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Young children's ability to solve spatial problems involving a choice

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When do young children become able to make an adequate choice between two alternatives based on spatial information? Children of 20, 30, and 40 months of age were either presented with two objects with different cross-sections and one aperture, or one object and two different apertures. In each trial there was one object–aperture match and the task was to find that match and insert the object. All the children understood the task and tried to solve the problems but the 20-month-olds performed randomly and not even the 40-month-olds chose all the correct correspondences consistently. The results also showed that it is easier to choose between apertures than objects. This contrasts with the ability to solve the insertion problem once the choice was made. When choosing the correct object or aperture, the 40-month-olds inserted the triangle successfully in 85% of the cases. The boys and girls were equally good at solving the task, but the boys did it faster. The results show that making a choice adds significantly to the difficulty of solving spatial problems. It requires systematic examination of the objects and apertures involved, a working memory that can handle at least three items at a time, and an ability to inhibit an incorrect choice. Such executive functions are typically found in older preschool children but the present task shows that with an appropriate setup their development can be traced from a much earlier age.

Keywords: Action planning; Choice behaviour; Manipulation; Means–end relationships; Mental rotation; Toddlers.

Cognition and action are mutually dependent. Together they form functional systems, around which adaptive behaviour develops (Piaget, 1952;

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Thelen & Smith, 1994; von Hofsten, 1993, 2004, 2007). Thus cognitive processes are a necessary part of any motor movement. All movements must be planned and represented in advance even for simple operations in early infancy. Claxton and Keen (2003), for instance, found that 10-month-old infants reached faster for a ball if they were going to throw it as opposed to use it in a precise fitting action. The way a tool is manipulated is a function of the particular purpose of the action (Manoel & Connolly, 1998). When faced with alternative ways of solving a problem, the planning process must also include the choice itself. Here we investigated how young children go about solving spatial problems that include a choice. Two kinds of such problems were presented to the children. First, the subjects were given one object that fitted into one of two horizontal apertures and, second, two objects one of which fitted a single aperture.

To be able to solve the task of fitting objects into apertures, the child must represent the spatial relationship between an object's three-dimensional shape and its two-dimensional projections. This problem is made more complicated by the fact that for most objects, many such projections exist. For example, a regular cylinder has a circular silhouette from a viewpoint parallel to its major axis, a rectangular silhouette from a viewpoint perpendicular to its major axis, and a family of silhouettes of more complex shapes from other viewpoints. Even adults may have problems finding the correspondence between the form of an object from an unfamiliar view and its 2D projections (Tarr, Bülthoff, Zabinski, & Blanz, 1997). To solve these kinds of problems, the child must also understand the relationship between the positive form of the object and the negative form of the aperture. Apertures are not represented as having shapes, but rather as expanding behind the borders of the surrounding surfaces (Bertamini & Croucher, 2003; Casati & Varzi, 1994; Peterson, 2003; Rubin, 1921). Bertamini and Croucher (2003) suggested that positive and negative spaces are represented differently in many circumstances and that the shape of a hole is only available indirectly from the shape of the surrounding object. Finally, to identify the correspondence between two objects or an object and an aperture requires that one form is rotated in the mind into registration with the other: a time-consuming and sometimes difficult task for adults (Shepard & Metzler, 1971).

The fitting problem

The solution of the fitting problem requires three kinds of spatial adjustments. First, the object must be placed over the aperture. Second, the longitudinal axis of the object has to be oriented perpendicular to the aperture in order to insert it. Third, the object has to be oriented in such a way as to make its cross-section correspond to the cross-section of the aperture. Passing a ball through an aperture requires only the first kind of adjustment. Inserting a cylinder requires the solution of the first two problems, that is, it must be placed over the aperture with its longitudinal axis oriented perpendicular to it. For every other fitting task, all three problems have to be solved. The difficulty of the third problem is a function of the number of possible ways the object fits into the aperture. Thus, for an object with a square cross-section, there are 8 specific orientations that fit the aperture (4 for each vertical orientation) and the number of reorientations required to get the object into an orientation suitable for inserting it in to the aperture is never very extensive. However, for an object with a triangular cross section with unequal sides, only one specific orientation fits the aperture and the required reorientations may be extensive.

