A COMPARATIVE STUDY OF THE UNDERSTANDING OF INVISIBLE OBJECT DISPLACEMENTS IN MACAQUE MONKEYS (MACACA MULATTA AND ARCTOIDES) AND CHILDREN (HOMO SAPIENS)

Victoria H. Southgate

A Thesis Submitted for the Degree of PhD
at the
University of St Andrews

2005

A COMPARATIVE STUDY OF THE UNDERSTANDING OF INVISIBLE OBJECT DISPLACEMENTS IN MACAQUE MONKEYS (*MACACA MULATTA* AND *ARCTOIDES*) AND CHILDREN (*HOMO SAPIENS*)

by

Victoria H. Southgate

A thesis submitted in conformity with the requirements
for the degree of Doctor of Philosophy
School of Psychology
University of St Andrews

October 2004

I, Victoria Southgate, hereby certify that this thesis, which is approximately 60,000 words in length, has been written by me, that it is the record of work carried out by me and that it has not been submitted in any previous application for a higher degree.

Date ..2-6-05.... Signature of candidate ... .

I was admitted to the University of St Andrews as a candidate for the degree of Doctor of Philosophy in 2000. The higher study for which this is a record was conducted between 2000 and 2004.

Date ..2-6-05.... Signature of candidate ... .

I hereby certify that the candidate has fulfilled the conditions of the Resolution and Regulations appropriate for the degree of Doctor of Philosophy in the University of St Andrews and that the candidate is qualified to submit this thesis in application for that degree.

Date ...15-6-05.... Signature of supervisor ....

In submitting this thesis to the University of St Andrews I understand that I am giving permission for it to be made available for use in accordance with the regulations of the University Library for the time being in force, subject to any copyright vested in the work not being affected thereby. I also understand that the title and the abstract will be published, and that a copy of the work may be made and supplied to any *bona fide* library or research worker.

Date ..2-6-05..... Signature of candidate ....

To my father, for sparking my interest in psychology.

ACKNOWLEDGEMENTS

First and foremost I want to thank my supervisor, Juan Carlos Gomez. His approach to supervision has allowed me to develop my own thoughts and to pursue my own direction, yet this thesis would not have been possible without his guidance, enthusiasm, knowledge and support. In the end, despite my best attempts, I think I agree with you about Piaget.

Secondly, I must thank Kerstin Meints for allowing me to work in her Babylab and for her encouragement, guidance and friendship since my interest in this field of research began. I would also like to thank Dick Byrne for his comments on various papers, talks and general insightful discussions about my work.

I would like to thank everyone who has helped me with the daily rigmaroles of data collection. The technicians in the Animal House (Wendy, Steve, Rhona & Mike) went far beyond the call of duty in helping me out with monkeys and I have Brian, Leslie, Jackie & Ken to thank for a huge amount of technical support, as well as Andy Burnley for building my apparatus. I would also like to thank Keith and the technicians at the MRC unit in Edinburgh for allowing me access to the monkeys there and accommodating me while I was there.

Of course, this thesis would not have been possible without my subjects: both of the human and animal kind. I would like to thank all the parents who kindly volunteered their children for the studies and the children for being so good and making my days of testing so fun.

On a more personal note, I want to thank all the people who have made my time in St Andrews so memorable. To Chris, for being there for me, believing in me and for showing me how not to do a PhD! To Lucy & Jenny for being the best friends I have and for putting up with me this last year. To Duncan & Hugo, for your friendship, and for making me laugh so much. To Alex, Rogerio, Vicky, Sophia & Tony, for your friendship and for sharing PhD life with me! I feel extremely grateful for the wonderful friends I have made here in St Andrews, and because of you all, I will miss St Andrews very much.

Finally, I would like to thank my family who have always supported whatever I wanted to do, in every way, and to assure them that I do now have a real job.

ABSTRACT

The ability to infer the invisible displacement of objects has long been thought to elude most species with the exception of humans and great apes. However, in recent years, a number of researchers have proposed that this elusive capacity, rather than reflecting profound differences in the conceptual abilities of monkeys and other nonprimates, may instead reflect differences in processing capacities (such as inhibition and working memory). This thesis investigated knowledge of occluded object movements involving gravity, in rhesus and stumptail macaques (*Macaca mulatta* and *arctoides*), and two- and three-year-old children (*Homo sapiens*). In the first part of the thesis, using manual search tasks, a behavioural analysis revealed a number of biases that influence search on invisible displacement tasks, but also showed that contrary to the contentions of some authors, these biases do not mask the existence of correct representations. One study did reveal how seemingly mundane differences between tasks might lead to markedly different patterns of search and emergence of biases. In the second part of the thesis, in the first direct test of the prediction-postdiction hypothesis, an analysis of anticipatory eye gaze suggested that an inability to predict the location of an object does not account for the looking-searching dissociation that has become so prevalent in both the developmental and comparative literature. In attempting to bring together the findings from all the chapters, a framework is suggested in which representations are viewed as differing in strength such that the strength of a representation may determine whether or not a pre-existing bias surfaces in behaviour.

CONTENTS

OVERVIEW OF THESIS

> "It was the White Rabbit, trotting slowly back again, and looking anxiously about as it went, as if it had lost something; and she heard it muttering to itself 'The Duchess! The Duchess! Oh my dear paws! Oh my fur and whiskers! She'll get me executed, as sure as ferrets are ferrets! Where **CAN** I have dropped them, I wonder?'"
>
> (*Chapter IV, Alice in Wonderland, Lewis Carroll*)

Alice in Wonderland is a story about a little girl who magically shrinks, goes down a rabbit-hole and enters a mysterious world of talking animals. Of course, it is fantasy children's fiction and we know that animals don't really talk, have tea parties or play croquet. However, while we can be fairly sure that animals do not engage in any of these cultural, probably uniquely human activities, whether or not the white rabbit can really ponder where he lost the fan and the white kid gloves is not so clear. For example, does he know that the things he has lost can only be somewhere he has been? Can he retrace his steps to find them? While rabbits are phylogenetically quite distant from humans in the evolutionary chain, there is considerable debate concerning to what extent even animals much more closely related to us are capable of finding hidden objects and thinking about where they could be.

This thesis investigates what three species, the rhesus and stumptail macaque and the human child, know about objects they can no longer see. Many years of research have, to date, provided conflicting reports on the extent to which monkeys are able to reason about objects that have disappeared from their sight. In numerous studies, monkeys are reported to resort to using strategies in their attempts to find objects, and in doing so, expose their apparent lack of appreciation that, for example, an object *can* only be found somewhere that its bearer has been.

But, do such behaviours really reflect a lack of appreciation for such a basic physical principle? A recent debate within the field of developmental psychology has suggested that a child's behaviour might be a misleading guide to what they really know, and this debate has fuelled a similar debate among comparative psychologists. Many claim that behaviour may *imply* a lack of understanding of physical principles without this really being the case.

The experiments to be presented in this thesis are motivated by this debate. In the chapter that follows (Chapter 1), I will explore what we know about object understanding in young children and animals (mainly non-human primates) and introduce the debate over what behaviour really reflects. In Chapter 2, I review the various studies that have been carried out with non-human animals to investigate their abilities to find hidden objects in invisible displacement tasks, and examine various interpretations that may account for performance. Chapter 3 takes a broader look at physical cognition in human children and non-human primates, focusing on what these subjects know about the physical world and how it constrains the behaviour of objects. Chapter 4 describes the general methodology employed in the empirical chapters and provides information about the subjects who took part in the experiments that follow. Chapters 5 – 9 report the results of a number of invisible displacement studies that were designed to investigate which elements of a task contribute to errors in both human children and non-human primates. Chapter 10 provides an introduction to the looking method, that has been so instrumental in fuelling the debate described above, and chapter 11 reports the results from a study that aimed to test one specific hypothesis that has stemmed from this debate. Finally, in Chapter 12, I bring together the results from the empirical chapters and attempt to provide a framework for thinking about these results and propose some directions for future research.

