.7%)
Cautious	10 (32.3%)	2 (12.5%)	8 (53.3%)

Table 5.1: Frequency and percentage of types of appreciation exhibited

Binomial tests revealed that children were correct more often than chance would predict (one position of 17 so .059 is the expected proportion): Three year olds: $p=.0011$; Four year olds: $p<.001$). The number of children performing cautiously was different from chance (six positions of 17 available, so an expected proportion of

.353) although the three year olds failed to achieve significance: Three year olds: $p=.056$; Four year olds: $p<.001$. For the risky appreciations (ten positions of 17 available, so an expected proportion of .588), the four year olds performed less risky than chance with none of them choosing a risky response ($p<.001$) but the three year olds did not ($p=0.764$).

We also ran a 3×2 Chi-square comparing the three year olds performance with the four year olds performance. This yielded a significant difference between their performances ($\chi^2(2)=14.401$; $p<.001$).

The precise point of the "switchover" from "can't see" to "can see" was also calculated and is shown in table 5.2.

More than 50% (n=9) of the three year olds have an early switchover between positions 0 and 7. Only one four year old has a switchover before point 7; in fact more than 90% (n=14) of the four year olds situated the switchover between 10 and 11, meaning that most of them had a clear but slightly imprecise appreciation of line of sight. In contrast, the three year olds seem to be more random in their responses with slightly less than a third of them situating the switchover at points 10 or 11.

Given this clear difference in types of incorrect response, we compared children who correctly predicted the correct switchover

	0	1	2	3	4	5	6	7	8	9	10	11	12	13-16
Three year olds	4 (25%)	2 (12.5%)	0	1 (6.3%)	2 (12.5%)	0	0	0	1 (6.3%)	0	4 (25%)	1 (6.3%)	1 (6.3%)	0
Four year olds	0	0	0	0	0	1 (6.7%)	0	0	0	0	6 (40%)	8 (53.3%)	0	0
All	4 (12.9%)	2 (6.5%)	0	1 (3.2%)	2 (6.5%)	1 (3.2%)	0	0	1 (3.2%)	0	10 (32.3%)	9 (29%)	1 (3.2%)	0

Table 5.2: Frequency distribution of the first point at which children predicted visibility

point or were less than one step away from a correct prediction (i.e. predicting the switchover occurred in steps 9 or 11) as opposed to children who did not. The results are summarised in table 5.3.

Appreciation	All (n=31)	Three year old group (n=16)	Four year old group (n=15)
Correct or Nearly Correct (points 9-11)	19 (61.3%)	5 (31.3%)	14 (93.3%)
Incorrect (0-8 & 12-16)	12 (38.7%)	11 (68.7%)	1 (6.7%)

Table 5.3: Frequency and percentage of switchover appreciation

5.4 Discussion:

Based on this data, there seems to be an evident shift from the inadequate evaluation abilities found in three year olds to the more grouped response pattern found in the four year olds. Despite the four year olds verging on being over-cautious, their responses were mostly grouped around the correct switchover point; this was not the case of the three year olds who showed a wide spread of responses throughout the tube.

5.4.1 Solving strategies

Two types of solving strategies were exhibited in this experiment. The first method apparently does not take the important issue of line of sight into account and is exhibited by most of the three year olds. The random spread of their chosen switchover points indicates an inconsistent method which probably bases itself on how much they think line of sight can curve towards its trajectory. More than 50% of these children placed the switchover point before the half-way point indicating a poor understanding of the linear properties of line of sight. They do, as the pre-testing task demonstrates, have a basic comprehension that sight cannot bend too far, but not that it must be straight. Failure seems to be due to one of two possible explanations:

- The child waits for the line of sights of both dolls to intersect (see figure 5.3). They may be assuming since line of sight 1 and line of sight 2 intersect in area 3, visibility becomes possible. In this context, they comprehend that line of sight must be straight but misunderstand in which setting two people can see each other.

- The child does not understand that line of sight must be straight, nor in what situation two people can see each other.

The second method is that exhibited by almost all the four year olds. Though they are not pinpoint perfect at placing the switchover point, the vast majority of them have understood in this context that line of sight must be straight and may not be able to bend around

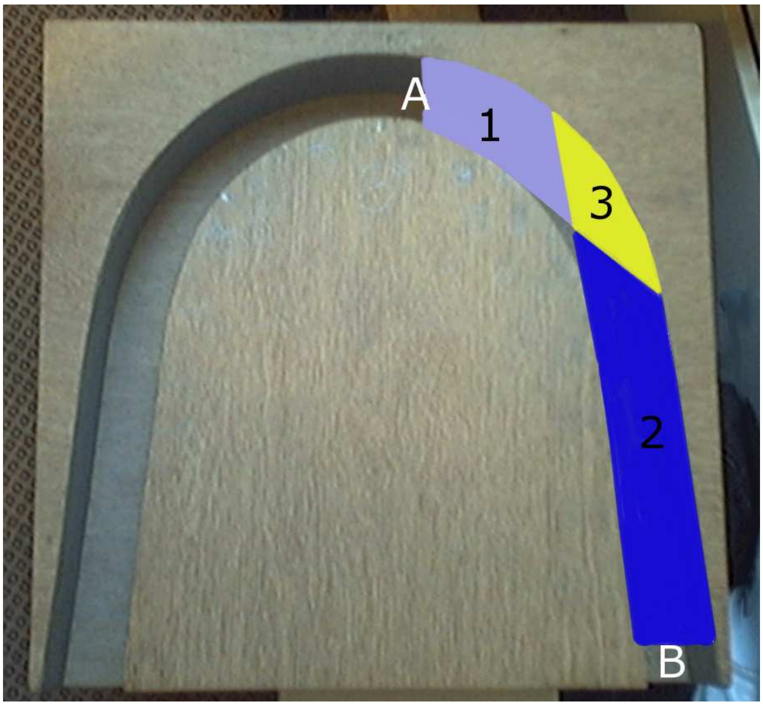

Figure 5.3: Possible resolution method used by the three year olds

the corner. Given their grouped responses around switchover points 10 and 11, it is apparent they are using a different strategy from the three year olds. They probably mentally trace a line from the doll's eyes and guess whether it intersects with the other doll. The use of this strategy is probably made easier by the placement of the looking doll in a similar position to theirs and would explain their good performance on this task. They seem able to divide the trench into two distinct areas (such as in figure 5.4) basing the delimitation on a straight line from the doll's eyes. This method is by no means foolproof, but is much more successful than the method used by most of the three year olds.

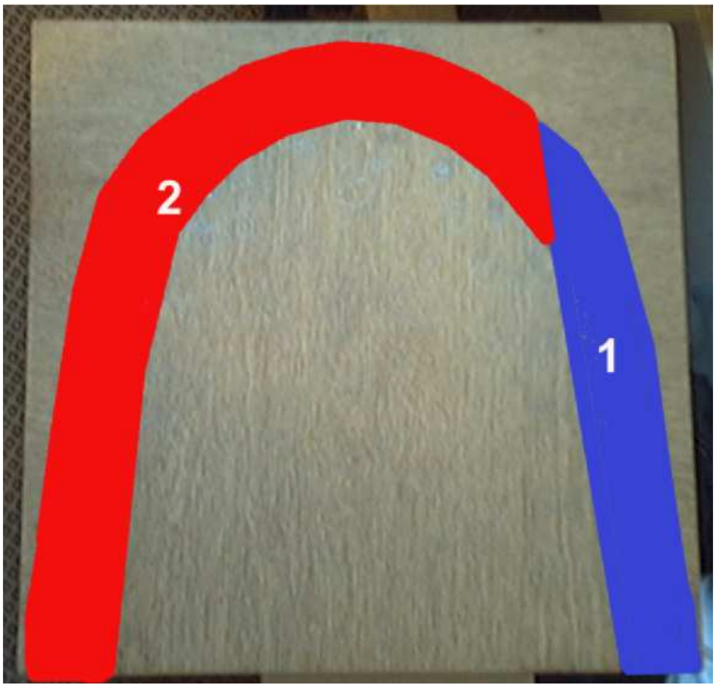

Figure 5.4: Possible method of solving used by four year olds

We also had to discount the results from two children who were both young three year olds - their answer was a repetition of “yes” then “no” throughout the trench. It is possible that these children have not yet acquired the verbal ability to comprehend the task or possibly had not devised a clear strategy to be able to solve this task hence their random response pattern.

5.4.2 Mental rotations

Following on from our previous experiments, this seems to show that three to four year olds have the ability to evaluate line of sight correctly under certain conditions (in this case, where no complex mental rotations are required[2]) although this appears only around the age of four.

However, in this experiment, the child should have been able to solve it relatively easily - the answer was not egocentric as the children could see both dolls all of the time[3], but it was definitely not as complex as, say, Piaget & Inhelder's mountain task.

5.4.3 Inference from previous experiments

As we saw in our first experiment, four year olds have trouble understanding how line of sight functions through a tube but performed adequately on the curved versions of the wall. Their performance here is clearly superior but this was possibly due to two differing factors:

- **Few mental rotations involved** - as previously stated, this task could be solved with the most basic of understandings of line of sight. The child only needed to understand that lines of sight must be straight to stand a fair chance of succeeding.
- **Different testing apparatus** - instead of the tubes and walls from the first two experiments, a trench with two walls was

[2] Although to imagine the line of sight of the travelling doll will require complicated mental rotations, the line of sight of the fixed doll in position B willl always be highly similar to the child's.

[3] We could argue that it is semi-egocentric i.e. very close to their own line of sight hence the ease with which the four year olds seemed to perform

used which may have made the task easier to solve. The outer wall of the trench would have intersected with the line of sight, something that did not occur in the wall task - in turn, the fact the doll's line of sight literally ran into a wall may have made some children believe that line of sight was less likely to travel round that point.

5.5 Conclusion

This experiment does show that if a task is made simple enough, four year olds *do* have a certain understanding of line of sight. The three year olds however have a rather more diffuse comprehension of it. They can solve the initial task and appreciate that line of sight must not be cut off by a screen or another object, but the general laws of line of sight seem to elude them.