A systematic study of how children develop the ability to fit objects into apertures was performed by Örnkloo and von Hofsten (2007). Infants between 14 and 26 months of age were encouraged to insert objects of various forms into snugly fitting apertures. Although all the infants were extremely motivated and challenged by the spatial puzzles and had no problems with grasping and handling the objects, the younger and older infants negotiated the task very differently. The 14- to 18-month-old infants had little comprehension of how to orient the objects in order to make them fit into the aperture. They did not even raise up objects that were presented lying down. Rather, they just lifted the object, moved it to the aperture, and tried to press it in. Consequently, they failed to insert the object in a large majority of the trials. In contrast, the 22- and 26-month-olds were quite successful in inserting the objects into the apertures. It was found that the most important difference between the children at these different age groups had to do with planning. The 22- and 26-month-olds moved the objects into a vertical position ahead of time and showed a strong tendency to turn the objects appropriately in the horizontal dimension before arriving at the aperture (Örnkloo & von Hofsten, 2007). Most importantly, only when the infants turned the object appropriately before arriving at the aperture did they succeed systematically with the task. The 26-month-olds succeeded in inserting the objects in 69% of the trials when it was correctly oriented ahead of time and in 5% when it was incorrectly oriented. When an object is moved from one position to another and its orientation is adjusted ahead of time as in the present task, this implies that the object is mentally rotated to the final position before the real reorientations are carried out (Örnkloo & von Hofsten, 2007). The objects with the more regular cross-sections have more goal positions that fit the aperture, but if the object was not turned to any of these positions ahead of time, the children were still lost.

When the fitting problem includes a choice

If, in addition to the fitting problem, the task includes a choice, it is necessary to invest more planning in solving it. Thus, instead of having two geometrical configurations, an object and an aperture, in mind when planning the action, three configurations need to be mentally compared and combined before a decision is made to choose one of the combinations. This places demands, not only on perception, but also on working memory. Thus, even if children are able to make the proper adjustment of single objects in order to make them fit corresponding apertures, they might not manage to decide which of two objects fit an aperture or which of two apertures an object will fit.

Children often fail to thoroughly compare several choices and instead they make decisions based on incomplete information (Vurpillot, 1968). Gauvain and Rogoff (1989) found that while older children more often take time to pause, scan, and gather enough information to find the smartest solution, younger children act more rashly. It can also be argued that making a choice includes the self-regulation of inhibiting alternative choices. Young children have problems with such tasks (Müller, Zelazo, Hood, Leone, & Rohrer, 2004; Rennie, Bull, & Diamond, 2004). If the child fixates one of the objects in a two-object task, the tendency to grasp it may be strong even when he/she knows that it is the wrong one. When only one object is presented as in the two-aperture task, the child may have difficulties in inhibiting the tendency to approach the wrong aperture. In typical development, the attention and the behaviour of a young infant is captured by whatever is the most salient at the time (Luria, 1973). The infant's original plan of action, for example crawling towards a toy, might be interrupted by another interesting stimulus that involves a new plan, which itself might get distracted by a third prepotent stimulus. Over the course of the first three years of life, infants develop an ability to inhibit responses to stimuli that are unrelated to their original plan of action. The disorganized and accidental behaviours diminish, and problem solving becomes more focused and goal directed. This corresponds to the developing executive function. Planning, mental operations, initiating appropriate actions, selecting relevant sensory information, and inhibiting inappropriate actions are the key factors in executive function (Murray et al., 2006). The brain areas involved in executive function, the frontal lobes and the prefrontal cortex, have a prolonged development. They are the last to mature, continuing to develop into adolescence and adulthood.

From these considerations, we expected that the choice task would be solved at an older age than the task of fitting one object into a single aperture, not because the spatial problem is more difficult, but because the choice itself introduces additional problems. These propositions are supported by Meyer (1940). Among other tasks she gave children two objects of different forms connected with a rod and challenged them to fit this arrangement into an aperture that corresponded to one of the forms. She found that children could not consistently orient this arrangement to insert the correct form before three years of age. It is not clear, however, whether it was the way of presenting the spatial problem, the fact that it was a choice task, or both, that made it more difficult to solve than the one-block-one-aperture task. The primary aim of the present study was to clarify the way that young children develop their ability to solve spatial problems involving a choice.

Three such problems were presented to 20-, 30-, and 40-month-old children. The first problem included objects and apertures with circular and square cross sections. The second problem included objects and apertures with rectangular and elliptic-like cross sections, and the third problem different triangular cross-sections (see Figure 1).

The questions asked

Three sets of questions related to young children's ability to solve these choice problems were asked. First, how is young children's ability to choose the correct object – aperture combinations related to their ability to fit an object into a corresponding aperture? In an earlier study, Örnkloo and