1

UNDERSTANDING OBJECTS

1.1 OBJECT KNOWLEDGE

On a daily basis, as humans, we are confronted with a multitude of objects and in order to make sense of our environment we need to have developed a multitude of skills. At the most basic level, the ability to be able to recognize that two adjacently situated objects are still two distinct objects, allows us to see our world in terms of distinct entities rather than a jumbled mess. Similarly, we need to know that an object continues to exist even when we can no longer see it, and that when that object reappears, it is that same object that was hidden. In order to predict the behaviour of objects, we need to understand the fundamental properties that objects possess. Such an understanding of these properties is so fundamental and so seemingly indispensable to everyday functioning, that it difficult to imagine how any organism could exist without them. Referring to the notion of object permanence – the principle that objects continue to exist even when they are no longer directly perceptible – Flavell writes, "the concept itself is so utterly basic and fundamental. If any concept could be regarded as indispensable to a coherent and rational mental life, this one certainly would be. Imagine what your life would be like if you did not believe that objects continued to exist when they left your field of vision." (Flavell, 1977) (p. 42).

As difficult as this may be to imagine, this is exactly the kind of world that a young Piagetian infant is confronted with. According to Piaget, before the age of about seven months, young human infants do not understand objects as being independent or permanent entities (Piaget, 1955). If an object that they are playing with is hidden from view, for example if a cloth is placed over the object, a young infant will not attempt to search for the object. This inability is so striking that even if the infant was in the middle of executing a reach towards a visible object, if a cloth is then placed over the object, they will interrupt this reach and behave as if the object is no longer attainable (Gopnik, Meltzoff, & Kuhl, 2001). Although Piaget dealt with many aspects of object understanding, his work on the child's developing notion of object permanence is arguably his most influential contribution to developmental psychology.

1.2 OBJECT PERMANENCE

Although Piaget will be most celebrated for his investigations into object permanence, that young infants do not appear to have an adult-like conception of objects was noted many years earlier by philosopher William James when he wrote that:

"A baby's rattle drops out of his hand but the baby looks not for it. It has 'gone out' for him as a candle-flame goes out; and it comes back when you replace it in his hand, as the flame comes back when relit. The idea of its being a 'thing' whose permanent existence by itself he might interpolate between its successive apparitions, has evidently not occurred to him." (James, 1890)

However, in carrying out numerous experiments with his own children, Piaget identified other errors that he claimed were indicative of young children's incomplete understanding of object properties. Even once an infant becomes able to search for a hidden object, thus demonstrating basic object permanence, if this object is then visibly hidden in another location, the infant will very often search for the object in the location where it was previously hidden. According to Piaget, this error, which has become known as the A-not-B error, demonstrates that although the child may have attained a rudimentary notion of object permanence, this understanding is by no means complete. The error of searching for an object in the place where it was previously found reflects the young infant's misconception that they can recreate the desired object wherever they want, simply through the process of engaging in search (Piaget, 1955).

It was Piaget's contention that a complete understanding of objects and their properties comes about through the child's experience with their environment and with objects in their physical world. As children manipulate objects in their actions, they abstract information from these interactions, and it is this assimilation and accommodation of information that eventually leads to a complete understanding of objects. Piaget's position, that intelligence emerges through interactions with the physical environment, led others to begin to ask the same questions regarding non-human species. After all, humans are not the only species who are confronted with a multitude of objects on a daily basis. The finding that young humans appear not to come into the world with knowledge about these basic and fundamental properties of objects led those in the comparative field to question the extent to which object understanding in non-human species might differ from our own, adult understanding. If such a fundamental capacity is not innate, then how can we be sure that animals see the physical world in a similar way?

However, research has now accumulated from many different species indicating that the capacity for object permanence appears to be widespread in the animal kingdom. What is more interesting though, is that animals appear to acquire a concept of object permanence in much the same way as humans, suggesting that in animals too, it is learnt through a process of interacting with the environment. For example, testing Piaget's object permanence tasks with great apes has revealed that they pass through the same stages as human children, making the same errors (e.g. the A-not-B error) *en route* to showing a full understanding of objects, the only difference being that they reach each stage at a slightly earlier age than human children (Redshaw, 1978). Similarly, research with different species of monkey and other animals (mainly cats and dogs) have shown that they too pass through the same stages, but at a decidedly quicker pace than human children and great apes (Wise, Wise, & Zimmerman, 1974; Diamond, 1990; Dore & Goulet, 1998). For example, whereas human children do not show the ability to retrieve a hidden object until eight months of age, infant monkeys can do this by about one month of age and cats can do this after about two weeks (Gomez, 2004).

Although there is certainly much debate over whether non-human species achieve a full understanding of objects, or a rather more partial understanding, if we are to believe Piaget's contentions, infants, be they of the human or animal kind, do not come into the world with pre-existing knowledge about objects and their behaviours. Rather this knowledge needs to be constructed through experience.

1.3 THE CURRENT DEBATE

However, Piaget's interpretations of his results have not gone unchallenged. In the past thirty years, with the birth of new methodologies, researchers have claimed to have found a much earlier understanding of objects and their properties than Piaget claimed. Most problematic for Piaget's constructivist theory, when tested in alternative ways, young infants appear to show an appreciation for object properties at an age where they have had little opportunity to interact with objects themselves. These studies and the methods that they employ will be described more thoroughly in Chapter 10, so only a brief discussion is included here.

Piaget's theory of object permanence development was based primarily on tasks that required infants to manually retrieve hidden objects. However, it is not until infants are about four months of age that they will even reach for a visible object (Piaget, 1960), suggesting that even if they did have an earlier existing notion of the permanence of objects, they would not be able to demonstrate it. It was probably this quandary that motivated a new movement within developmental psychology, a movement away from a reliance on tasks that required manual responses to one that relied instead on an infant's visual response. These new tasks revealed what appeared to be a very precocious understanding of object properties. For example, in the earliest studies exploiting an infant's visual response, Bower and colleagues found that infants as young as two months were able to anticipate the reappearance of an object that had stopped behind a screen by "looking to that half of the movement path the object would have reached had it not stopped" (Bower, Broughton, & Moore, 1971 p. 183). In order to anticipate the re-emergence of the object, infants must appreciate that despite disappearing behind the screen, the object continues to exist.

In a number of now well-renowned studies employing a method known as habituation, Baillargeon and colleagues have claimed to demonstrate an understanding of object permanence in infants as young as two-and-a-half-months, well before they are able to reach out and manipulate objects for themselves (Baillargeon, Spelke, & Wasserman, 1985; Baillargeon, 1987, 2000). In these studies, infants look longer at events that violate object permanence and such findings have been taken to suggest that longer looking reflects a reaction of surprise. The infant is surprised because the event violates what they know to be true and so they look longer towards this event.

The findings of Baillargeon and her colleagues, along with those of other developmental researchers (e.g. Mehler & Bever, 1967; Bever, Mehler, & Epstein, 1968), signalled a new movement within developmental psychology which was to divide the field into those who, like Piaget, believed that young children were conceptually or representationally impoverished relative to human adults, and those like Baillargeon, who argued that the representations of young children were not profoundly different from those of human adults, but, for a number of reasons, young children are unable to demonstrate what may be quite a sophisticated understanding of the physical world.