Chapter 6

Experiment four: expanding on trenches

6.1 Introduction

The performance of the four year olds on the previous experiment gave us a clearer image of the solving methods that children use at this age. Based on the developmental shift, we concluded that they use at least two distinct solving methods (see page 109).

The unexpected increase in performance by the older children between both experiments one and two and experiment three could be explained by two changes we made in the latter:

- *Low rotational demands:* The third experiment lowered the rotational demands made on the child to a minimal level. This in turn could have led to making the task easier to solve. Liben & Downs (1993) has argued that with maps, children perform much worse when given a map rotated around by 180° than they would perform when the map was correctly orientated.

- *Change in setting:* The use of the trench was not seen as a major deviation from the previous materials but, on reflection, it could have enhanced their performance. In the wall tasks, the doll's line of sight would have been impeded on only one side (the side on which the wall was present) but the rest of the doll's field of vision would have remained free. However, this was not the case in the trench task where the doll's vision would have been impeded on both sides, giving them more clues that vision was going to be restricted (see figure 6.1 and 6.2). This recalls the Flavell et al. (1991) paper, which showed in their second experiment that young children were quite poor at evaluating line of sight along a curvy tube (more than 60% failing), but were significantly better when asked whether they could see another doll along a similar curve around a barrier (two thirds of them evaluted this correctly). In our case, the children may be judging that visibility is impossible because of the outside wall acting as a barrier.

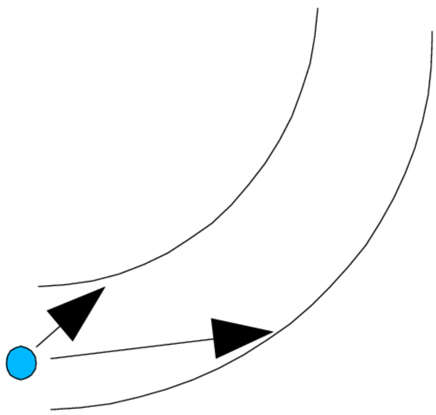

Figure 6.1: Line of sight on the trench task

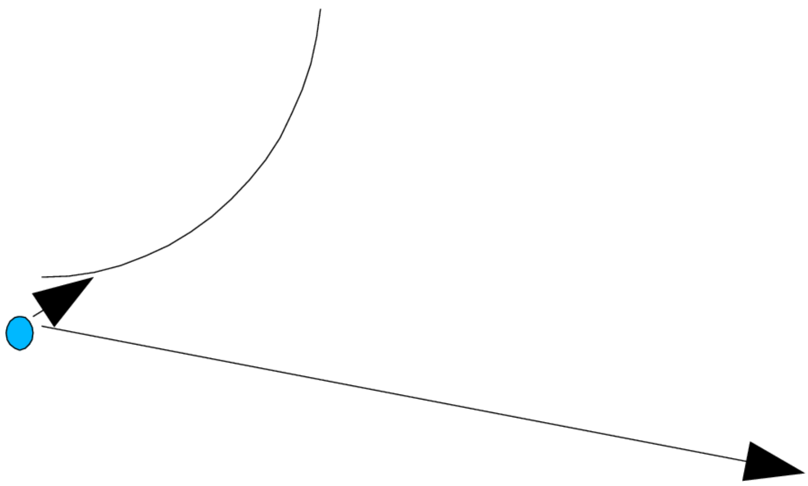

Figure 6.2: Line of sight on the wall task

We therefore decided to return to the same rotational complexity as that used in Experiments One and Two to see whether the four year olds' performance was due to the closeness between their own line of sight and that of the doll's or rather by the new setting.

It also seemed worthwhile to test the consistency of the switchover point. In the previous experiment, one of the dolls was moved sequentially down the trench, so that almost all the children kept a consistent switchover point. That is, when they believed vision became possible, they were unlikely to decide it was no longer possible after that point. If the task was presented with the doll being moved from position to position randomly, would the children remain consistent in their positioning of the switchover point?

Since there seemed to be a notable difference between the curved walls and the angled walls used in Experiment Two, we felt we should also introduce this independent variable. Once again, we used the same three degrees of turn (50°, 90° and 180°) and for each of them we had an angled version and a curved version. If the trench was structurally easier for the children to solve, we would expect children to show very good performances on the angled trenches, and a relatively good performance on the curved trenches.

6.2 Method

6.2.1 Participants

The participants were 31 children (16 male and 15 female). Their age sranged from 3;4 to 5;9 (mean age: 4;10). The children were drawn from a university playgroup and a local school. All were tested in two separate sessions a day apart. This was due to the length of the tasks. The child sat on a chair to enable him/her to clearly see the set-up and to allow him/her to see both toys at the same time. When subdivided into two groups, the younger group ranged from 3;4 to 4;10 (mean age: 4;5 n=16) and the older group ranged from 4;11 to 5;9 (mean age: 5;3 n=15).

6.2.2 Materials:

We used six wooden blocks with a trench cut into them, similar in design to that used in the third experiment. The depth of the trench was 78 mm. There were three degrees of turn used for the trenches: 50°, 90° and 180°. Each degree of turn had two different types: one being a curved trench and the other being an angled trench. Thus a total of six trenches were used in this experiment. We used two different Playmobil dolls: one male, the other female. Their height was 50 mm.

6.2.3 Procedure:

Pre-testing phase

The child was introduced to the two dolls that were to be used in the experiment, called Tommy and Susan. The two dolls were first placed facing each other. The child was then asked if the toys could see each other or not[1]. We then placed a cardboard barrier between the two dolls (so they were unable to see each other) and the same question was repeated. The order of these two questions was randomised. This task aimed to firstly check if the child could appreciate basic notions of vision and line of sight and secondly to make them feel that it was acceptable to respond negatively to the questions they were going to be asked.

Testing phase

After this, the child was shown one out of the six different trenches and one doll was fixed to one end (B), while the other was placed at the other end of the trench (A) (see figure 6.3). The fixed doll was always placed at a 90° angle to the left of the child (the doll's line of vision therefore being perpendicular to the child's).

The child was then told that we were going to place Tommy

[1] The verbatim instructions were "This doll is Tommy and this doll is Susan. I will place them like this [Experimenter places them facing each other]. Now can Tommy [Experimenter touches Tommy's head] see Susan [E. touches Susan's head]?"

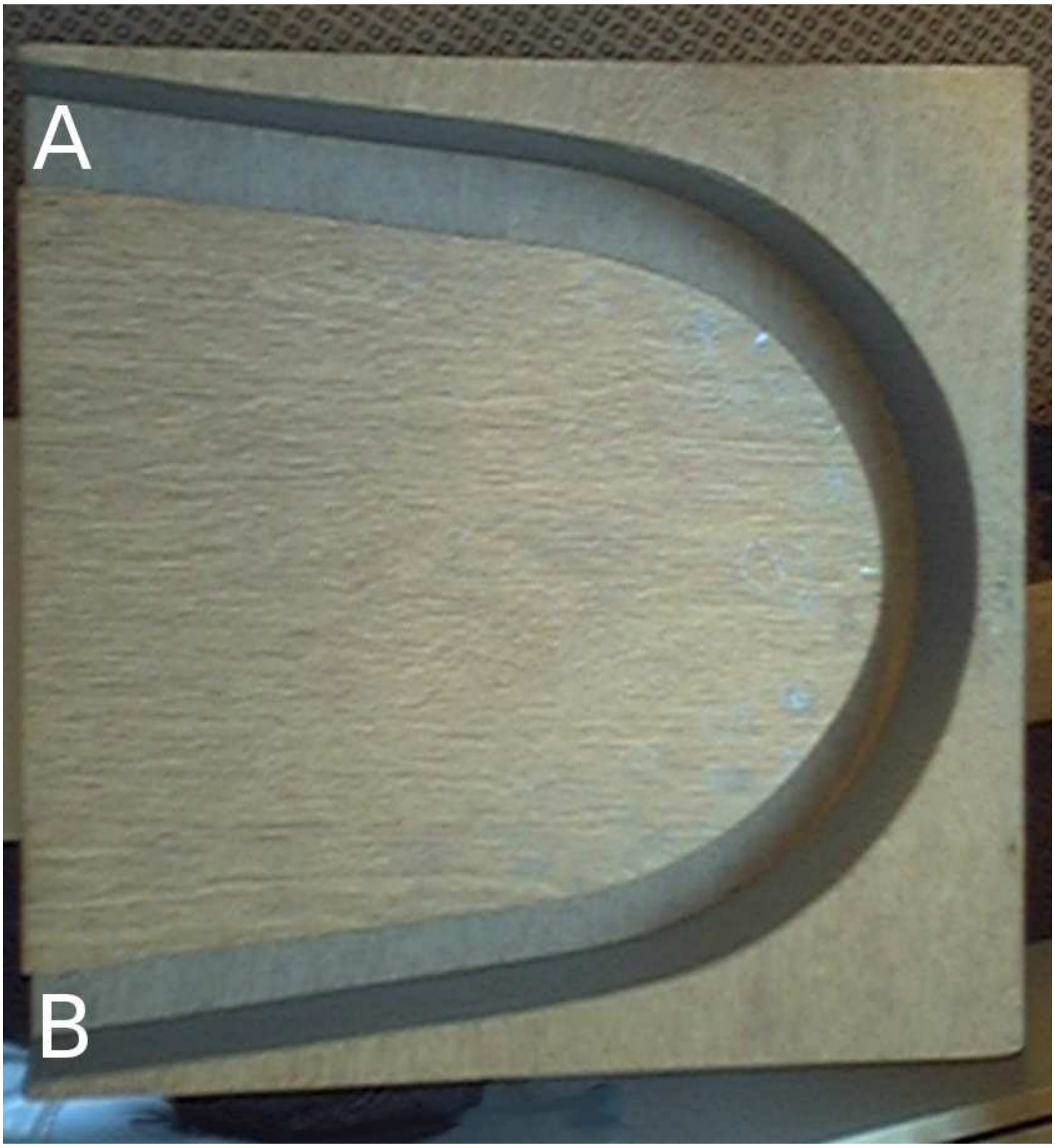

Figure 6.3: Dolls' initial positioning in the trench

at different points along the corridor. Tommy was then placed at a point in the trench and the child was then asked, "Now, can Tommy (pointing to him) see Susan (pointing to the fixed doll)?" The response was then noted and Tommy was moved on to a different position. The choice of positions was randomised so that the doll was not progressively brought down the corridor. The number of positions per trench varied slightly between the different trenches: the 50° and 180° tasks (both angled and curved versions) had seven positions whereas the 90° tasks (angled and curved) had six positions due to it being slightly shorter in length than the other two trenches. The order of presentation of the trenches was also randomised. The child was randomly assigned to start with either a block of three curved tasks or a block of three angled tasks. The order of these tasks was also randomised within each block. When the child finished their first block they would move onto a block of either curved or angled tasks depending on which block they started with. By the end of the experiment, each child would have completed a block of three curved tasks and one block of three angled tasks.