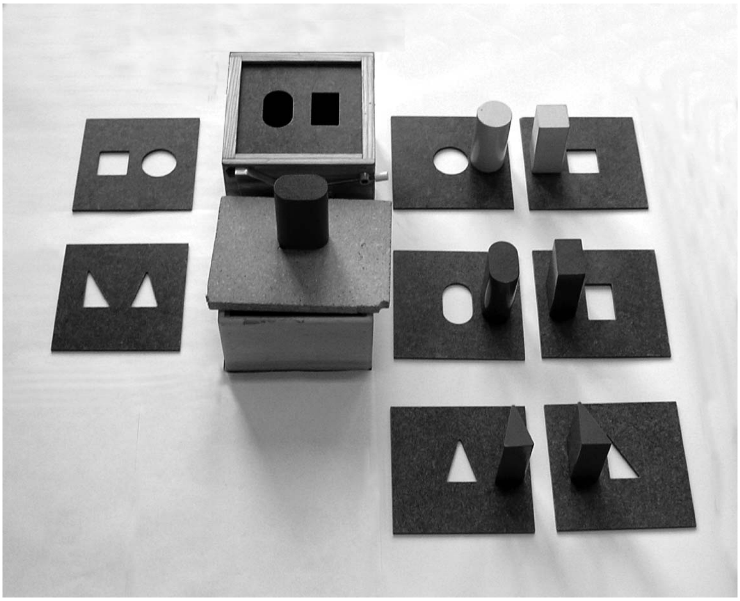

Figure 1. The different objects used in the experiment.

von Hofsten (2007), showed that by 22 months of age, children inserted the cylinder and the square rod successfully into corresponding apertures, they inserted the rectangular and elliptical rod significantly better than chance, and by 26 months, they inserted the triangular forms successfully. Would 20-month-olds be able to use their knowledge of circular and square forms to solve the simplest of these choice problems or would the increased demands associated with more extended planning, working memory, and executive function prevent them from doing so? How would the decreased number of fitting orientations of the rectangular – elliptical problem relative to the circular – square problem affect the ability to make a correct choice? Finally, how is choice behaviour affected when the two alternatives are members of the same geometrical category (triangular forms)? It is possible that category membership is important for deciding whether two forms are the same or not.

Second, we asked how the extent of planning would influence children's choice behaviour. To answer this question, we varied the stage at which the choice had to be made. In one set of problems, two objects and one aperture were presented and the choice had to be made at the beginning of the action when the object was picked up. In the other set of problems, one object and two apertures were presented. In this case, the choice could be made on the way to the apertures. It was expected that when the choice had to be made at an earlier stage of the action, more errors would occur.

Third, we asked about the relationship between making a correct choice and the ability to insert the object into the aperture. It can be argued that when a correct choice is made, the child has also realized how to go about solving the spatial problem. Thus, it may be argued that if the subjects had chosen the correct object in the choice situation, the relationship between the chosen object and the form of the aperture would be clearer to them. Consequently, they should insert the objects more successfully than when presented with just one object and one aperture as in Örnkloo and von Hofsten (2007).

METHOD

Subjects

Altogether 55 healthy infants from 3 different age groups were studied. The youngest group consisted of 8 boys and 9 girls with a mean age of 20.1 months ($SAD = 18.2$ days). The middle-aged group consisted of 8 boys and 11 girls with a mean age of 30.2 months ($SAD = 16.0$ days). The oldest group consisted of 11 boys and 8 girls with a mean age of 40.0 months ($SAD = 7.5$ days). All participants came from a Swedish town of medium size. The families were identified by birth records and contacted by mail.

Those who were interested in participating were contacted by telephone. The parents were primarily Caucasian middle class, having at least a high school education. A written consensus was signed in accordance with the Helsinki Declaration. The experiment was approved by the Ethics Committee at Uppsala University.

Experimental set-up

A set of objects and a box with interchangeable lids were used for the experiment. The objects and the box were presented on a table (59.5×120 cm) between the experimenter and the subject. The box ($14 \times 14 \times 11.5$ cm) was fixed to the table 5 cm from the edge on the side where the subject was seated. The objects were presented on a platform behind but at the same level as the box with the aperture.

Stimuli

Different lids were attached and locked to the wooden box. There were six lids with one of the following apertures: circular (3.5 cm diameter), square (3.2 cm side), rectangular (2.5 and 4.0 cm), ellipse-like (a central part of this object had a cross-section of 1.4×2.8 cm and was surrounded by two half cylinders with a diameter of 2.8 cm) isosceles triangular (4, 4, and 2.6 cm sides) and right-angled triangular with unequal sides (4, 4.7, and 2.6 cm sides). In addition, there were 3 lids each with two of the apertures described above: circular together with square, rectangular together with ellipse-like, and isosceles triangular together with right-angled triangular. When there was only one aperture, it was positioned at the centre of the lid. When the lid included two apertures, they were presented side by side. When the apertures were elongated, they were presented with the short side in the fronto-parallel plane (Figure 1).