1.4 WHAT DEVELOPS WITH AGE?

However, despite these demonstrations of precocious object knowledge, Piaget's observations have been replicated numerous times and appear to be very robust (Uzgiris & Hunt, 1975; Harris, 1985). So, if the behaviours that Piaget observed do not reflect an impoverished object concept and the advancement from one stage to the next does not reflect developing knowledge about objects, what *does* it reflect?

Opinions on what such Piagetian behaviours and errors reflect are wide and varied. A simple inability to reach for and uncover objects seems unlikely to be the whole story as by seven months – before infants begin to search for hidden objects – they can already uncover an object under a transparent cup (Bower, 1974) or behind a transparent screen (Munakata, McClelland, Johnson, & Siegler, 1997). As the motor demands on the child are the same irrespective of whether the object is hidden under or behind a transparent or opaque occluder, it would appear that there must be another explanation.

One possible explanation for some of the childhood errors observed by Piaget is that they reflect an immature or underdeveloped "executive functioning system". Executive function has been defined as "the ability to maintain an appropriate problem-solving set for attainment of a future goal" (Welsh & Pennington, 1988 p. 201) and is thought to encompass a number of abilities such as planning, set-shifting, inhibition and working memory (Griffith, Pennington, Wehner, & Rogers, 1999). One of the indications that young infants have an immature concept of objects, according to Piaget, is his observation that if one object is placed in contact with another object, infants will fail to reach for and retrieve the object, even though they could competently retrieve the object if it was placed alone. According to Piaget, this reflects the infant's lack of understanding that, even though the object now shares a boundary with another object, it is still the same independent object that it was before it was placed in contact with the other object. In their investigations into why children are unable to retrieve an object when it is contiguous with another object, Diamond & Gilbert (1989) used a transparent box with a desired object inside. Seven-month-olds had no problem retrieving an object when it was in the middle of the Plexiglas box such that it did not share a boundary with any of the box walls. However, as soon as the object became contiguous with the box (e.g. when it was placed inside the box against the front wall), infants of this age were unable to retrieve it. Diamond & Gilbert noticed that when children were unsuccessful at retrieving the object, they tended to end up grasping the edge of the box instead of the object. On the basis of these observations, the authors contended that it was not that infants had difficulty representing the object as a separate entity, as Piaget had argued, but that infants this young were simply incapable of making an accurate reach for the object. When there is another object nearby, if they touch this object first (which they often do), their grasp reflex leads them to grab hold of that object instead (e.g. the edge of the box). So, although it appears that the infant is not appreciating that the desired object is a separate entity that they can still obtain, this inability to retrieve the object rather reflects imprecise motor control and an inability to inhibit a reflexive grasp[1].

1.5 Inhibition and Cognition

According to Diamond (1991), "Cognitive development can be conceived of, not only as the progressive *acquisition* of knowledge, but also as the enhanced *inhibition* of reactions that get in the way of demonstrating knowledge that is already present" (p. 67). When the child attempts to reach for the object that is contiguous with another object, the child cannot inhibit a reflex that causes her to grab hold of the first object her hand comes into contact with. Because of this, it appears as if the child is unable to appreciate the object's individuality when in actual fact they may simply have an inability to inhibit a reflex that in other situations is extremely useful.

Inhibition is the capacity to suppress behaviours that are inappropriate to the situation and although probably not evolved for this purpose, an increased capacity for inhibition has the added advantage of allowing for greater attentional abilities and better concentration (Bjorklund & Kipp Harnishfeger, 1995). The greater an individual's ability to inhibit unwanted behaviours, the more flexible their behaviour can be. For example, although the grasp reflex is probably vestigial in human infants, it is essential for the young monkey who needs to ride on its mothers back. However,

[1] However, the grasp reflex disappears in human infants at around four months of age, and so Diamond & Gilbert's conclusions should be treated with caution.

while useful to the neonate, this reflex is useless to the older monkey and would probably be quite a hindrance if it could not be suppressed.

As noted above, the grasp reflex disappears in human infants at around 4 months of age and its disappearance is associated with frontal lobe maturity, such that persistence of the grasp reflex is taken to indicate the presence of a frontal lobe lesion in human children (Schott & Rossor, 2003). The neocortex, specifically the dorsolateral prefrontal cortex, is thought to be critically involved in the ability to inhibit unwanted or inappropriate behaviours (Fuster, 1980; Goldman-Rakic, 1987), the majority of evidence for which comes from studies of monkeys and brain-damaged human adults (Milner, 1963; Diamond & Goldman-Rakic, 1989). Following lesions to this area of the brain, rhesus monkeys perform badly on a delayed response task (a task similar to the A-not-B task) in which, after the monkey has retrieved an object from one hiding location, it is hidden at another hiding location, and after a short interval the monkey is allowed to search for the object. Typically, monkeys with frontal lesions search in the old location suggesting that the lesioned area of the brain is important in allowing the monkey to inhibit inappropriate or prepotent response tendencies. A prepotent response tendency can be either innate or conditioned (Diamond, 1991).

1.5.1 Innate prepotent responses

Innate tendencies are those that, during the course of evolution, have been adaptive in some way to that species (Hauser, 2000). The grasp reflex is an obvious example of an innate response tendency. Another example of failures to inhibit innate prepotent responses may be seen in the inability of young children and non-human primates to delay gratification. Boysen carried out a study in which she attempted to teach chimpanzees a rule whereby if they picked the smaller of two arrays of food, they would be rewarded with the larger array. If the chimpanzee picked the larger array, another chimpanzee would receive the larger array, and they would get the smaller one. Chimpanzees could not learn this rule, instead each time they would pick the larger array and end up themselves receiving the smaller array. These results were interpreted as suggesting that chimpanzees were unable to inhibit picking the larger amount of food and delaying gratification (Boysen, 1996). Young children appear to have a similar difficulty. In a task known as the 'windows task', children see two boxes with windows, and through the windows the child can see that one box is empty and one box contains a treat. In order to obtain the treat, the child has to infer a rule that indicating the empty box to an opponent will yield the treat for them. Three-year-olds are unable to infer this rule, pointing instead to the box that contains the reward, ensuring that their opponent receives the treat (Russell, Mauthner, Sharpe, & Tidswell, 1991). Similarly, in a study by Peskin (1992), three-year-old children were very poor at deceiving a competitor about which sticker they wanted to keep for themselves. Even though they were aware that the competitor would take for them self whichever sticker the child indicated as their favorite, they persistently pointed to the sticker that they wanted, rather than to the one they did not want.

1.5.2 Conditioned prepotent responses

A conditioned prepotent response, on the other hand, is a response that becomes dominant through experience and repeated elicitations. Diamond argues that the Piagetian A-not-B error that young children make or the error that monkeys make on the delayed response task is a conditioned prepotent response (Diamond, 1991). When the object is hidden at 'A' over a number of trials and having made a number of reaches to that location, reaching to 'A' becomes the prepotent response and when the object is switched to 'B', because of insufficient inhibitory capacities, infants are unable to stop themselves from making the prepotent response again – and reach erroneously to 'A'. Support for this claim, that the A-not-B error reflects a prepotent response, comes from findings by Marcovitch et al. (2002) showing that infants who receive more 'A' trials prior to a 'B' trials are more likely to make the A-not-B error than infants who have received less 'A' trials, suggesting that the more conditioned the response becomes, the stronger is the likelihood of failing to inhibit it.