6.3 Results:

None of the children failed any of the positions in the angled trenches - the only mistakes made were within the three curved trenches. Three children were removed from the final analysis as they gave incoherent responses - none of them kept the switchover point consistent in their responses on the curved tasks.

6.3.1 Accuracy of prediction:

The data for these tasks is summarised in tables 6.1 to 6.3

50° curve	Risky	Correct	Cautious
4-year olds	14 (87.5%)	1 (6.3%)	1 (6.3%)
5-year olds	14 (93.3%)	1 (6.7%)	0
All	28 (90.3%)	2 (6.5%)	1 (3.2%)

Table 6.1: Frequency of predictions for the 50° curve task

90° curve	Risky	Correct	Cautious
4-year olds	13 (81.3%)	2 (12.5%)	1 (6.3%)
5-year olds	13 (86.7%)	2 (12.5%)	0
All	26 (90.3%)	4 (12.9%)	1 (3.2%)

Table 6.2: Frequency of predictions for the 90° curve task

180° curve	Risky	Correct	Cautious
4-year olds	12 (75%)	4 (25%)	0
5-year olds	10 (66.7%)	5 (33.3%)	0
All	22 (71%)	9 (29%)	0

Table 6.3: Frequency of predictions for the 180° curve task

Binomial tests revealed that in none of the conditions were the children performing differently from chance (one position of six or seven so the expected proportions were .143 for the 50° and the 180° trenches and .167 for the 90°) except in the 180° task where the 5 year olds performed better than chance (p=0.035). We also tested if the children were more risky than chance (two positions out of seven in the 50° trench, one out of six for the 90° trench one out of seven for the 180° task which gives us respectively proportions of .286, .167 and .143) - binomial tests revealed that on the 50° task both four year olds and five year olds were making more risky predictions than chance would predict (four year olds: p=0.014; five year olds: p=0.005) but none of the other tasks revealed a significant difference. Although these tests assume a null hypothesis of random responses, we know - from the consistency of the switchover point - that they are not responding randomly. Therefore the riskiness observed is genuine rather than the result of guessing.

To give a greater insight into whether the children were missing by a long way or narrowly failing, we decided to collapse the near misses and the successful assessments into one group and the rest of the responses into clear fails. Given that there were fewer viewing points than in experiment three, we decided to count the correct switchover point and the *preceding* point as a pass/near miss and any switchover occurring at another point as a fail. The results are summarised in tables 6.4 to 6.6.

50° curve	Pass/near miss	Fail
4-year olds	5 (31.3%)	11 (68.7%)
5-year olds	9 (60%)	6 (40%)

Table 6.4: Frequency of appreciation for the 50° curve task

90° curve	Pass/near miss	Fail
4-year olds	4 (25%)	12 (75%)
5-year olds	7 (46.7%)	8 (53.3%)

Table 6.5: Frequency of appreciation for the 90° curve task

180° curve	Pass/near miss	Fail
4-year olds	8 (50%)	8 (50%)
5-year olds	12 (80%)	3 (20%)

Table 6.6: Frequency of appreciation for the 180° curve task

Binomial tests showed the five year olds choice of the pass/near miss points were significantly better than chance (two positions out of seven so a proportion of .286 for the 50° and 180° trenches, two positions out of six so a proportion of .333 for the 90° trench) on the 50° curve task ($p=0.007$) and the 180° curve task ($p<0.0001$). The four year olds did not show any significant difference from chance although on the 180° curve task they almost achieved significance ($p=0.058$).

6.3.2 Switchover:

To give more precision to the children's evaluations, it is worth looking at the breakdown of the switchover points chosen by the children (see tables 6.7 to 6.9).

50° curve	1	2	3	4	5 [1]	6	7
4-year olds	4 (25%)	4 (25%)	2 (12.5%)	4 (25%)	1 (6.3%)	1 (6.3%)	0
5-year olds	2 (13.3%)	1 (6.7%)	3 (20%)	8 (53.3%)	1 (6.7%)	0	0
All	6 (19.4%)	5 (16.1%)	5 (16.1%)	12 (38.7%)	2 (6.5%)	1 (3.2%)	0

[1] Correct point of visibility

Table 6.7: Switchover point for the 50° curve task

90° curve	1	2	3	4	5 [1]	6
4-year olds	3 (18.8%)	5 (31.3%)	3 (18.8%)	2 (12.5%)	2 (12.5%)	1 (6.3%)
5-year olds	2 (13.3%)	2 (13.3%)	4 (26.7%)	5 (33.3%)	2 (13.3%)	0
All	5 (16.1%)	7 (22.6%)	7 (22.6%)	7 (22.6%)	4 (12.9%)	1 (3.2%)

[1] Correct point of visibility

Table 6.8: Switchover point for the 90° curve task

180° curve	1	2	3	4	5	6 [1]	7
4-year olds	2 (12.5%)	0	0	6 (37.5%)	4 (25%)	4 (25%)	0
5-year olds	0	0	0	3 (20%)	7 (46.7%)	5 (33.3%)	0
All	2 (6.5%)	0	0	9 (29%)	11 (35.5%)	9 (29%)	0

[1] Correct point of visibility

Table 6.9: Switchover point for the 180° curve task

We scored the performance on these tubes by giving five points for a correct response, four points for a response that was one step away from the correct reponse (i.e. a step beyond and beneath the correct point would get a four) and so on for each position. A child who declared that the dolls could see each other on the first point of the 50° trench would therefore score only one point.

A 2×3 (Age by Angle) repeated measures ANOVA was run on the switchover score and yielded an effect of angle ($F(2, 58) = 6.795, p = .002$) but no interaction or group age effect. A post-hoc Sheffé test was run between the angles and showed a significant difference between the 180° task and the 90° task and the 180° task and the 50° task but not between the 50° and 90° tasks.

Figures 6.4 to 6.6 visually demonstrate the difference in the chosen switchover point between four year olds and five year olds.

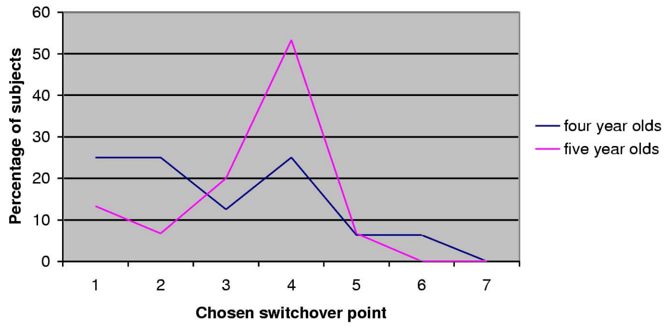

Figure 6.4: Switchover spread on the curved 50° task

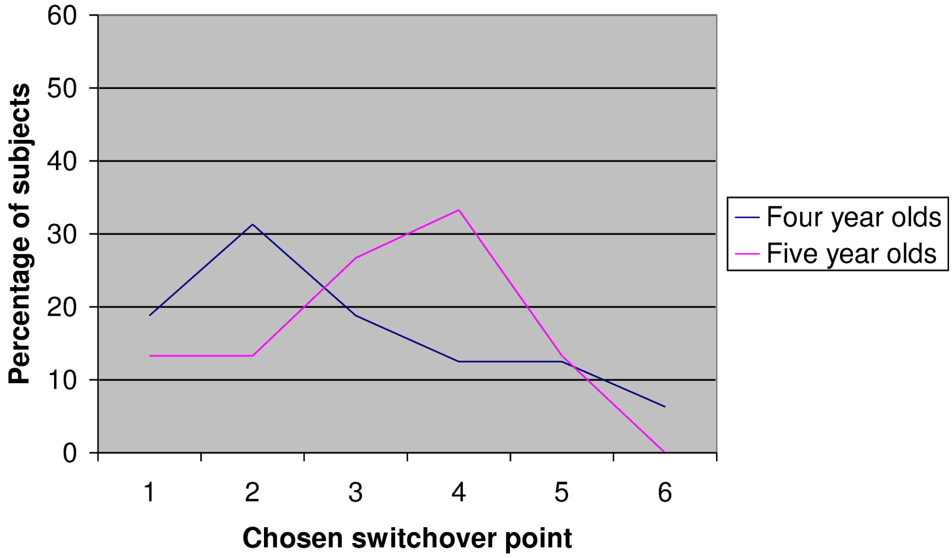

Figure 6.5: Switchover spread on the curved 90° task

Figure 6.6: Switchover spread on the curved 180° task

6.4 Discussion:

6.4.1 Over-estimation

Once again, a pattern of over-estimation of line of sight is evident. Across both age groups, almost all the incorrect responses over-estimate how soon visibility occurs. However, when we look at the area in which the children place the switchover point, it emerges that the older children have a better understanding of where this point is meant to be and their errors are mostly of precision. The younger children show a somewhat different picture: on all three tasks they tend to either expect the switchover much earlier than the older children (see figure 6.5) or do not have a clear idea when the switchover is going to occur (see figures 6.4 and 6.6). This is consistent with our theory of two distinct solving mechanisms being used by the older and the younger children.