There were six wooden blocks that snugly fitted into the corresponding apertures. All the blocks had a length of 7 cm. The objects fitted into the aperture in different number of ways. As long as the longitudinal axis of the cylinder was vertical, it fitted in every possible orientation. The block with the square cross section (called square block) fitted the aperture in four ways in each of the vertical orientations. The block with the rectangular and the ellipsoid-like cross sections (called the rectangular and ellipsoid blocks) fitted the aperture in two ways in each of the vertical orientations. The blocks with the triangular cross sections (called triangular blocks) fitted in just one way when not turned upside down. There were four differently coloured versions of each object (red, blue, yellow, and green). When the objects were presented in pairs, the colours were identical. The set-up is depicted in Figure 1.

All the objects were presented in an upright position. The blocks with elongated cross-sections, i.e., the rectangular, the ellipse-like, and the triangular forms, were presented with the longest cross-section oriented in the fronto-parallel plane of the child. Thus, those objects had to be turned 90° around their vertical axis to fit the aperture. This was done to force the subjects to reorient those objects before fitting them into the aperture. Moreover, the right-angled triangle, with only one insertion possibility, was never placed with the incorrect side up.

Procedure

Preparing for the experiment. After greeting the child and the parent, the experimenter explained the purpose of the study and the parent signed an informed consent form. Meanwhile, the experimenter played with the child to become familiar with him or her. The parent was then invited to sit in an adjustable chair with the child on his/her lap, so that the child could easily see the cross-sections of the objects. He/she was permitted to encourage the child, but not to give any assistance during the trials. Before the experiment started, the child was introduced to the box. For training, some objects (two rubber balls and a steel rod) were handed to the child so that he/she could manipulate them for a while. The experiment did not start until the child seemed to understand that the objects were going into the hole.

The experiment. The experimenter presented the trials one by one. The objects and lids that were not used on a particular trial were out of reach of the child. There were 24 trials. On 12 of them, there were one object and two apertures. On those trials, one object was placed in front of the child on a platform at the far side of the box. The child was encouraged to pick up the object and insert it into one of the two holes of the box. On the other 12 trials, there were two objects and one aperture. The two objects were placed side by side on the platform in front of the child. The child was encouraged to pick up one of them and insert it into the box. In the one object – two apertures conditions, six object – aperture combinations were included. The cylinder and the square blocks were presented with cylinder – square apertures, the rectangular and ellipsoid blocks were presented with the rectangular – ellipsoid apertures, and the triangular blocks were presented with the triangular apertures. In the two objects – one aperture condition, another six object – aperture combinations were presented. The cylinder and square apertures were combined with both of those objects, the ellipse and rectangle apertures with both of those, and the two triangular blocks with both of those. The presentation order was randomized. The 12 trials were presented twice. The position of the two objects/two apertures were switched between the two parts of the experiment. The combination of the four different coloured objects was randomly determined for each trial. The experimenter remained neutral during the choice of the objects or apertures.

Sometimes, however, when the child had chosen the wrong object–aperture combination and was unable to insert the block into the box, the experimenter could verbally encourage him or her to try the other object or aperture. That was only to prevent the child from losing interest in the task, and therefore this second try was not included in the analysis.

Most of the children finished the whole experiment within 20 minutes with some exceptions. If the child was attentive and eager to perform, the session could be completed in as little as 12 minutes. If the child was easily distracted and lacked concentration it could take as long as 1 hour including pauses. The whole experiment was video recorded. For the analysis, the analogue videotapes were digitally transformed.

Data analysis

The actions on the objects were analysed in the following way.

Correct decision. It was determined whether the first contact with the lid was made with the correct object or correct aperture. Only the first choice was counted.

Successful insertion. For each correct choice of object or aperture, the attempt to insert the object into the aperture was coded as successful or unsuccessful. Successful insertion meant that the child had managed to insert the object through the aperture.

Time. Three different time intervals (in seconds) were registered: First, the time from grasping the object to touching the aperture. Sometimes the child would grasp one object, and then put it down again, alternatively use both hands to grasp both objects, without the intention to carry them to the aperture. Thus, the clock started when the child fixated the aperture(s) and began to approaching it/them. Second, the time from touching the aperture to inserting the object into the aperture was measured. Third, the time the child persisted when an incorrect choice had been made was measured. The clock was stopped when the child gave up, i.e., clearly losing interest in the task, starting wandering around with its eyes, or made another choice.

Statistical analyses. To analyse the choice data, a mixed general linear model was used with repeated measurements of the task variables and between-subject measurements of the age groups. Post hoc tests with pairwise comparisons were used. Missing data were replaced with random choices. All post hoc tests were Bonferroni corrected. The choice between the three shapes (circle or square, ellipsoid or rectangular, and isosceles or right-angled triangle) is referred to as the Form Problem (FP), and the two types of choice (whether it was made between the apertures or the objects) is referred to as the Choice Problem (CP) in the analyses.