1.6 INHIBITION AND EVOLUTION

We have seen from the literature reviewed so far that it is not only young children who appear to have difficulty inhibiting prepotent responses. Non-human primates also appear to have difficulties with tasks that require inhibition. Although all mammals have a prefrontal cortex, there are probably subtle yet crucial differences in the underlying connectivity that play a fundamental role in the animal's inhibitory capabilities (Hauser, 1999). Although it seems doubtful that there is any difference in the relative size of the frontal cortex (Semendeferi, Lu, Schenker, & Damasio, 2002), or the prefrontal cortex when allometrically scaled (Deacon, 1997) between humans and great apes and as such, it is unlikely that size alone can account for differences in inhibitory capacities between species, both humans and great apes do have relatively larger frontal cortices compared to those of the lesser apes and monkeys. Furthermore, the structure of the prefrontal cortex in primates is subtly different from those of other mammalian species because one of the six layers is granular in primates and agranular in nonprimates (Goldman-Rakic, 1987). Any of these differences in size, connectivity and structure could have major consequences for the functioning of the prefrontal cortex and lead to large differences in inhibitory capacities – the proposed central function of this brain region (Diamond, 1991).

Rumbaugh (1997) looked at the relationship between brain evolution and transfer of learning. Transfer learning involves having the subject learn to select a particular object in exchange for a reward and then, once the subject has learnt this rule, the object which produces the reward is switched such that the previously incorrect object is now the correct object that yields the reward. Animals with relatively smaller brains, monkeys and lesser apes, show negative transfer such that the more trials they had prior to transfer, the worse they do on transfer trials whereas those animals with relatively larger brains (specifically the four great ape species) show positive transfer such that the more trials they had prior to transfer, the better they do on transfer trials. This is thought to be because the great apes are able to learn something about the rule, such that the more they learn, the better they can do in the future (on transfer trials), whereas those animals with smaller brains are restricted to stimulus-response learning and only learn that a particular object is associated with the reward. The type of learning afforded by the larger and more complex brained animals allows for greater behavioural flexibility compared with smaller and less complex brained species.

Rumbaugh's findings suggest that there should be differences between species in how they perform on tasks requiring inhibitory capacities. Those species with more developed prefrontal cortices should do better on these tasks than those species with less developed prefrontal cortices. This prediction already has some support. In a task called the object retrieval task, a desired object is placed inside a transparent box that has an opening either on the top or at the side. Either way, in order to obtain the object, the subject has to make an indirect reach – reaching directly for the object will result in the subject hitting the box and not retrieving the object. Before about 7 months, human infants are unable to make a detour reach, instead reaching directly towards the object (Diamond, 1981). Diamond argues that performance on the object retrieval task is crucially dependent on an ability to inhibit a prepotent tendency to reach directly for a desired object (Diamond, 1981) and her contention is supported by evidence showing that adult rhesus monkeys who have lesions in the prefrontal cortex make the error of reaching directly for the reward, whereas adult rhesus monkeys with intact frontal cortices do not make this erroneous response. However, the smaller brained (with a smaller prefrontal cortex) cotton-top tamarin does not need to have a frontal lesion in order to make this error on the object retrieval task – adult cotton-top tamarins make the error anyway (Santos, Ericson, & Hauser, 1999). This finding suggests that the smaller brained cotton-top tamarin has inferior inhibitory skills to the larger brained rhesus macaque (Hauser, 1999).

1.7 EVIDENCE FOR EXISTING KNOWLEDGE

The claim that some organisms have difficulty inhibiting prepotent responses, be they innate or conditioned, is only a part of Diamond's argument. She also claims that prepotent responses mask knowledge that is already present, and if it were not for these prepotent responses, this knowledge would be able to be reflected in the solving of a task.

The idea that prepotent responses might mask existing knowledge comes from a number of sources. For example, one of the hallmarks of prefrontal damage in adults is their failure on the Wisconsin card sort test. In this test, subjects are required to sort cards, first according to one rule, and then according to another. While failure is marked by continuing to sort cards according to a now obsolete rule, these same patients can verbally report that they know they are doing the wrong thing (Milner, 1963). Similarly, Zelazo et al. (1996) reported similar findings for school-age children, who despite making the same mistake of sorting according to an old rule, are able to articulate what the new rule is whilst sorting according to the old one.

Furthermore, although nonverbal subjects like infants and animals cannot tell us that they really do have the correct knowledge, there may be telling signs in their behaviour. For example, Diamond reports that often, infants who err and erroneously reach to 'A' on the A-not-B task, do not even look in to 'A' to see if the toy is there but go straight to 'B', and even on occasion, infants can be seen reaching to 'A' but simultaneously looking towards 'B' (Diamond, 1991). These behavioural signs may suggest that infants have knowledge of where the toy is despite not being able to demonstrate this knowledge in their explicit responses.

Finally, as discussed previously, the most persuasive indication that young children really may have knowledge despite not being able to demonstrate it, comes from the mass of data collected via the looking task measure. As mentioned, a more thorough discussion of looking time studies will follow in Chapter 10, and so the discussion here will be limited to one study which seems to indicate an accurate appreciation of contiguity in infants younger than those whom Diamond reported were unable to reach for an object when it shared a boundary with another object (Diamond & Gilbert, 1989). Needham & Baillargeon (1998) demonstrated that 4.5-month-old infants who were given a five second exposure to a particular object, then looked longer at an event in which that object appeared to move together with another object as if they were joined together, than at an event in which the object they had been exposed to, moved separately. These results indicate that young infants do still appreciate the individuality of an object despite it subsequently being contiguous with another object.

1.8 DEVELOPMENT OF INHIBITORY CONTROL IN CHILDREN

Although performance on Piaget's A-not-B task has been the focus of much of the speculation regarding inhibition, other researchers studying other tasks on older children have echoed Diamond's contention that inhibition failures may mask existing conceptual knowledge. For example, Carlson et al. (1998) have argued that young children's failure to pass false-belief tasks may reflect an inability to suppress a conditioned prepotent response. Before about 4 years of age, children are unable to pass this task, and when asked where the experimenter will look for an object, children tend to point to the box where the object actually is, despite the fact that the child, but not the experimenter witnessed the object being moved from its original location to a new location. However, in a modified version of this task, rather than requiring the child to point, the child had to place a pictorial cue on the box that they think the experimenter will look in, children were able to pass the false-belief task at 3 years. Carlson et al. (1998) propose that "children may well possess these concepts but nevertheless have difficulty acting on them." (p.686) possibly because the act of pointing is a well-practiced, often-used response for young children that they usually make "faithfully to true locations and identities" and so it may be very difficult for children to make this same response in an alternative way (Carlson et al., 1998, p. 674).

Thus, although errors like the A-not-B error occur when infants are quite young, at about 8 months, problems with inhibition may also be seen in older children. In fact, problems inhibiting prepotent responses may occur throughout childhood and may even be present in normal adulthood under circumstances in which cognitive load is particularly high. Berger (in press) has argued that because cognitive capacity is finite, the more taxing a task is for a child, the more likely they are to make a perseverative response. In a locomotor version of the A-not-B task, Berger found that 13-month-old infants could inhibit a prepotent response of walking to the 'A' location on 'B' trials when the locomotor demands were quite low (walking on flat ground) but perseverated at 'A' on 'B' trials when the locomotor requirements were higher (such that the infant had to descend down a staircase). Berger interpreted this finding to indicate that infants perseverate when their attentional capacities are otherwise taken up so that their capacities are not then available to inhibit the prepotent response. As Berger suggests "as cognitive capacity improves, children need increasingly complex task demands to elicit perseverative behaviours" (p. 27).