6.4.2 Mental rotations and performance

The four year olds were almost the same age as the four year old group used in Experiment Three so the difference in performance is striking in that by merely adding a 90° rotation, performance has become much poorer. Only 50% are passing or almost passing the curved 180° trench task, whereas more than 90% of the four year olds were passing in experiment three. This raises a common problem with much of the past research - the complexity of the mental rotations seemed to not be fully taken into account and have probably caused researchers to overestimate children's egocentric tendencies. An egocentric response could be a form of default response. When having to calculate the various rotations, the child may find it exceedingly complicated and taxing and therefore chooses to fall back on the most readily available response in their mind - the one that is literally staring at them. In the Piaget & Inhelder (1963) task, a great deal of mental agility is required in order to select the correct photo. First, one must be able to appreciate the overall 3-D nature of the mountains (their positioning, size and so on). Then one must imagine what a character on the other side of these mountains would be able to see from their angle if they were to be looking up at the mountains. Performing correctly on this experiment is no mean feat. As we found in our first experiment, some children incorrectly report being able to see the doll through a bent tube although they patently cannot. This helps them remain consistent with what they have been telling us previously about vision. Could it be that when faced with very complicated mental rotations, the children tested by Piaget chose the "easy" option of pretending the doll's field of vision coincided with their own when they probably knew this not to be the case?

6.4.3 Angles and Curves

As we expected, children's understanding of vision around corners is quite outstanding. None of the children failed to evaluate vision correctly in any of the angled trenches. This success reinforces the view that children have a very clear understanding of the way in which angled walls affect vision from an early age but fail to transfer this knowledge to the curved tasks. The possible reasons for this could be numerous, but we shall look at a few potential explanations.

- *Children do not look for straight-line access from seer to seen*: children have learnt that whenever there is an angle, visibility becomes impossible but have not learnt that for visibility to be possible there must be a straight-line of sight between the seer and the seen. This in turn means they do not seek out whether straight-lines access is possible in these tasks..

- *Children do look for straight lines but find it difficult to integrate these lines into a curved trench*: the children in this case understand that there must be straight-line access between the seer and the seen but in this case find it difficult to apply this knowledge to the given context. For example, it could be possible that the curves that make up the trenches are a strong distractor - the child finds it difficult to imagine a non-curved line embedded within this context. This is similar to the Gestalt experiments that show how our senses can be deceived by context.

The lack of practise/experience with curves in their everyday environment may account for this. It could also be possible that curves are too much of a distractor, making it difficult for the child to hold the idea of a straight line embedded within or along a curve.

- *Soft/peripheral occlusion versus hard occlusion*: in the case of the trenches, the argument made in the chapter introduction, that trenches provided more evidence of occlusion than the wall tasks, could be extended to the children's performance on the angled tasks compared to the curved tasks. In the angled tasks, the opposite wall formed a very clear obstacle in the way of vision almost equivalent to a barrier. In the curved task however, the wall was made out of one continuous piece of wood making the salience of the barrier attributes less noticeable.

6.4.4 Difference between settings

This brings us to the issue that has been recurring throughout our experiments that children's evaluations seem to be strongly influenced by the setting in which they are required to make the evaluation. Though the performance on the trench tasks were by no means perfect, it was emphatically better than the performance with tubes in our initial experiment. It must be remembered that the tube task required children to imagine line of sight going up and down rather than the more typical left and right. This could have been a possible complication in the task and better results may have been obtained if the tube were placed horizontally.

6.5 Conclusion

Though the expected difference between angles and curves remains, in general children performed better on the trench task than their counterparts had on the tube or curved wall tasks in previous experiements. Therefore it seemed logical to continue our experiments by comparing performance on tubes, walls and trenches in one single experiment to see how much these different settings affect children's performance.

Chapter 7

Experiment five: trenches, tubes and walls

7.1 Introduction

Having sought to quantify various aspects of the trench task in the previous experiment, we decided to do a cross-task study involving the tube task from the first experiment, the wall task from the second experiment and the curve task from the third and fourth experiments and see what, if any, differences will emerge in children's performances on these three distinct tasks.

Learning from tasks

Given the nature of the tasks, we suspected there would be a strong learning effect between the tasks as all the children would be tested on all three tasks. We therefore decided to test a large sample of children and present the tasks in different orders and check for any learning effect. In total, we used five distinct settings: one tube, two trenches (one curved, the other angled) and two walls (also one curved, the other angled) but we decided to split them into three distinct groups to reduce the amount of possible permutations. The three groups were tubes, walls and trenches. This reduced the amount of possible permutations from 120 to six. We decided that the easier of the two tasks (i.e the angled version) would always precede the curved version in each block. We expected this to maximise the learning potential across the experiment.

Angle and rotation

We chose to use only one degree of turn in this task to avoid making the task excessively long and repetitive for the children - in this experiment, we used an angle that seemed to pose the most problems to children of this age which was the angle of 50°. We decided to keep the rotational difficulty constant by keeping one of the dolls - the seeing doll - 90° to the left of the child. In all the tasks the rotational difficulty, the distance between the toys and the turn/angle would be the same. Our major aim was to make sure the sole difference between the tasks was the nature of the setting.

Response pattern

If we placed the dolls at the extremities of each tube, wall or trench, the correct response would always be "no". Some children may start to vary their response after being asked the same question five times in a row so we decided to insert a setting for each task where the dolls would be able to see each other and the correct response would be "yes". This we hoped would make the children most likely to answer to the best of their ability in each individual task.

Age shift

As the five year olds did not perform at ceiling in the last experiment, we decided to test children between five and six years of age, to see if the older children would demonstrate a ceiling effect and demonstrate a different solving method from the younger children.

7.2 Method

7.2.1 Participants

The participants were 79 children taken from two different local schools. Their ages ranged from 5;4 to 7;0 with a mean age of 6;4 (sd: 4.7 months). The gender distribution was balanced with 40 boys and 39 girls taking part in this study.

For the purpose of analysis, they were later subdivided into two groups: the five year old group ranged from 5;4 to 6;4 with a mean age of 6;0 (sd: 2.8 months) and comprised 38 children (18 boys and 20 girls). The six old group ranged from 6;5 to 7;0 with an average age of 6;8 (sd: 2.5 months) and comprised 41 children (22 boys and 19 girls).

7.2.2 Apparatus

We used similar cardboard walls and trenches to those found in the previous experiments. The tube task demanded a slight alteration from its original setting: we added a "secret door" which would open and shut. This door was added about 15cm from the opening of the tube, so that one could open it and place a doll in the tube through this door. This way the doll in the tube and the doll at the opening of it would be able to "see" each other.

We also used the same two Playmobil dolls again though in this case they were attached to a 50 $\times$ 50 mm piece of cardboard which allowed them to be moved about without falling over (unlike the original tube experiment where one of them was physically fixed at the opening of the tube).

The tube had an interior diameter of 75 mm (exterior diameter of 77mm). The walls and the trenches had a depth of 78mm. We made sure that the distance between the dolls was the same across the settings. This distance varied depending on whether the dolls were placed where they could see each other (15 cm apart) or whether they could not see each other (approx. 50 cm apart). This distance was measured as a straight line between the two dolls.

7.2.3 Procedure

Each child was tested in a quiet environment with the materials placed on a low table and the child seeing them from above at an approximate angle of 60°.

Pre-testing phase

The child was introduced to the two dolls that were to be used in the experiment, called Tommy and Susan. The two dolls were first placed facing each other. The child was then asked if the toys could see each other or not[1]. We then placed a cardboard barrier between the two dolls (so they were unable to see each other) and the same question was repeated. The order of these two questions was randomised.

This task aimed to:

1. satisfy ourselves that they understood that we accepted that the dolls could "see",
2. make clear to the child it was acceptable to answer in the negative and the postive,
3. to see if they understood the basic questions that were being asked,
4. ensure that the children had at least a rudimentary understanding of line of sight and
5. introduce them to the two toys (Tommy and Susan) who were going to be used.

Testing phase

In total there were 5 tasks to be accomplished: the tube, the curved trench, the angled trench, the curved wall and the angled wall (an

[1] The verbatim instructions were "This doll is Tommy and this doll is Susan. I will place them like this [Experimenter places them facing each other]. Now can Tommy [Experimenter touches the Tommy's head] see Susan [E. touches Susan's head]?"

angled tube was not physically possibile). There were six possible presentation orders as detailed in table 7.1 and each child was assigned to one of these groups so that we ended with approximately the same amount of subjects in each group.. After having passed the pre-testing phase task, the child was presented with each block one after the other. The angled version of each task always came first and was followed by the curved version of it. For example, a child who was in group 1 would do the tasks in the following order:

1. Tube
2. Wall (angled)
3. Wall (curved)
4. Trench (angled)
5. Trench (curved)

Tube, Wall, Trench (UWT) group 1	Tube, Trench, Wall (UTW) group 2
Wall, Tube, Trench (WUT) group 3	Wall, Trench, Tube (WTU) group 4
Trench, Wall, Tube (TWU) group 5	Trench, Tube, Wall (TUW) group 6

Table 7.1: Orders of presentation

Each child was presented with the task. The toys were placed in a position that either afforded no visibility or one that did and were asked “Can Susan see Tommy now?”. If no verbal response was made, the child was encouraged to give one. After the response was given, the experimenter took note of it and moved on to the next position (two per task). The order in which the two different visibility positions were presented was randomised throughout to avoid a pattern developing. For the position in which they could see each other, we endeavoured to use settings that were not too easy neither too ambiguous (i.e. one affording incomplete visibility of the other toy). The same positions were used for all children. In total a child would answer ten questions. For example, a child assigned to block one would have to answer questions in this order.

1. Tube

   Can See position

   Can Not See position

2. Wall (angled)

   Can See position

   Can Not See position

3. Wall (curved)

   Can Not See position

   Can See position

4. Trench (angled)

    Can See position

    Can Not See position

5. Trench (curved)

    Can Not See position

    Can See position

After the final task, the child was thanked and was asked why they answered the way they did. Their responses were noted.

7.3 Results

As usual, none of the children failed the pre-testing phase.

7.3.1 Scores

We devised a scoring system whereby children would get one point for each correct answer and none for an incorrect answer. In total, they were asked ten questions in the testing phase so their maximum score could be ten. Conversely, a child who answered all their questions incorrectly would score zero points. The grand total could also be broken down according to the task with a score out of two for each task.