RESULTS

Number of completed trials

The task of inserting objects into slots proved to be very attractive and the subjects completed 1256 out of 1320 possible trials (4.8% missing trials). If the subjects grasped the object presented and moved it to the lid of the aperture-box, the trial was considered completed. The 20-month-olds completed 90.4% ($M = 21.76$ trials out of 24; $SD = 2.84$), the 30-month-olds 95.0% ($M = 22.79$ trials out of 24; $SD = 4.06$), and the 40-month-olds 99.6% ($M = 23.89$ trials out of 24; $SD = 0.32$). No subject was excluded due to fussing or fatigue.

Correct decision

The children made correct choices on 780 trials. A mixed general linear model repeated measurements ANOVA with FP (3) and CP (2) as within-subject variables and Age (3) and Sex (2) as between-subject variables was carried out. A main effect of FP was obtained, $F(2, 98) = 19.547$; $p < .000$, $\eta^2 = .285$ (see Figure 2). Pairwise comparisons showed a significant difference between the triangular forms and the cylinder/square and ellipsoid forms, but not between the cylinder/square and ellipsoid forms. There was also a main effect of CP, $F(1, 49) = 14.203$; $p < .000$, $\eta^2 = .225$ (see Figure 3), i.e., it was more difficult for the subjects to choose between 2 objects than between 2 apertures. There was a main effect of Age, $F(2, 49) = 30.610$; $p < .000$, $\eta^2 = .555$. While the children in the oldest age-group were rather successful, those in the youngest age group were at chance. Furthermore, there was a significant interaction between FP and Age, $F(4, 98) = 5.463$; $p < .001$, $\eta^2 = .182$ (see Figure 2). While the children improved significantly with age on the cylinder/square, and rectangle/ellipsoid problems, they did not on the triangular problem ($p > .05$). None of the interactions, CP $\times$ Age, CP $\times$ FP, or CP $\times$ FP $\times$ Age, were significant.

Successful insertions

When making a correct choice, the 20-month-olds succeeded in inserting the object into the aperture in 46% of the attempts, the 30-month-olds in

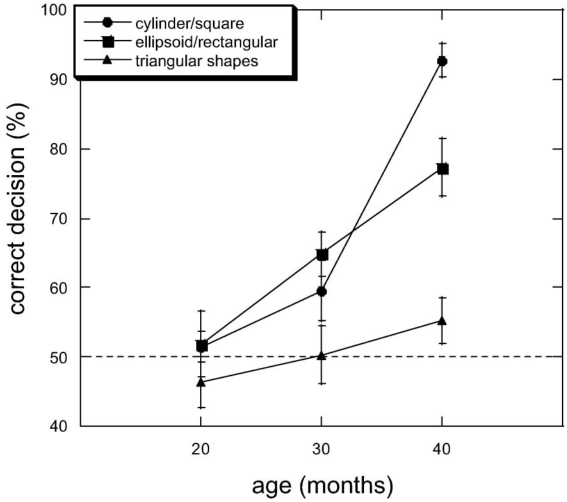

Figure 2. Percent correct choices for the three different form problems as a function of age.

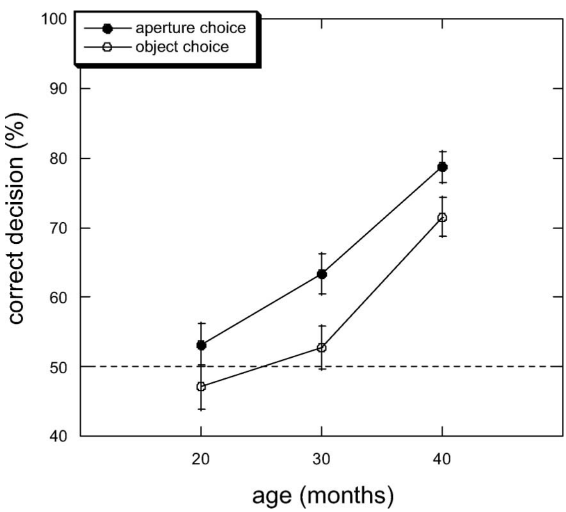

Figure 3. Percent correct choice in the object choice and aperture choice situations as a function of age.

81% of the attempts, and the 40-month-olds in 93% of the attempts. The success depended on object form. When choosing correctly the isosceles triangular form, the 20-month-old children succeeded in inserting it, on the average, in 12% of the cases, the 30-month-olds in 57% of the cases, and the 40-month-olds in only 91% of the cases. In comparison, the 20-month-olds successfully inserted the cylinder in 89% of the cases, the 30-month-olds in 97%, and the 40-month-olds, in 99% of the cases (see Figure 4).