Berger also proposes that the cognitive load explanation can account for why, on occasion, even human adults make responses inappropriate to the situation – for example, rather than going straight home after work, you may decide to visit a friend but because you are having an argument with someone in your car you may not be concentrating on your route and you may find yourself mistakenly driving the normal route home instead. The prepotent response of driving the normal route home, which through experience, has become conditioned, wins out because the attentional capacities that would normally be used to inhibit this response and implement an alternative response (driving to a friend's house) are being taken up by attending to the argument you are having.

* *

It seems then that problems inhibiting prepotent responses are not limited to infancy and may present themselves even in adulthood in situations where attentional resources are stretched. Furthermore, problems inhibiting prepotent responses may be especially prevalent in non-human species throughout their lives if their inhibitory capacities remain inferior to those of humans. The literature reviewed above raises the intriguing possibility that some task failures are not due to a deficit in conceptual understanding but rather may be due to limits in executive functioning. The number of instances of potential inhibitory failures described above furthermore suggests that such difficulties may manifest themselves in a wide variety of situations, and at many different ages. The following chapter will review the literature on a task that has generated a substantial amount of investigation not only in human children, but also in a multitude of non-human species: the invisible displacement task. Passing this task was thought to signal a new stage in representational reasoning in human children (Piaget, 1955) but as research continues to turn up new examples of errors due to inhibitory failures in other tasks, it is necessary to consider whether failure on invisible displacements might also be attributable to limitations in executive functioning.

2

UNDERSTANDING INVISIBLE DISPLACEMENTS

2.1 INVISIBLE DISPLACEMENT

As explanations for task failures in childhood have shifted from the conceptual to the executive, more and more questions have been raised about other tasks that are commonly thought to assess representational understanding in young children. Piaget's position, that the A-not-B task error reflects conceptual difficulties, has largely been discounted, and although there is wide disagreement on what the A-not-B error does reflect, it is generally accepted that it probably does not reflect an immature object concept (Thelen, Schoner, Scheier, & Smith, 2001). If the A-not-B error can be explained in other ways unrelated to whether or not the child has a mature or complete object concept, then it raises doubts about whether other errors which are thought to be characteristic of various stages of object concept development really do reflect profound developments on the road to complete object concept understanding, or whether they too can be explained in other, possibly non-conceptual, ways.

As noted in the previous chapter, the extent of object understanding in non-human species has received considerable interest, on the one hand because the revelation that young children can come into the world without a notion of object permanence raises intriguing questions regarding whether such a seemingly fundamental concept might also be lacking in other species, and on the other hand because Piaget's methodologies presented themselves as so easily transferable to other species (Pepperberg, 2002). These studies have revealed considerable similarity in the development of object knowledge among a wide range of species (Tomasello &

Call, 1997). However, despite this similarity, very few animal species have shown convincing evidence of being able to achieve what Piaget believed to be the crowning stage of object permanence: the ability to solve an invisible displacement problem (stage 6).

An invisible displacement problem is one in which an object is invisibly hidden from the subject, so that they do not see the final hiding place, and have to infer this in some way. A typical invisible displacement involves placing a desired object into a container and then moving that container behind a screen. Without the subject seeing, the experimenter then removes the object from the container and leaves it behind the screen. The container that had previously carried the object is then brought out from behind the screen and the subject sees that the container is now empty. The subject then has to infer that the object must be behind the screen, despite the fact that they never actually saw it being deposited there. One of the reasons why Piaget's tasks were seen as easily applicable to the study of animal cognition was because they appeared to mirror situations that animals might encounter in their natural habitats. For example, when a hunted prey animal disappears behind a rock, may be of huge adaptive advantage for the hunter to search for that animal behind the rock (Vauclair, 1996). If the animal is not behind the rock however, it would be useful for the hunter to then look behind other nearby rocks (Wynne, 2001). Likewise, deBlois et al. (1999) point out that male monkeys often track the movements of female monkeys in oestrus and may need to infer the monkeys movements if they temporarily get distracted and find that the female is no longer visible.

The immense interest in the ability of non-human species to be able to solve invisible displacements stems, in part, from what Piaget believed this ability reflects. Rather than simply reflecting a quantitative difference in processing capacity, Piaget argued that the transition from being able to solve visible displacements to solving invisible displacement problems represents a much larger transition in cognition from sensorimotor to symbolic representational thought (Piaget, 1955). In order to solve an invisible displacement task, not only do children need to be able to mentally represent the continued existence of a hidden object, they also need to possess the capacity for logical deduction; the ability to be able to deduce, based on the newly-acquired object principles, where the object physically *can* be (Piaget, 1954; Watson et al., 2001). Another way to think about invisible displacements is as a means of distinguishing between learning and reasoning. Solving an invisible displacement problem representationally involves the subject *inferring* or reasoning where the object is, based on incomplete information. To solve an invisible displacement, the subject has to infer the location of the object even though they did not see the object being hidden at that location. The debate about whether animals are capable of reasoning or are just proficient rule learners continues to divide many comparative researchers (Call, 2004). In addition, a further reason that may have provoked such interest in this crowning stage of object permanence capacities in non-human species is the contention by some authors that the representational skills required to reach this stage are critical to the subsequent onset of symbol use (i.e. language) in human infants (Piaget, 1955; Bates, 1976).

The various tasks used to assess object permanence with visible displacements, which most animals seem able to do, can all be solved through fairly primitive representations or simple learnt heuristics. For example, although the young child needs to appreciate that an object continues to exist even when they cannot see it, in order to solve a visible displacement, even one in which an object is hidden in several successive locations, they simply need to search for the object where they last saw it.

However, in an invisible displacement task, the child needs to mentally recreate the pathway that the object must have taken, even though they themselves never witnessed that pathway. Such a task may ostensibly something qualitatively different from the subject.

However, with the growing debate over whether or not other of Piaget's tasks (like the A-not-B task) really do reflect conceptual difficulties, there have been similar doubts concerning what various successes and failures on invisible displacement tasks can really tell us (Cummings & Bjork, 1981). It is possible that, rather than lacking the type of conceptual knowledge purported to be required to succeed on an invisible displacement task, it may be that those subjects that perform poorly simply lack the requisite executive capabilities. The following section will look at some arguments for why young children and monkeys might fail invisible displacement tasks for reasons other than not having the representational competence.

2.2 CONSIDERING REASONS FOR INVISIBLE DISPLACEMENT SUCCESSES AND FAILURES

It is indicative of what was the general consensus, that in Parker & Gibson's model of evolution, in which phylogeny is recapitulated in ontogeny, they label one of their stages in child development 'the Old-World monkey stage' (Parker & Gibson, 1979). At this stage, they see children as having incomplete object permanence because they are unable to solve an invisible displacement problem. Although there are some studies in which authors claim various species of monkey are able to solve an invisible displacement problem, others have argued that the monkeys in these studies may have solved the tasks without mentally representing the pathway the object took (Dore & Dumas, 1987). Of those studies that have adequately controlled for strategies that allow the task to be solved non-representationally, the only species, other than humans, that appear capable of succeeding are great apes and surprisingly, psittacine birds (Redshaw, 1978; Mathieu & Bergero, 1981; Natale, Antinucci, Spinozzi, & Poti, 1986; Pepperberg & Kozak, 1986; Pepperberg & Funk, 1990; De Blois, Novak, & Bond, 1998; Call, 2001).