Total scores

The mean of the total scores are summarised in table 7.2

	N	Mean score	Standard deviation	Score range
All	79	8.27	1.17	5-10
Five year-olds	38	8.39	1.31	5-10
Six year-olds	41	8.15	1.04	6-10

Table 7.2: Mean total score for each group

A one-way ANOVA yielded no significant effect of age ($F(1, 77) = .882, p = .351$).

We then subdivided the total score into two groups - the curves (Tube, Curved Trench and Curved Wall) and the angles (Angled Trench and Angled Wall). The maximum score was six for the first group and four for the second.

The results are summarised in tables 7.3 and 7.4.

	N	Mean score	Standard deviation	Score range
All	79	4.82	1.12	3-6
Five year-olds	38	4.84	1.10	3-6
Six year-olds	41	4.80	1.14	3-6

Table 7.3: Mean total score for the curved tasks (scores out of 6)

	N	Mean score	Standard deviation	Score range
All	79	3.91	0.29	2-4
Five year-olds	38	3.84	0.44	2-4
Six year-olds	41	3.98	0.16	3-4

Table 7.4: Mean total score for the angled tasks (scores out of 4)

Given that the scores were not comparable as one was graded out of six and the other out of four, we transformed the score into a success rate expressed as a percentage.

	Curved Tasks	Angled Tasks
All	80.3%	97.8%
Five year olds	80.7%	96%
Six year olds	80%	99.5%

Table 7.5: Mean scores on the tasks expressed as a percentage

Again one-way ANOVAs yielded no significant effect of age (Curved tasks: $F(1,77) = .022; p = .884$; Angled tasks: $F(1,77) = 3.371; p = .07$) but we found a significant effect of task group overall ($t = 8.363; df = 78; p < .001$) and for each age-group separately (Five year olds: $t = 5.281; df = 37; p < .001$. Six year olds: $t = 6.943; df = 40; p < .001$). In all cases, angled presentations were easier to judge.

Task scores

By breaking down the scores further, we ended up with a score out of two for each task (Tube, Curved Wall, Angled Wall, Curved Trench, Angled Trench). The mean scores for each group are shown in table 7.6.

As we can see, the scores for each task varied quite clearly. A 2 (age) $\times$ 5 (task) repeated measures ANOVA showed a significant

	Tube	Angled Wall	Curved Wall	Angled Trench	Curved Trench
All	1.43	1.96	1.57	1.95	1.82
Five year olds	1.42	1.92	1.58	1.92	1.84
Six year olds	1.44	2.0	1.56	1.98	1.80

Table 7.6: Mean total score for each tasks (score out of 2)

main effect for task ($F(4, 308) = 38.985; p < .001$) but no significant effect of age or interaction.

As expected, the angle tasks bordered on ceiling performances with almost all the children getting all their responses right. These two tasks showed a significant effect when compared with all the curved tasks. We ran paired t-tests on them looking at the whole sample and the results were as follows:

- Tube - Angled Trench: $t = 8.365; df = 78; p < .001$
- Tube - Angled Wall: $t = 8.365; df = 78; p < .001$
- Curved Trench - Angled Trench: $t = 2.785; df = 78; p = .007$
- Curved Trench - Angled Wall: $t = 3.552; df = 78; p = .001$
- Curved Wall - Angled Trench: $t = 6.009; df = 78; p < .001$
- Curved Wall - Angled Wall: $t = 7.098; df = 78; p < .001$

Other significant effects were found in the following:

- Tube - Curved Trench: $t = 7.098; df = 78; p < .001$

- Tube - Curved Wall: $t = 2.359; df = 78; p = .021$
- Curved Trench - Curved Wall $t = 4.567; df = 78; p < .001$

These significant effects were mostly replicated when looking at each age group individually:

Five year olds:

- Tube - Angled Trench: $t = 5.529; df = 37; p < .001$
- Tube - Angled Wall: $t = 6.083; df = 37; p < .001$
- Curved Trench - Angled Trench: $t = 1.138; df = 37; p = .262$
- Curved Trench - Angled Wall: $t = 1.781; df = 37; p = .083$
- Curved Wall - Angled Trench: $t = 3.621; df = 37; p < .001$
- Curved Wall - Angled Wall: $t = 4.383; df = 37; p < .001$
- Tube - Curved Trench: $t = 5.187; df = 37; p < .001$
- Tube - Curved Wall: $t = 1.968; df = 37; p = .057$
- Curved Trench - Curved Wall: $t = 3.635; df = 37; p < .001$

Six year olds:

- Tube - Angled Trench: $t = 6.223; df = 40; p < .001$
- Tube - Angled Wall: $t = 6.532; df = 40; p < .001$

- Curved Trench - Angled Trench: $t = 2.87; df = 40; p = .007$
- Curved Trench - Angled Wall: $t = 3.114; df = 40; p = .003$
- Curved Wall - Angled Trench: $t = 4.857; df = 40; p < .001$
- Curved Wall - Angled Wall: $t = 5.595; df = 40; p < .001$
- Tube - Curved Trench: $t = 4.804; df = 40; p < .001$
- Tube - Curved Wall: $t = 1.403; df = 40; p = .168$
- Curved Trench - Curved Wall $t = 2.905; df = 40; p = .006$

The significant effect found when comparing the results on the tube and the curved wall disapeared when analysing the groups individually. This is most probably due to the fact that the difference was relatively small and would only be found significant in large datasets.

7.3.2 Group effects

As the children had been assigned to six different groups with differing orders of presentation, we ran an ANOVA to test if these order groups had a significant effect on their overall score. This was not the case ($F(5, 73) = .845; p = .522$). Table 7.7 shows the mean score for each presentation order from the hardest to easiest (see 7.1 for more details on each presentation group).

Presentation group	Mean overall score
Group 2 (Tube, Trench, Wall)	7.85
1 (Tube, Wall, Trench)	8.00
4 (Wall, Trench, Tube)	8.23
3 (Wall, Tube, Trench)	8.46
5 (Trench, Wall, Tube)	8.46
6 (Trench, Tube, Wall)	8.62

Table 7.7: Mean overall score for each presentation group (n=13 for all groups except group 1: n=14)

The results were also broken down between the age groups. It should be noted that as we did not know when testing, which group the child was going to belong to, the number of subjects in each group is uneven.

Presentation group	n	mean overall score	std. deviation	range
Group 1 (Tube, Wall, Trench)	10	7.8	1.32	6-10
2 (Tube, Trench, Wall)	6	7.66	1.75	5-10
3 (Wall, Tube, Trench)	4	8.75	1.26	7-10
4 (Wall, Trench, Tube)	6	8.5	1.22	7-10
5 (Trench, Wall, Tube)	6	9.0	1.1	7-10
6 (Trench, Tube, Wall)	6	9.17	0.41	9-10

Table 7.8: Mean overall score for each presentation group in the five year old group

We finally reduced the six presentation groups to three by collapsing the two groups that had the same initial task. This meant that Groups 1 and 2, Groups 3 and 4 and Groups 5 and 6 were merged with one another. We then ran one way ANOVAs on each age group individually - the six year olds showed no significant effect

Presentation group	n	mean overall score	std. deviation	range
Group 1 (Tube, Wall, Trench)	4	8.5	0.58	8-9
2 (Tube, Trench, Wall)	7	8.0	1.41	6-10
3 (Wall, Tube, Trench)	9	8.33	0.87	7-9
4 (Wall, Trench, Tube)	7	8.0	0.82	7-9
5 (Trench, Wall, Tube)	7	8.0	1.29	7-10
6 (Trench, Tube, Wall)	7	8.17	1.21	7-10

Table 7.9: Mean overall score for each presentation group in the six year old group

of presntation group ($F(2, 38) = .053, p = .949$) but the five year olds did ($F(2, 35) = 4.39, p = .019$). A post-hoc Sheffé test was run between the presentation groups for the five year olds and showed the trench group (i.e. group 5 and 6) performing significantly better than the tube presentation group (i.e. group 1 and 2).

7.4 Discussion

In this experiment, many of our predictions were reflected in the data and some new findings come to complete the overall picture.

7.4.1 Age difference

In previous experiments, the age difference between four year olds and five year olds was a constant but with our choice of older samples this has all but disappeared. It seems that there is little change in performance on these tasks between the ages of five and six : this implies that the solving mechanism we had described in chapter 5 (see section 6.4.3) seems to remain the prevalent solving method for six year olds also. This solving method may not in fact shift much for the next few years of their lives - the anecdotal accounts we received from the children was quite similar between the five and six year olds. Many of them did not provide very coherent explanations why they thought the dolls should be able to see each other through the tube, but gesticulated to indicate that the line of sight may be moved off course by the mere structure of the tube. Even the children who were correct with the tube task were not always able to explain exactly why they thought the toys couldn't see each other. The closest we got to a good explanation was "it's too much of a bend" from a 6-year old.

7.4.2 Angles versus curves

The difference we have observed throughout our experiments is once again found here in both the five year olds, as we expected, and also in the six year olds. This effect has been the most robust finding in our research and we have previously discussed in previous chapters why this may actually be the case.

7.4.3 Difference between the tasks

Our major finding in this experiment is the clear variation we found between the various settings. We have previously hypothesised on the reasons for this and the current experiment confirms our overall impression that context is a crucial factor in any child's performance on this type of tasks. By merely switching between a curved tube to a curved wall, the overall performance changed significantly. The difference in performance between the tube and the curved trench is even more marked.

Structurally the tube bears many structural aspects in common with the trench - it provides two walls (of sorts) which should allow the child to better imagine the occlusion that the doll's vision will suffer from. Despite this similarity their performance on this task is poorer than on the curved wall task. This seems to indicate that maybe the structure of the setting is not exactly what the child is relating to, but rather their experience of it. This however would not clearly explain why they perform better on the curved trench task than on either the tube or the curved wall, but it could be that this is due to another factor: the obvious outer wall. In chapter 4, we talked about the barrier nature of the outer wall - that the children may be equating it to something that vision "runs into", effectively "blocking" vision from travelling any further. More simply, it could just be possible that the fact it is open, (as opposed to the tube) and the presence of the second wall could allow children to mentally lay out their imaginary lines of sight with greater ease.