A main effect of Object Form on successful insertion was obtained, $F(5, 535) = 48.15$; $p < .001$, $\eta^2 = .31$ (see Figure 4). The results demonstrate that the children were most successful in inserting the cylinder, and least successful in inserting the right-angled triangle. The order of the insertion success was cylinder, square, ellipsoid, rectangle, isosceles, and right-angled triangle. A main effect of Age was obtained, $F(2, 107) = 89.03$, $p < .001$, $\eta^2 = .63$. Pairwise comparisons showed that the 40-month-olds did significantly better than the 30-month-olds, who did significantly better than the 20-month-olds in inserting the object. There was a significant interaction between FP and Age, $F(10, 535) = 11.26$, $p > .001$, $\eta^2 = .17$. This is illustrated in Figure 4.

Duration measures

The duration of the approach, from grasping the object to reaching the box, was not systematically affected either by FP, CP, Age, or by any interactions between those variables ($p > .05$). The time it took to successfully insert an object after a correct choice had been made showed a main effect of FP, $F(5, 245) = 24.96$, $p < .001$, $\eta^2 = .34$. The cylinder was

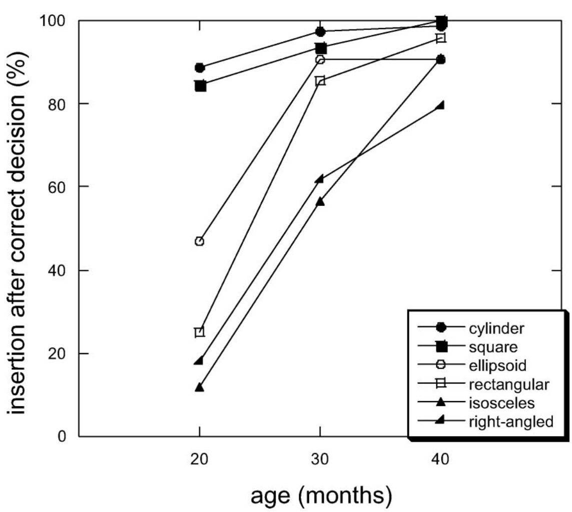

Figure 4. Percent successful insertions for the six forms as a function of age.

inserted most rapidly ($M = 0.9$ s), followed by the square ($M = 2.7$ s), the ellipsoid ($M = 2.6$ s), the rectangular ($M = 3.4$ s), the isosceles triangle ($M = 4.7$ s), and finally the right-angled triangle ($M = 6.6$ s). There was a significant effect of Age, $F(2, 49) = 28.912$; $p < .001$, $\eta^2 = .541$, that is, it took a longer time for the 20-month-olds to insert the objects than for the older children. The 30- and 40-month-olds used similar durations for getting the object through the aperture for all forms except the triangular ones where the duration was longer.

The persistence, that is the time the children continued to try with an incorrectly chosen object, is shown in Figure 5. The 30- and 40-month-olds spent more time trying to insert the triangular blocks than the 20-month-olds, and less time trying to insert the cylinder–square and rectangular–elliptic blocks. When the 30- and 40-month-olds failed to insert the easier blocks, they rapidly switched to the other block or tried with the other aperture. Overall, there was no significant effect of Age. However, there was a main effect of FP, $F(2, 104) = 25.543$; $p = .000$, $\eta^2 = .329$, and a significant interaction between FP $\times$ Age, $F(4, 104) = 18.903$; $p = .000$, $\eta^2 = .421$. Figure 5 shows that while the time differences between persistence for the different form pairs was small for 20-month-olds they were quite substantial for the 40-month-olds. Although the 40-month-olds rapidly perceived what was wrong with their cylinder–square and rectangle–ellipse choices, they persisted with their triangular choices.

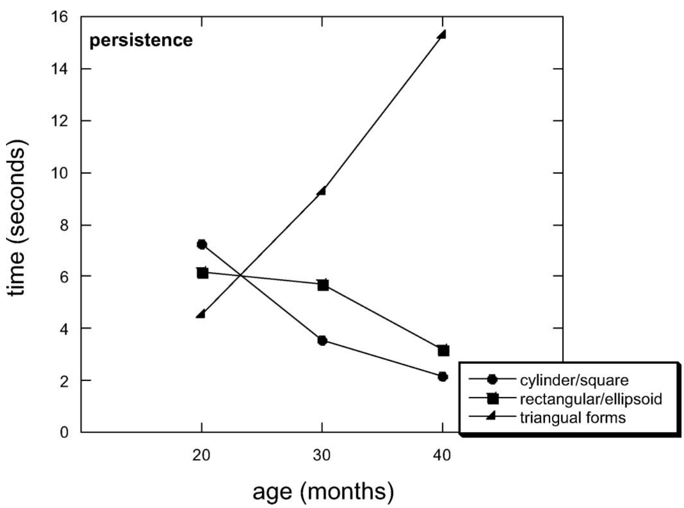

Figure 5. The time used to insert the different objects after a correct choice was made.