However, the problem with interpreting the search behaviour of particular species as indicative of an inability to solve invisible displacement tasks representationally, is that there may be other reasons why animals fail these tasks, which does not preclude them from having representational abilities. The task then lies in determining what other factors might influence search behaviour. The remainder of this chapter will review the literature on invisible displacement performance in both children and non-human species, looking at whether task failures could be explained in ways other than by attributing representational or conceptual deficits.

2.2.1 Stimulus Enhancement

Spence (1937) coined the term 'stimulus enhancement' to refer to behaviour that results from increased attention towards something that another being has attended to. One problem with many invisible displacement studies, including those of Piaget, is that only the location(s) where the object could have been deposited are manipulated by the experimenter. Part of solving an invisible displacement task is the ability to infer that the object can only be in a location that has been touched by the experimenter and so only searching in these manipulated locations. However, one objection to claims that some species can pass invisible displacement problems is that these particular studies have not controlled for this possibility. Monkeys or other species (including human children) might pass the task by only looking in places that were manipulated by the experimenter, not because they understand that this is the only place where the object could be, but because these locations have a privileged status by virtue of being manipulated. Without controls that include trials in which the experimenter also manipulates a container but does not insert the displacer into the container, it is not possible to differentiate between these two possible ways of solving the task.

A related problem with some studies of invisible displacement is the problem of recency. In Piaget's invisible displacement task, the object tends to be left in the last location visited, and there are two simple ways of solving this problem. Firstly, subjects could learn the simple strategy of always searching in the last place visited. Secondly, the last location manipulated may be privileged because of recency effects: subjects choose this location because it is the location to which they have most recently attended. Several of the early studies of invisible displacement purporting to show success with animals have used one of these two methods. For example, Wise et al. (1974) claim that object concept development in the infant rhesus monkey (*Macaca mulatta*) follows a similar trajectory to that described by Piaget for human infants, culminating in stage six object permanence, and the solving of invisible displacements. However, since the object is always left under the last screen visited, the task can be solved using the rule 'search under last screen touched', without the need for mental representation. Without appropriate controls, it is impossible to know whether anything more sophisticated can be attributed to these animals than proficient rule learning capacities. In a recent investigation into stage 6 object permanence in cotton-top tamarins (*Saguinus Oedipus*), Neiworth et al. (2003) claim that these monkeys can solve a typical invisible displacement task. However, the same criticism might be made of this study as the Wise et al. (1974) study: namely that in all conditions except control trials, the object is hidden in the last location visited. When 'catch' trials are included so that the item is hidden in the first location visited rather than the second, performance did not differ from chance.

However, although stimulus enhancement has generally been thought of as unfairly helping the subject to pass the task, it is also possible that it has a hindering effect on performance. For example, in the Neiworth et al. (2003) study, the experimenter does attempt to control for recency effects by including trials in which the last cup manipulated is simply touched by the experimenter but the displacer is never inserted and so the object in the displacer could not be in the last cup touched. However, it is feasible that this act of touching and drawing attention to this location is sufficiently distracting to the subject, leading them to attend to this location and subsequently search there. As Goldman-Rakic (1987) has pointed out, the behaviour of subjects with insufficient prefrontal function may be "excessively controlled by external stimulation". The act of searching in this location may be unrelated to the subject's belief about where the food reward is, it may simply be the result of the subject being unable to inhibit searching at a location that has most recently received attention.

2.2.2 Memory requirements

It has been proposed that conflicting reports of successes and failures on invisible displacement tasks might be understood by looking at the differing memory requirements of the different invisible displacement procedures (De Blois, Novak, &

Bond, 1999). According to Dumas & Brunet (1994), invisible displacement tasks can be generally divided into two kinds: those that use a logical procedure and those that use a comprehensive procedure. In the logical procedure, the experimenter shows the subject whether or not the displacer still contains the target object or not, in between each displacement, whereas in the comprehensive procedure, it is only at the end of all the displacements that the subject is shown the empty displacer. The difference between these two types of tasks is important because it has serious implications for what one can infer from successful search behaviour. In the comprehensive procedure, akin to the procedure Piaget described, any one of the visited locations is a possible place where the object could be found, and so subjects must maintain each of the visited locations in memory. However, in the logical procedure, because the subject is shown whether or not the displacer still contains the object or not after each visit, there is only one possible location that the object could be hidden. As such, if, after the first visit, the displacer is withdrawn and shown to still contain the object, the subject can disregard any displacements prior to this. If, on the other hand, the displacer is withdrawn and shown to be empty, the subject can disregard any future displacements. In terms of memory load then, the comprehensive procedure is more taxing than the logical procedure.

De Blois et al (1999) asked whether differing memory requirements could account for the differences seen between performance on visible and invisible displacements. For example, orangutans (*pongo pygmaeus*) in their study may have failed some trials because they could not remember the second location visited by the experimenter. However, in a subsequent study, they tested monkeys and apes on a visible and an invisible displacement task that they claim entail equal memory demands on their subjects. As such, if memory requirements can account for problems on invisible displacement tasks, then subjects should perform equally on both. The task involved placing a reward in one box and moving this box next to another box, where the reward is transferred from the first to the second box. The only difference between the tasks is that on the invisible displacement version, the boxes are touching and the reward is transferred invisibly, whereas in the visible displacement tasks, a small gap is left between the two boxes so the subject sees the reward being transferred. There was also a third version whereby the box containing the reward was moved next to the second box but the reward was not transferred and remained in the first box. Results showed that performance was significantly lower on invisible displacements than on visible displacements or no displacement problems for both species, but that apes outperformed monkeys on invisible displacement problems.

However, it could be argued that these problems are not at all comparable in terms of the memory demands they place on the subject. Regardless of the number of preceding steps, in the visible displacement task, the subject *sees* where the object is hidden. There is no need for them to remember the number of steps prior to the final hiding. De Blois et al. argue that if memory requirements really were an issue, then subjects should also perform equivalently on the invisible displacements and the no-displacement problems because subjects "could not determine the location of the object before all the manipulations were completed". However, given that we know from several studies that monkeys or other animals are adept at using a strategy whereby they search in the location closest to where they last saw an object disappear (Goulet, Dore, & Rousseau, 1994; Santos, 2004), this kind of strategy may also serve them well on the no-displacement problem. If monkeys approached these three different problems (visible, invisible and no displacements) with this kind of strategy, the following predictions could be made. For the visible displacements, we might expect the subject to succeed because the correct location is also the location where they last see the object; for the invisible displacements, we might also predict that the subject should search first in the original baited box (where they last saw the reward disappear), except that in this design, the subject is shown that the baited box is empty before they begin searching, so this strategy would not work for invisible displacements. For the no-displacement problems, subjects would be expected to search in the box where they saw the object last, which again, would be the correct box, as no transfer took place.

Whilst the results from the animal studies are inconclusive regarding the role of differing memory demands, there is some fairly persuasive evidence that memory may indeed play an important role when young children are presented with invisible displacement tasks. One study suggesting that memory deficits may contribute to failure on the standard invisible displacement task, was carried out by Cummings & Bjork (1981). Instead of the standard two or three search locations, infants were presented with a choice of five search locations in a row, where an object was hidden either in the far right or far left container. Having invisibly deposited an object from a smaller container into a search well, the child was allowed to search. Cummings & Bjork found that twelve- to fourteen-month-old infants searched mostly at a location around the correct location, if they did not search at the correct location itself. They suggest that young infants may have difficulty maintaining an exact memory of the location and that by providing them with a number of options, experimenters may find that infants know 'roughly' where the object is. Furthermore, Bremner (1978) found that nine-month-old infants did better on a visible-displacement task when the two locations were distinctly coloured, possibly as this reduced confusion between the two locations at the time of search, another indication that memory plays an important role.