From the verbal responses we collected, none of the children had a clear comprehension that line of sight must be categorically straight - they all seemed to believe in a certain "flexibility" to it - that the dolls may just be able to make it bend sightly further than straight lines would travel. This flexibility may be caused by their realisation that they can in effect change their own line of sight by craning their neck to one side. Although the doll's did not in effect have a neck (and their heads were blocked in a straight forward looking position), it seems unavoidable that since we are asking the children to assign a human feature to an inanimate object, they may give it more human characteristics than we had bargained for.

7.4.4 Difference between the presentation of the tasks

Although we tried to use a large sample, it may just be that we were a little short on the amount of children in each subgroup for us to be able to detect a significant effect of order of presentation or that the sample was too old to show an overall effect. We did, however, find that the in the five year olds would perform better if they were to begin with the Trench tasks as opposed to the Tube task. It is also interesting to note that the two poorest overall performances were provided by children who had to start with the tube block. Conversely, two of the best performances were provided by children who started with the Trench task. It therefore seems that there may be a minor effect causing the children who start with the easier tasks (the Trench tasks) to then be able to transfer this information to the harder tasks though this effect seems to become less significant with age.

The lack of a clear learning effect does indicate in part that there is a strong possibility that children's performance is strongly related to the setting - that their ability to perform on the trench task will not necessarily mean they will be able to perform on the tube task. Most of our research so far does seem to indicate a piece-meal building of children's understanding of vision with little evidence of an over-riding theory that governs their decisions. When moving from one setting to another, a global theory should produce similar results but often this does not seem to be the case.

7.5 Conclusion

From this study, it seems clear that children's understanding of line of sight is highly dependent on the setting in which they are tested and extends beyond a mere difference between a better performance on angled tasks and a poorer one on curves. The differences we found between the three curved trials of the tube, the wall and the trench point to a lack of coherent structure to deal with each environment with a uniform solving method and bring into question a lot of the conclusions that have been made in past research. It seems that children's understanding of line of sight may actually not be as developed as we assumed or, at least, not as flexible as we would expect based on previous research.

Chapter 8

Discussion

The overall aim of the present research was to investigate how children's appreciation of line of sight changes depending on the rotational complexity of the task and the nature of the setting in which they have to evaluate line of sight. Most of the preceding research has assumed to some extent that the ability to evaluate line of sight depends on a simple underlying ability. However, the contradictory results found, point to a more complex picture that goes beyond the simple question "can the child understand line of sight?" or "does the child understand that lines of sight must be straight". In this chapter, we shall start by summarising the findings from our experiments after which we will seek to compare, as best we can and whenever it is possible, the results from each experiment.

8.1 Summary of results

8.1.1 Experiment 1

The initial experiment aimed to replicate and expand upon Flavell, Green, Herrera & Flavell's (1991) experiment. By and large, our results replicated theirs. It also demonstrated that older children (five year olds) initially experienced some difficulty with this task, since less than half of the five year olds predicted visibility correctly on the first 50° and 90° tasks. However, when it was demonstrated to them that they could not see through the tube when it was curved to 50°, the five year olds changed their response pattern in the subsequent block. This was not the case for the four year old group who generally persevered in their prediction that one would be able to see through a tube curved to 50°. The lack of improvement after feedback in the younger group was also related to the finding that a large portion of them mistakenly reported visibility through the tube in the feedback session: after having predicted that they would be able to see the doll at the end of the tube, eight out of eighteen went on to claim they could *actually* see the doll when in fact they could not. The degree of curvature also affected their performances - the smaller the curvature, the higher the chance of the child incorrectly predicting they would be able to see through it.

8.1.2 Experiment 2

The second experiment changed the initial experiment by discarding the tubes in favour of a set of walls that were either "curved" (i.e. gradually bent like the tubes) or "angled" (i.e. two walls linked together to form an angle). Each degree of curvature had one curved version and one angled version. Again the same three degrees of curvature were used (50°, 90° and 180°). It was expected that children would find this task simpler, since previous experiments (Flavell et al., 1978; Hughes & Donaldson, 1979; Flavell et al., 1991) had shown that children had a good understanding of how walls functioned and to what extent line of sight could be impeded by them. Both the three year olds and the four year olds performed well in the "angled" versions of the task - a minimum of 80% of any group of children performed correctly on any "angled" task. Performance on the "curved" walls was much poorer. Age affected scores significantly. The younger children struggled on the "curved" tasks: only one out of fifteen predicted vision correctly on the curved 50° task and a little more than half performed correctly on the curved 90° task. The four year olds performed better but were not yet at ceiling - less than two thirds judged correctly in the curved

50° task. The degree of curvature on the "curved" task also yielded a strong effect - the smaller the curvature, the higher the chance of the child incorrectly predicting that they would be able to see through it. This effect, however, was not found in the "angled" versions of the task.

8.1.3 Experiment 3

In the third experiment, the setting was once again changed - this time to trenches. The experiment sought to determine the "switchover" point - the precise point in the trench where a child judged that vision between two dolls changed from being impossible to being possible. A trench shaped like a "U" was used with one doll fixed at one end and another doll starting at the opposite end, but who was then gradually moved forward through the trench. The child was repeatedly asked if the dolls could see each other for each point the doll stopped at.

Almost two thirds of the three year olds overestimated the position of the switchover point but one quarter evaluated it correctly. In contrast, almost half the four year olds evaluated the position of the switchover point correctly; the rest *under*estimated the switchover point and none overestimated this point. Given the precision required to complete the task successfully, the data was later broken down into successful evaluations and near misses on one hand, and clear misses on the other. This showed that two thirds of the three year olds gave clearly incorrect evaluations, whereas only one four year old in 15 did so. This difference in performance was further underlined by analysis of the response patterns. It was found that more than half of the three year olds incorrectly expected vision to become possible in the first half of the trench (that is, far in advance of the switchover point).

8.1.4 Experiment 4

The relative success exhibited by the four year olds on the previous experiment may have been due to its making fewer demands on the children's rotational abilities. Both Experiments One and Two had required them to imagine the point of view of a doll who was placed to their left. This was not the case in Experiment Three, where the doll was facing the same way as the child, and this probably made it much easier to solve. Experiment Four returned to the same rotational complexity as Experiments One and Two, but examined children's performance in a series of trench tasks. Again there were two groups of trenches - "curved" and "angled" and the same degrees of curvature used in Experiments One and Two were retained (50°, 90° and 180°).

A very strong effect of trench shape (angled versus curved) was found. No child failed to understand at what point visibility became possible in the angled trenches, but there was a lack of clear comprehension of this in the curved trenches. Children showed a strong tendency to over-estimate the switchover point. When split between correct/nearly correct and fails, the results showed that four year olds still struggled on all three curved tasks, with a pass rate ranging between 25% and 50%. The five year olds performed better with a pass rate ranging between 46.7% and 80%.

8.1.5 Experiment 5

The final experiment sought to measure the differences between five different settings - a curved tube, a curved trench, an angled trench, a curved wall and an angled wall. In this experiment, the dolls were not moved along the corridor in order to determine the switchover point, but were simply placed alternately in a position where they could see each other and another where they could not.

The children used were drawn from an older age group and it might therefore be expected that performance in curved settings would improve. However, performance was still consistently and significantly better on the angled tasks than on the curved tasks. Children found the tube task to be significantly more difficult than the curved wall, which in turn was significantly more difficult than the curved trench. No clear effect of order of presentation was found.

8.2 Meta-analysis

As some of the experiments only differed slightly from each other, it seemed useful to compare and contrast the collected data to see if the results were consistent across the experiments or not.

8.2.1 Tubes

Experiment One measured the children's performance on a 50° tube four times in total. The tube in this case was held vertically (i.e. the tube looked to the child as if it were going downwards) and the child was asked if they were to look in one end of the tube, would they see the toy at the other end of it? In a similar context, Experiment Five also measured their performance on a 50° tube, but here the tube lay on the horizontal plane (i.e. the tube was laid flat on a table) and this time the child was asked to predict whether *two* dolls could see each other. We decided to compare the success rate of children in Experiment One (first presentation of the 50° tube) with their success rate on the tube task in Experiment Five. The results are summarised in table 8.1.

	Experiment 1	Experiment 5
Four year olds	0%	
Five year olds	42%	42.1%
Six year olds		46.3%

Table 8.1: Percentage of children performing correctly on the 50° tube in Experiment One and Experiment Five

The data fits nicely together. Similar pass rates were observed in both experiments with a consistent result for the overlapping age. Two things stand out from this comparison. First of all, the plane on which the tube is placed does not seem to matter - whether vertical or horizontal, performance does not seem to be noticeably different. Secondly, changing the question from "If you look in here, would you see the lady that's here?" to "Can Tommy see Susan?" does not seem to change their performance noticeably either.

We could have, perhaps, expected a higher success rate on Experiment Five as a consequence of the co-presence - in randomised order of presentation - of a Trench task or a Wall task, which could have potentially improved their chance of succeeding on the Tube task. However, the data does not seem to bear this expectation out.

8.2.2 Walls

The 50° wall tasks appeared in exactly the same fashion in both Experiment Two and Five - only the order of presentation was varied between the experiments. In Experiment Two, the 50° wall was used alongside five other wall type tasks. In Experiment Five, the wall was used with different settings such as trenches and tubes. The results have been summarised in table 8.2.

	Experiment 2	Experiment 5
Three year olds	6.7%	
Four year olds	64.3%	
Five year olds		57.9%
Six year olds		58.5%

Table 8.2: Comparison of performance on the curved wall task between Experiment Two and Experiment Five

The first thing to note is the very poor performance of the three year olds on this task with under 7% of them correctly predicting visibility. The performance level then shoots up with almost two thirds of the four year olds performing correctly on it. In Experiment Five, the performance of the five year olds and six year olds is slightly poorer than that of the four year olds in Experiment Two, but all three results are within margins of error, and may therefore be counted as similar. From this data, it seems that children's understanding of the wall task matures more rapidly than their understanding of the tube task, but remains still quite vague and imprecise at least until beyond the age of six.

8.2.3 Trenches

Both Experiment Three and Four made use of trenches, but only Experiment Four made use of a trench with a curvature of 50°. In Experiment Five, there was also a 50° trench. However, we did not move the doll to several points of the trench. To allow a fair comparison, we computed the percentage of children who responded correctly in Experiment Four when both dolls were placed at the extremities of the trench as this setting was exactly the same as that of Experiment Five. The results are summarised in table 8.3 below.