Sex differences

No difference with respect to sex was found either for correctness of choice ($p > .05$), either for the Sex, Age × Sex, FP × Sex, or FP × Age × Sex ($p > .05$). However, when analysing the time it took to insert each of the six forms, there was a main effect on Sex, $F(1, 49) = 22.105$; $p = .000$, $\eta^2 = .311$. Boys were significantly faster ($M = 2.8$ s) in solving this problem than girls ($M = 4.2$ s). There was also a significant interaction between Age × Sex, $F(2, 49) = 17.424$; $p = .000$, $\eta^2 = .416$. The time difference was largest for the 20-month-olds.

DISCUSSION

The difficulty introduced by the choice

It is quite clear that making the children choose the appropriate action from two alternatives made the task much more difficult than just trying to insert one object into one aperture. The 20-month-olds did not select the correct object/aperture better than chance, not even for the choice between the cylinder and the square block. In contrast, as soon as the choice was made, they inserted the cylinder successfully in 89% of the cases and the rod with the square cross-section in 85%. This performance is comparable to the success rate in the one-object – one-aperture case when objects and apertures identical to those in the present study were used (Örnkloo & von Hofsten, 2007). Thus, it is obvious that at this age, even in the cases when the children mastered the insertion of the objects, they were unable choose the correct one when presented with pairs of them. Considering the rather large difference in age between the solutions of the different choice problems, it cannot be said that children solve spatial problems involving a choice at a certain age. On the contrary, it depends on the choice to be made. It is obvious that the choice between certain features are handled at an earlier age than others, maybe because the spatial difference is more distinct between a circle and a square or because certain forms cross category boundaries while others do not.

As expected, the pair of apertures was significantly easier to choose between than the pair of objects. It is somewhat surprising that the obtained difference between these conditions is not greater. When choosing between the pair of objects, the children had to be clear about the appropriate relationship with the aperture already when grasping the chosen object. When the choice was between apertures, the decision of where to go could be made during the approach itself at a closer distance. This possibility was rarely exercised, however. When the object was picked up in this condition, it was transported to one of the apertures as rapidly as the chosen object in the two-object condition.

Attention

The greater demands on planning the actions ahead of time in the present study compared to a one-object – one-aperture problem cannot explain why the 20- and 30-month-olds did so poorly. Rather, the difficulty seems to be associated with the choice itself. When making a choice, the child has to keep both alternatives in mind and compare them with respect to the goal. Earlier research, on children's comparisons of complex pictures to determine whether they were identical or not, indicated that young children do not evaluate different action alternatives in an exhaustive way. On the contrary, they act rashly and base their choices on incomplete information (Vurpillot, 1968). In the present study, this is, for instance, reflected in the fact that the 20-month-olds could not even make a correct choice between the rods with cylindrical and square cross-sections, but after having made a correct choice, they were able to fit them into the aperture as well as in the one-object – one-aperture task.

Inhibitory control

Another aspect of choosing one item over another is the question of inhibitory control (Rennie et al., 2004). In the present study, when the child had to choose between two objects or between two apertures, it seems that the incorrect one could be chosen even when the child should knew the correct answer. The difficulty in inhibiting a prepotent response is clearly expressed by the A-not-B error (Piaget, 1954). Several studies have found that young children have difficulties in inhibiting an earlier successful response in this situation (Brainerd & Reyna, 1993; Durston, Thomas, Yang, Ulug, Zimmerman, & Casey, 2002; Munakata, 1998). It has even been reported that infants in this situation may look at the correct hiding place but reach for the incorrect one (Mareschal, 2000). Children have been found to show interference in the A-not-B task as late as at 12 years of age. (Bunge, Dudukovic, Thomason, Vaidya, & Gabrieli, 2002; Carver, Livesey, & Charles, 2001). During the early years of life, children become gradually proficient at exercising self-control and applying more mature rules (Diamond & Taylor, 1996). By 24 months, infants may become self-controlling in some situations even in the absence of external monitors. None of the children studied were totally self-regulating in the context of the present choice problem. Even when the children knew the correct answer, their ability to choose the correct object was still poor.

The difficulties in making choices in the present study can be compared to the studies by Keen and colleagues (Keen, 2003, 2005; Kloos & Keen, 2005; Kloos, Haddad, & Keen, 2006; Shutts, Keen, & Spelke, 2006). In these studies, a ball rolling down a ramp could be blocked at different points by a barrier. In front of the ramp there was a screen, opaque in some experiments, and transparent in others. There were doors in the screen at each possible barrier position. The barrier that was visible on top of the screen indicated which door was the correct one. The results showed that 2-year-old children had trouble identifying the ball's final resting place. Children's success depended only on the direct cues of actively tracking the ball. They failed to use the barrier cue, probably because it required a choice to be made from indirect information.