Arguably memory load is greater for most invisible displacement problems than for visible displacements by virtue of the fact that the object is out of sight for a longer time and must therefore be held in memory for a longer time. As a result, subjects who have limited working memory capacities may fail a task not because they have an inability to represent invisible changes in location or invisible object pathways but because they are simply unable to keep active a memory for long enough to solve the problem.

2.2.3 Inhibition

Call (2001) has pointed out that failure to solve the most difficult kinds of invisible displacements may not necessarily be due to a lack of mental representation or memory problems. Although great apes do well on certain invisible displacement problems, they too have problems when presented with double non-adjacent invisible displacements. In these tasks, the displacing container visits two non-adjacent boxes such that there is typically one box in between these two boxes that is never visited by the displacer. When subjects are allowed to search, both great apes and young children have difficulty bypassing the centre box, even though the displacer never visited this box. They had no difficulty solving double adjacent invisible displacements where the two boxes visited included the centre box (Call, 2001). From this, Call concluded that inhibition does indeed play a role in these failures because subjects could pass all other conditions. However, it is difficult to know whether apes and children search in the middle location because they find it difficult to inhibit this tendency despite possibly knowing that the object is not there, or whether they search in the middle location because by the time they have searched in the first location and not found the object, they have simply forgotten which other box the experimenter visited with the displacer.

Similarly, in a study by Natale et al. (1986) a Japanese macaque (*Macaca fuscata*) failed to solve a double non-adjacent invisible displacement and the authors concluded that this was because the macaque could not solve invisible displacement tasks in a representational way. However, it is possible that, like the Great Apes in Call's study, the macaque was unable to resist the lure of the next sequential container, but that this inability may not reflect the monkey's true belief about where the object is.

* * * * * * * * * * * * * * *

So, as is the case for Piaget's A-not-B task, it may be that monkeys and young children have problems with invisible displacements, not because they are unable to mentally represent the invisible change of location of the object but because they have limited memory and inhibition capacities. One factor that the Piagetian invisible displacements discussed above have in common is that they involve displacements that are unlikely to be seen in an animal's natural environment (Dumas, 1992) and although they may approximate problems animals encounter in the wild, they involve additional factors that animals are unlikely to ever witness. For example, to be successful, animals need to understand that an object can be carried by another object and that an inanimate object can be removed from the displacer without any obvious intervention (Wynne, 2001). As such, it could be argued that the conclusion that non-human species lack the capacity to solve invisible displacement tasks is simply a result of experimenters not designing ecologically relevant enough tasks.

In fact, the most recent claims for an understanding of invisible displacement have come from studies that have used tasks that may more closely approximate situations that animals are likely to encounter naturally. These studies, motivated by claims that both young children and animals may have knowledge that they are unable to demonstrate, have pointed to a number of instances where failure to solve invisible displacements *are* primarily due to an inability to inhibit prepotent responses (Hood, Hauser, Anderson, & Santos, 1999; Hauser, 2001, 2003), rather than to an inability to correctly conceptualise the task.

In the kind of tasks that such claims originate from, to be described in more detail in subsequent chapters, subjects encounter natural object trajectories, dictated by such physical forces as gravity and inertia. In addition, these sorts of invisible displacement tasks involve additional physical constraints that the subject must understand in order to solve the invisible displacement task. For purposes of illustration, two of these kinds of tasks are pictured in figure 2.1.

The studies of authors like Hood (1995) and Hauser (2001) have gone beyond simply claiming that failure on certain tasks might be due to a failure to inhibit prepotent responses, to explore and propose reasons for the origins of certain prepotent responses. Specifically, the authors of these studies have evoked naïve physics as the culprit in some prepotent responses that mask an otherwise existing ability to solve invisible displacements. Again, the argument goes that, because of under-developed inhibitory capacities, some subjects cannot suppress responses, conditioned or innate, in certain situations. These responses though, are based on 'theories' about how objects in the physical world behave. The following chapter will review this proposal in more depth.

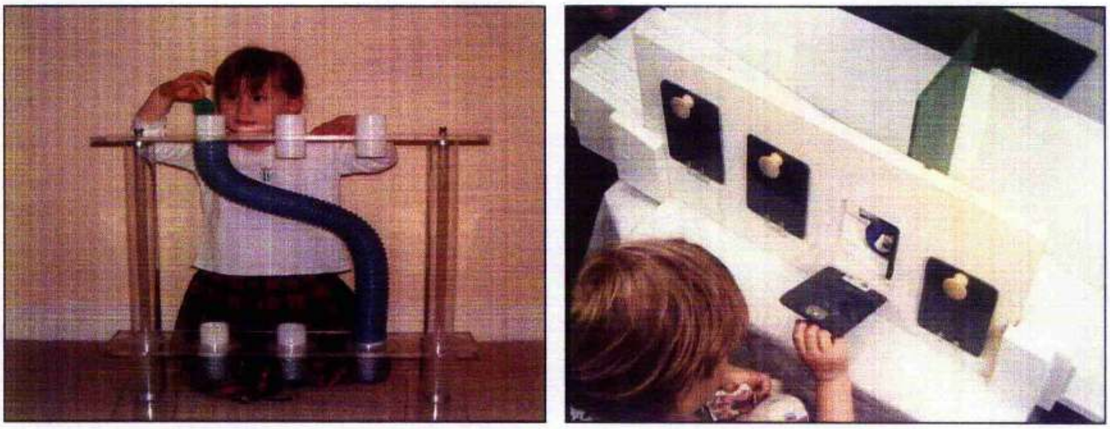


Figure 2.1 Invisible displacement task of Hood (1995) in which a ball is dropped down an opaque tube (left) and invisible displacement task of Berthier et al. (2000) in which a ball is rolled down a ramp behind an opaque panel where the ball's ongoing trajectory is prevented by a solid wall (right). Photos reproduced from authors' websites.

However, in claiming that certain invisible displacement failures are due to an over-reliance on naïve physical theories, these authors are proposing that subjects have the requisite physical knowledge that would be required to solve the task were it not for the interference of the prepotent response. For example, on one of these tasks (pictured on the left in figure 2.1), to be discussed in more detail in Chapter 5, subjects need to have an appreciation of how the solid nature of a tube acts to constrain the pathway of an object inside it (Hood, 1995). In another task, to be discussed more in Chapter 6, subjects need to appreciate that a solid wall stops the ongoing linear movement of an object (Hauser, 2001). Evidence that young children and monkeys do show an appreciation for such physical constraints would be essential for any explanation of invisible displacement failures which attributes failure to an inability to inhibit a prepotent response, rather than to conceptual limitations. It would be difficult to propose that these subjects fail tasks because of inhibitory weaknesses if it were not possible to demonstrate that, in the absence of the prepotent response, these subjects could demonstrate an accurate appreciation for such physical constraints.

The following chapter will look at the kind of knowledge young children and animals have about the physical world, before addressing some of the claims put forward in accounts that implicate such theories in failures to solve invisible displacements.

3

NAÏVE PHYSICS IN HUMAN AND NONHUMAN PRIMATES

3.1 NAÏVE PHYSICS

The term naïve physics refers to the untrained perception of basic physical phenomena (Smith & Casati, 1994), knowledge that is acquired informally rather than explicitly taught. First coined by Köhler, the term naïve physics refers to the "physics of ordinary men" and although one can acquire physical knowledge through explicit scientific teaching, it is "the non-scientific form (that) constantly determines our whole behaviour" (Köhler, 1925 p. 129). Naïve physics or folk physics is the kind of common-sense view of the world that young children possess (Povinelli, 2000) and that probably permeates our view of the physical world long beyond childhood (Shanon, 1976). This kind of knowledge aids us in our everyday dealings with the world. If we do not balance something sufficiently, we know that it will probably fall and we don't need any explicit teaching about Newton's law to foresee this. Although if pushed, you might invoke an explanation about gravity, the concept of gravity is, to most of us untrained physicists, really just a label we have been taught to use to explain the reason why objects fall down if they are not supported, but we do not need such a label to be able to predict and use physical events in practice.