	Experiment 4	Experiment 5
Four year olds	75%	
Five year olds	86.3%	84.2%
Six year olds		80.5%

Table 8.3: Comparing performance on the curved trench task between Experiment Four and Experiment Five

The data seems to fit together more coherently here with similar pass rates in the five year olds in Experiment Four and Five. Between the ages of four and six, the proportion of incorrect responses decreases from one quarter to around one fifth which is a moderate increase in performance. The overall high scoring rate prevents us from being certain that there is a levelling of success happening by the age of five or six.

The randomisation of the positioning of the seeing doll in Experiment Four may have helped the children - it seems somewhat strange that as many as 75% did not believe visibilty was possible from the extremities yet almost 70% of them were not even close to correctly predicting at which point the switchover occurred (see table 6.7). If we were to have tested the children used in Experiment Five in the same way (i.e. moving the doll to various points up and down the trench), the six year olds may have performed better overall than the four and five year olds in Experiment Four and Five.

Throughout the experiments, clear differences in performance emerge depending on the type of setting used. Apparently, children will consistently find predicting vision through a tube more difficult than they would through a curved trench or along a curved wall. This could be due to their familiarity with the different settings: walls and corridors are familiar places to most children but a tunnel or a tube are much less frequent in everyday life. The better performance on trench tasks is somewhat surprising, since a trench is structurally quite similar to a tube.

8.3 Theoretical explanations

8.4 Vision and travelling

Children's poor performance on the curved tasks could be due to a misunderstanding or a misinterpretation of what is asked of them. When asked if two dolls can see one another, the child may instead consider whether they can easily travel towards one another (or consider line of sight as something that can travel in a similar way). In the angled tasks, the travelling would be interrupted by a sharp change in direction at some point along the corridor, but this is not the case in the curved tasks where the change of direction is constant and thus not so obvious to young children. Theoretically, the number of changes in direction in the curved tasks is infinite. This makes this concept quite complicated for the child to grasp and possibly beyond their conceptual reach.

8.5 Occlusion

The preceding explanation fails to explain fully the differences in performance between a curved wall and a curved trench. As discussed in section 6.4.3 (page 132), the effect of occlusion of vision by the outer wall could affect the child's judgement. The constricted nature of the trench may explain why the children perform better on that task than on the single wall task. However, this factor won't explain poor performance in the tube task, which, on the face of it, has much more in common with the trench task than it has with the wall task. However, no real walls of any sort are present in the tube - the child has to grasp the fact that both sides of the tube are going to act as walls. This may seem to be common sense to an adult, but not necessarily that simple for children. There could also be a certain element of "magic" attributed to the tube - either that it "helps" vision along, or that it "invites" vision to "flow" through it. Regardless of what the children are really attributing to the tube, it is undeniable that it will probably always induce children to overestimate line of sight through it, just by its very nature.

Hood (1995, 1998) tested two to four year olds on a different type of tube task: he used curved tubes that were placed vertically. For example, one tube would snake from the top left to bottom right of the display. If one were to place a ball in it, the ball would end up a dozen or so centimetres to the right from where it began. Two and three year olds however did not understand how the tube could work as a conduit for this ball and tended to search the receptacle that was directly beneath where the ball was dropped. Around the age of four, they start to understand that the tube will change the course of the ball and their strict belief that all objects must fall vertically is abandoned.

8.5.1 Feedback

performance related to feedback on the first experiment. Their pattern seems to be consistent with the type of conservatism reported in much of the literature such as

In Experiment One, we looked at the effect of feedback on children's understanding of line of sight. The results were quite similar to that found by Flavell et al. (1991) in that younger children did not necessarily make the connection between being shown that they could not see through a tube bent to 50° and subsequently changing their response.

According to Piaget (1952), the children we tested were all in the Preoperational Stage in the Intuitive period (estimated to be between four and seven years of age). Children are believed to exhibit visual egocentrism, a lack of clear logical thought and a certain amount of "magic" beliefs (such as animism). Research (Flavell, Shipstead & Croft, 1978; Flavell, Botkin, Fry, Wright & Jarvis, 1968) has moderated the degree of visual egocentrism usually attributed to children at this age. We found little evidence of typically egocentric response patterns. However, our research seems to show that younger children found it quite hard to apply quite basic rules of inquiry to come to a correct inference in the tube task. Again, it is interesting to note that Hood (1995, 1998) found that four year olds *were* able to learn from their mistakes and change their responses accordingly. So if they are able to change their beliefs relatively easy on a similar task, why were they persevering in our experiment? Let us imagine that a child may have gone to the effort of changing their views so that they now realise that objects, when placed in a tube, do not fall vertically but exit the other end. When they are shown that this rule doesn't apply to vision, they can start to amend their rule by splitting it in two (e.g. "objects will exit the tube when held *only* vertically, vision does not follow suit") or they can be more economical and judge lack of visibility to be an aberration that does not force them to change the theory they have acquired. This approach is quite similar to the philosophical problem of science expounded by David Hume (1999):

> The bread, which I formerly eat, nourished me; that is, a body of such sensible qualities was, at that time, [endowed] with such secret powers: but does it follow, that other bread must also nourish me at another time, and that like sensible qualities must always be attended

> with like secret powers? The consequence seems nowise necessary. (*from section 29*)

It is true that it is not necessarily prudent nor economical for children to change their theories too rapidly, especially if they are unable to construct a theory sufficiently concise to encompass the current event (in our case, that vision cannot travel through a tube bent to a certain degree) within a similar theory (for example, that an object inserted into a tube would come out the other end if the tube slopes downward).

8.6 Photography

We discussed in section 2.3 research pertaining to children's performance on photography tasks. It seems pertinent now to discuss how that research relates to ours. Young children have great difficulty in performing well on a photography task: their performance is poorer than their performance on a False Belief task (Zaitchik, 1990). In our experiments, they have little difficulty in showing understanding of line of sight in very similar settings to those used by Zaitchik. However, as we have seen, if we increase the complexity of the environment, the children will start to struggle. These considerations make it likely that there is some additional difficulty caused by the symbolic/representational nature of the photograph and this could explain their poor performance on Zaitchik's experiments and their relatively good performance on our own. Liben (2003) has also demonstrated that children develop their understanding of the mechanics of photography between the age of three and five. For instance, she found that three year olds were able to appreciate that two photographs were distinct but they were not able to state that the photographer had changed position. Again, the fragmented nature of their experience of photographs may be a cause of their poor performance and may prevent them from fully appreciating the rotation or movement that has occurred between photograph A and B.

Our task bears a lot of similarities with the latter task. The child has to imagine what a doll would be able to see from a certain position and thus it differs little from asking them what photograph could have been taken from that position. The symbolic/representational issue underlines once again that the type of response required from the child is can underestimate their underlying knowledge of the phenomena. As a result, it seems that the method we elected to use avoids underestimating their abilities by bypassing this methodological issue. It follows that children who succeed on one of our line of sight tasks will probably fail on a photographic version of the same task .

8.7 Theory of development

As discussed in the literature review (see section 2.1), there are various competing theories regarding the way in which children develop their own theories of the workings of different phenomena. The research done by Vosniadou et al. (2004),Vosniadou & Brewer (1994, 1992, 1987) and Nobes et al. (2003, 2005) focused on phenomena in which the child has been receiving contrary feedback - every child would have experienced a lot of instances that could have been taken as implying that the earth was not round but in fact flat (such as overall flat appearance of their surroundings for example). Vosniadou et al argue that through a series of restructuring of their theories of the earth based on their experience, the child will eventually arrive at a correct understanding of the earth being round. Nobes et al, however, argue that this theory places too little emphasis on the cultural learning that takes place. The knowledge the child acquires on a day-to-day basis is in effect fragmented and inconsistent, making it difficult or even impossible for them to form a structured theory.

8.7.1 Is there a cultural element to line of sight?

In contrast with the research into children's understanding of basic cosmology, it is unclear whether we can contend that there is a cultural element to the understanding of line of sight. A child will be confronted with many representations of the earth as a round globe and will probably also have it explained to them. However, in the case of line of sight, it is not a clear-cut statement of fact - in some cases, sight is possible while in others, sight is not possible so it seems unclear that children really have a culturally structured knowledge of line of sight.

8.7.2 Children's ability to create a consistent theory

Also, in our case, the children have probably been receiving feedback from their environment that is both frequent and intuitively correct. As a result, unlike cosmology, it seems unlikely that their theory of line of sight would be fragmented and contradictory as a result of this feedback. We do however have a clear case of split performance between the angles and the curves and this can be explained in two different ways:

A *Understanding of vision along curves and angles are two distinct theories* therefore there is little transfer of performance between the two and there is no clear unifying theory - or at least, there is none at this point. In part, their mental framework would be similar to that found by Nobes et al. (2005): their knowledge is fragmented and sometimes contradictory.

B *They are governed by the same theory, but the curved task is just more complicated.* As we have seen, there is a clear increase in complexity with the curved tasks and also a counter-intuitive trap with the curvature being able to better "afford" vision than an angle. A unitary theory is at work but it may not have developed enough in-built "error-correction" so their theory will still produce some glaring mistakes as a result.

It now seems clear that the way in which children make decisions concerning visibility and line of sight is by no means a simple binary catch-all rule such as "Is the line of sight able to travel along a straight line?" but involves many other factors that will change the way in which the child answers this question. Basing ourselves on previous research and our own findings, the following diagram (see figure 8.1) seems to best present the way a child younger than six comes to such a decision.