Choice and spatial cognition

The children's ability to make correct choices was not totally independent of their spatial insights. The circle–square distinction yielded much better choice performance than the triangular distinction. The 40-month-olds chose the correct circle–square alternative in over 90% of the cases while they still chose the triangular alternatives at random. The choice task required the subject to simultaneously compare each of the three involved forms (objects and apertures), which required them to represent the forms while switching attention between them. The distinction between the circular, square, elliptical, and rectangular forms could also be facilitated by their category membership, while the two triangular forms did not cross category borders. The results indicate that although the 40-month-old children understood what to do with the triangular blocks when they had made their choice, they couldn't use the distinction between them when making the choice. The inability to discriminate between the two triangular shapes may not just be confined to young children. Occasional adult visitors to the lab have made the same mistake.

Considering the rather large difference in age between the solutions of the different choice problems, it cannot be said that children solve spatial problems involving a choice at a certain age. On the contrary, it depends on the choice to be made. It is obvious that the choice between certain features are handled at an earlier age than others, maybe because the spatial difference is more distinct as between a circle and a square or because certain forms cross category boundaries while others do not.

Motor control

In the present study, the dexterity of the children was not a determining factor in solving the aperture problem. Children of all the ages studied could grasp, transport, and turn the objects without difficulties. The differences between the success rates in inserting a correctly chosen object and the proportion of successful choices were striking. At 40 months of age the children chose the two triangular shapes randomly but when a correct choice had been made, the two triangles were inserted successfully in 85% (isosceles in 91%, right-angle in 79%) of the cases. The age of the child did not influence the transport time to the aperture box but it influenced the time it took to insert the correct block once it had been placed upon the aperture. The younger children spent significantly more time on the positional adjustments than the older ones before the block slipped in.

Motivation

The results were not determined by changes in motivation with age. One of the most striking results of the present study was the children's consistently high motivation for solving the problems. The children in all the age groups completed over 95% of the trials. The determination of the 20-month-olds who only succeeded in 24% is quite impressive, especially when compared with the 40-month-olds, who succeeded in as much as 71%.

The inherent attractiveness of the fitting task makes it an interesting candidate for testing executive functioning in very young children. Most of these tasks require an understanding of verbal instructions but the present task does not. This makes it possible to use the fitting task as an early indicator of degree of executive control.

Time measures

The time spent by 20-month-old children in trying to insert the correctly chosen object was not clearly related to the difficulty of the problem as measured by the success rate. The exception was the cylinder for which the children produced exceptionally successful and rapid solutions. The 30- and 40-month-old children, however, used much longer time to insert the more difficult triangular forms than the simpler ones with circular, elliptical, square, and rectangular cross sections. It is as if they could not quite make the distinction between the two triangular forms as discussed above. On the other hand, because the two triangular forms were similar, the horizontal adjustments needed to insert them were also similar. This might explain why the 40-month-olds inserted them in 85% of the cases after a correct choice had been made.

When choosing an incorrect block, or moving a block to the wrong aperture, however, the amount of time spent in trying to insert it varied between ages and forms. While the 30- and 40-month-olds persisted longer with the triangular blocks, the 20-month-olds rapidly gave up and tried the other alternative. This is another indication that the triangular forms differed in a way that was not obvious to the children.

Sex differences

Adult males have earlier been reported to have an advantage over females on tasks requiring mental rotation (Voyer, 1995). This advantage is, however, much less distinct in children, if present at all (Roberts & Bell, 2002; Voyer, 1995). As proposed by Hyde (2005) and Spelke (2005), adult men and women have equivalent cognitive abilities, but slightly different approaches to cognitive problems that can be solved with multiple strategies. Men and women are apt to choose different solutions, but when they are encouraged to choose one source of information the gender gap of reasoning is narrowed and they tend to perform equally well (Spelke, 2005). In the present study the boys and girls were equally successful at all the ages studied but the boys inserted the block more rapidly than the girls once the choice had been made. These results are in line with recent findings that girls and boys do not differ in their abilities to learn about objects, numbers, and space (Spelke, 2005) but as proposed by Hyde (2005), genders may use slightly different strategies in solving problems.

CONCLUSIONS

Adding a choice to the spatial task of fitting objects into holes makes the problem much more difficult. Instead of solving it at 2 years of age, infants do not even perform perfectly at 3 years. The increased demands on preparing the action ahead of time in the object-choice condition only explained a minor part of the difficulty. It is suggested that the major reason why the choice problem poses difficulties to the child is that it relies on the development of executive functions, like working memory and inhibitory control. The present highly motivating task reflected the emergence of these cognitive functions remarkably well. In particular the fact that the present task was not based on verbal instructions makes it an important instrument for future studies of the emerging executive functions in young children.

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