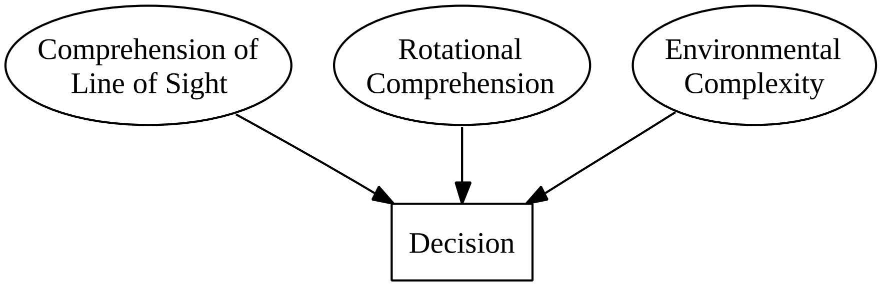

Figure 8.1: Proposed solving model

An adult will come to focus only on the line of sight component as it will always give a correct response. Children however seem not to rely too much on that aspect, although they do have a good understanding that lines of sight cannot travel around salient obstacles (Hughes & Donaldson, 1979). The rotational aspect is crucial - as Experiment Three showed. Children will find it quite easy to imagine a line of sight that is not too different from their own. However, when this is not the case, they will find it harder to imagine it correctly. Finally, the setting is a clear factor - it could be a simple distractor that confuses the children as Borke (1975)'s research seems to imply, or it could be a lack of experience with a new type of environment. It could also be certain aspects of these environments such as the difference in occlusion we pointed out. It does, however, remain clear that there is no guarantee that a child's performance on line of sight task will be the same regardless of the setting. This brings us to assume that children have a piecemeal understanding of line of sight which is highly contextually dependent making them unable to transfer their acquired skills across settings.

Appendix A

Appendix

group	age	gender	c501	c502	c503	c504	c505	c506	c507	c901	c902	c903	c904	c905	c906	c1801	c1802	c1803	c1804	c1805	c1806	c1807
1	40	1	0	0	0	0	1	1	1	0	0	0	0	1	1	0	0	0	0	0	1	1
1	47	2	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1
1	48	1	1	0	0	0	1	1	1	1	0	0	0	1	1	1	1	1	1	1	1	1
1	49	2	1	0	0	0	1	1	1	1	0	0	0	1	1	1	1	1	1	1	1	1
1	51	2	0	0	0	0	1	1	1	0	0	0	0	1	1	0	0	0	0	0	1	1
1	52	1	0	0	0	0	1	1	1	1	0	0	0	1	1	1	1	1	0	0	1	1
1	53	1	1	0	0	0	1	1	1	1	0	0	0	1	1	1	1	1	0	0	1	1
1	54	1	1	0	0	0	1	1	1	1	1	0	0	1	1	1	1	1	0	0	1	1
1	55	1	1	1	1	0	1	1	1	1	1	1	0	1	1	1	1	1	1	0	1	1
1	55	2	1	1	1	0	1	1	1	1	1	0	0	1	1	1	1	1	1	1	1	1
1	56	1	1	1	0	0	1	1	1	1	0	0	0	1	1	1	1	1	1	0	1	1
1	57	2	0	0	0	0	1	1	1	0	0	0	0	1	1	1	1	1	0	0	1	1
1	57	2	1	1	0	0	1	1	1	1	1	0	0	1	1	1	1	1	0	0	1	1
1	58	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1
1	58	2	1	1	1	1	0	1	1	1	1	1	1	0	1	1	1	1	1	1	0	1
1	58	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	0	1	1
2	59	1	1	1	1	0	1	1	1	1	1	0	0	1	1	1	1	1	1	0	1	1
2	59	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	59	1	1	1	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	59	2	1	1	1	0	1	1	1	1	1	0	0	1	1	1	1	1	0	0	1	1
2	60	1	1	1	1	0	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1
2	60	1	1	1	1	0	1	1	1	1	1	1	0	1	1	1	1	1	1	0	1	1
2	61	2	0	0	0	0	1	1	1	0	0	0	0	1	1	1	1	1	0	0	1	1
2	61	2	0	0	0	0	1	1	1	0	0	0	0	1	1	1	1	1	0	0	1	1
2	62	1	1	0	0	0	1	1	1	1	0	0	0	1	1	1	1	1	1	0	1	1
2	64	2	1	1	1	0	1	1	1	1	1	0	0	1	1	1	1	1	1	0	1	1
2	65	2	1	1	0	0	1	1	1	1	0	0	0	1	1	1	1	1	0	0	1	1
2	66	2	1	1	1	0	1	1	1	1	1	0	0	1	1	1	1	1	1	0	1	1
2	68	2	1	1	0	0	1	1	1	1	1	1	0	1	1	1	1	1	1	0	1	1
2	69	1	1	1	1	0	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1
2	68	1	1	1	1	0	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1

Figure A.1: Raw data for experiment 4 - the curved tasks (The c indicates a curved task, the middle two or three numbers, the degree of curvature, the last digit is the position in the trench)

group	age	gender	a501	a502	a503	a504	a505	a506	a507	a901	a902	a903	a904	a905	a906	a1801	a1802	a1803	a1804	a1805	a1806	a1807
1	40	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1	47	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1	48	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1	49	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1	51	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1	52	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1	53	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1	54	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1	55	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1	55	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1	56	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1	57	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1	57	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1	58	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1	58	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1	58	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	59	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	59	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	59	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	59	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	60	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	60	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	61	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	61	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	62	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	64	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	65	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	66	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	68	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	69	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	68	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Figure A.2: Raw data for experiment 4 - the angled tasks (The a indicates an angled task, the middle two or three numbers, the degree of curvature, the last digit is the position in the trench)

Age	Group	Tube nv	Angled Wall nv	Curved Wall nv	Trench Angles nv	Curved Trench nv	Tube nv	Angled Wall v	Curved Wall v	Angled Trench v	Curved Trench v
74	1	0	0	0	1	0	1	1	1	1	1
76	1	0	0	0	1	0	1	1	1	1	1
78	1	1	1	1	1	1	1	1	1	1	1
82	1	0	1	1	1	1	1	1	1	1	1
72	1	0	1	0	1	1	1	1	1	1	1
83	1	0	1	1	1	0	1	1	1	1	1
78	1	1	1	1	1	1	1	1	1	1	1
73	1	0	1	0	1	1	1	1	1	1	1
74	1	0	1	1	1	1	1	1	1	1	1
70	1	0	1	0	1	1	1	1	1	1	1
75	1	1	1	1	1	1	1	1	1	1	1
70	1	1	1	0	1	1	1	1	1	1	1
70	1	0	1	0	1	1	1	1	1	1	1
72	1	0	1	0	1	1	1	1	1	1	1
84	2	1	1	1	1	1	1	1	1	1	1
80	2	0	1	0	1	1	1	1	1	1	1
75	2	0	0	0	0	0	1	1	1	1	1
82	2	0	1	1	1	1	1	1	1	1	1
75	2	0	1	0	1	1	1	1	1	1	1
84	2	0	1	0	1	0	1	1	1	1	1
74	2	1	1	1	1	1	1	1	1	1	1
78	2	0	1	0	1	0	0	1	1	1	1
69	2	1	1	1	1	1	1	1	1	1	1
70	2	0	1	0	1	0	1	1	1	1	1
78	2	0	1	1	1	1	1	1	1	1	1
73	2	0	1	0	1	1	1	1	1	1	1
78	2	1	1	1	1	1	1	1	1	1	1
77	3	1	1	1	1	1	1	1	1	1	1
82	3	0	1	1	1	1	1	1	1	1	1
78	3	0	1	1	1	1	1	1	1	1	1
74	3	0	1	0	1	1	1	1	1	1	1
84	3	0	1	0	1	1	1	1	1	1	1
77	3	1	1	1	1	1	1	1	1	1	1
81	3	1	1	1	1	1	1	1	1	1	1
81	3	0	1	1	1	1	1	1	0	1	1
77	3	1	1	0	1	1	1	1	1	1	1
72	3	1	1	1	1	1	1	1	1	1	1
78	3	1	1	0	1	1	1	1	1	1	1
71	3	1	1	0	1	1	1	1	1	1	1
73	3	1	1	1	0	1	1	1	1	1	1
84	4	1	1	1	1	1	1	1	1	1	1
72	4	1	1	1	1	1	1	1	1	1	1
78	4	1	1	1	1	1	1	1	1	1	1
84	4	0	1	1	1	1	1	1	1	1	1
77	4	1	1	0	1	1	1	1	1	1	1
75	4	1	1	1	1	1	1	1	1	1	1
80	4	0	1	0	1	1	1	1	1	1	1
81	4	0	1	0	1	1	1	1	1	1	1
75	4	0	1	1	1	1	1	1	1	1	1
69	4	0	1	0	1	0	1	1	1	1	1
64	4	1	1	1	1	1	1	1	1	1	1
78	4	0	1	0	1	1	1	1	1	1	1
68	4	0	1	0	1	0	1	1	1	1	1
79	5	0	1	1	0	0	1	1	1	1	1
74	5	0	1	1	0	1	1	1	1	1	1
78	5	1	1	1	1	1	1	1	1	1	1
77	5	0	1	0	1	0	1	1	1	1	1
82	5	0	1	0	1	0	1	1	1	1	1
73	5	1	1	1	1	1	1	1	1	1	1
77	5	0	1	0	1	0	1	1	1	1	1
78	5	1	1	1	1	1	1	1	1	1	1
73	5	0	1	1	1	1	1	1	1	1	1
78	5	1	1	1	1	1	1	1	1	1	1
70	5	0	1	1	1	1	1	1	1	1	1
70	5	1	1	1	1	1	1	1	1	1	1
76	5	1	1	1	1	1	1	1	1	1	1
83	6	0	1	0	1	0	1	1	1	1	1
84	6	1	1	1	1	1	1	1	1	1	1
77	6	0	1	0	1	1	1	1	1	1	1
80	6	1	1	1	1	1	1	1	1	1	1
75	6	1	1	1	1	1	1	1	1	1	1
79	6	1	1	0	1	1	1	1	1	1	1
75	6	1	1	1	1	1	1	1	1	1	1
72	6	0	1	1	1	1	1	1	1	1	1
71	6	0	1	1	1	1	1	1	1	1	1
65	6	1	1	1	1	1	1	1	1	1	1
70	6	0	1	1	1	1	1	1	1	1	1
77	6	1	1	1	1	1	1	1	1	1	1
80	6	0	1	0	1	1	1	1	1	1	1

Table A.1: Raw data from Experiment Five. (nv - no line of sight between the dolls; v - a clear line of sight between the dolls)

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