However, by virtue of being naïve, these beliefs are not always correct. For example, McCloskey et al. (1980) found that when adults were asked to predict the trajectory that a ball would take upon leaving a c-shaped tube, many erroneously predicted that it would continue to take a circular trajectory. In another study by McCloskey et al. (1983), they found that when adults were asked to predict the pathway that an object dropped from a moving plane would take, many adults said that the object would fall straight down. Children, it seems, also share such naïve physical theories. Kim & Spelke (1999) asked two- to six-year-old children to predict the landing point of a ball after it rolled off the end of a ramp. Children under five years erroneously predicted that the ball would take a straight-down trajectory upon leaving the ramp, whereas children of six years and above predicted that the ball would follow a parabolic trajectory.

3.2 ORIGINS OF NAÏVE PHYSICAL BELIEFS IN HUMANS

Spelke believes that there is a body of physical knowledge that the human infant is innately endowed with. This body of knowledge – termed 'core knowledge' because it is believed to be "central to common-sense reasoning throughout development" (Spelke, 1994) p.439. – consists of an appreciation of a number of constraints on object behaviour. These constraints have been identified as continuity and solidity (Spelke, Breinlinger, Macomber, & Jacobson, 1992) as well as cohesion and contact (Spelke, 1994). The first principle (continuity) means that infants know that objects only move on connected paths and that they do not jump from one place and time to another and the second principle (solidity) allows infants to reason that objects only move on unobstructed paths. Spelke's conviction that such principles are innate in humans, stems from a number of studies done by her and her colleagues using the looking time method. These studies appear to show that infants as young as three months pay more attention to events in which objects appear to violate these two principles than to events in which objects behave in accord with these principles. Increased attention towards events depicting 'impossible' outcomes is interpreted as surprise on the part of the infants – and the reason they display greater attention towards such events is because they are aware that these events are impossible and violate the principles they are innately endowed with. Further studies using variations of the looking-time method have shown that even infants as young as 2.5 months appear to recognize the impossibility of one solid object passing through another solid object (Spelke et al., 1992).

It is of course possible that these principles are not innate, since two-and-a-half-months may be a sufficient time frame for a principle to be learnt (Haith, 1998). However, as Spelke (1994) points out, it is difficult to imagine how a child could ever learn how other physical laws affect the behaviour of objects if they were not innately predisposed to reason that objects are continuous and that the object the infant saw over 'there' is the object they now see over 'here'. As Spelke argues "learning systems require perceptual systems that parse the world appropriately" (p. 439).

The principles of cohesion and contact state that "a moving object maintains its connectedness and boundaries" and that "objects affect one another's motion if and only if they touch" (Spelke, 1994; p. 435). For example, studies by Baillargeon and colleagues found that 2.5-month-old infants expected an object to be displaced when another object collided with it and appear to be surprised when an object begins to move without first having been hit by another object (Baillargeon, 1995). Similarly, studies by Leslie and colleagues show that infants appear surprised when an object does not immediately move upon being impacted by another object (Leslie & Keeble, 1987; Leslie, 1994).

However, although Spelke argues that these principles are innate, and that they form the core of adult physical reasoning, she argues that other physical principles are not innate, but rather learnt. Two principles, those of gravity and inertia, both appear to develop with time and as such, may be more peripheral to adult physical reasoning.

The physical principle of gravity tells us that objects will fall downwards if they do not have sufficient support and the principle of inertia tells us that objects do not change their motion spontaneously (Spelke et al., 1992). In a number of experiments, Spelke and colleagues demonstrated that four-month-old infants do not pay more attention to an event in which a falling ball appears to stop in mid-air (thus violating the principle of gravity) and five-month-olds do not pay more attention to an event in which an object rolls down a slope with inappropriate acceleration or at an event in which a ball appears to roll *up* a slope (Kim & Spelke, 1992; Spelke et al., 1992). However, by seven months, infants do look longer at an event with inappropriate acceleration and one in which a ball rolls up a slope, indicating that they are beginning to reason in accord with the principle of gravity. In another study, also employing the looking-time method, Spelke et al. (1994) showed that 8-month-olds, but not 6-month-olds looked longer at an event in which a linearly moving object disappears behind an opaque screen and is revealed at a non-linear location, contrary to the law of inertia.

On the basis of these studies, Spelke argues that infants are not born with knowledge of the principles of gravity and inertia, but that these principles develop with experience over the course of infancy. Further evidence for a lack of appreciation for the effect of gravity come from observations by Piaget (1955), who noted that it is when infants begin to sit unaided, at around six-months of age, that they begin to predictively look down when an object is dropped. Rochat (1992) has suggested that prior to being able to sit unsupported, human infants do not observe enough events that allow them to form a theory about necessary conditions for support and Dan & Takahide (2002) have shown that only self-sitting infants know that objects should fall straight down. In a looking time study, these authors showed children a possible event where an object was released and fell straight down and an impossible event in which the object was released but fell diagonally down to one side. Only children whose parents reported they could competently sit by themselves looked longer at the impossible event, suggesting that prior to this age infants do not have expectations about the effects of gravity.

All of the findings reported above are based on variations of the looking-time method, which do not require the infant to make a manual response. When we look for an appreciation of physical principles in the infant's own interaction with objects, the picture is less clear. On the one hand, young infants do show an appreciation for some physical constraints in their own actions, whereas in other cases they do not.

For example, utilizing Piaget's (1952) support problem in which a desired toy is placed out-of-reach of an infant, either on or off a cloth, Willatts looked at whether or not young infants show evidence for understanding the support principle. In one condition, the object is placed on a cloth and the infant can pull the cloth towards them to obtain the toy and in the other condition, the toy is not on the cloth such that pulling the cloth will not bring the toy within reach of the infant. Willatts found that 9- but not 6-month-old infants did show an appreciation of support, only pulling the cloth when the toy was on it (Willatts, 1984). In another study however, Willatts found suggestive evidence that even 7-month-olds may show evidence of appreciating the support principle in their actions as they made more attempts to pull the cloth towards them when the toy was on the cloth as opposed to when the toy was not on the cloth (Willats, 1999).

However, when we look at childrens' actions, the evidence for an appreciation of the need for support to prevent objects from falling, is less convincing. Karmiloff-Smith & Inhelder (1975) carried out a study in which young children were required to balance blocks on other blocks. They found that even four-year-old children made errors that indicated they did not appreciate how much contact is needed for an object to balance, a conclusion also reached years earlier by Köhler when he observed that "very young children, in attempting to pile one thing on another, try, by holding, and sometimes pressing, one against the other, to fix them in different and often curious positions. It is quite obvious that they too lack that kind of statics." (Köhler, 1925; p. 130). In a task originally used to assess causal understanding in non-human primates, Limongelli found that young children fail to show an understanding of what will happen to an object if it loses its support, and do not adjust their behaviour to prevent the object from being lost due to a lack of support (Limongelli, 1995 cited in (Visalberghi & Tomasello, 1998).

3.3 NAÏVE PHYSICS IN NON-HUMAN SPECIES

As Santos (2004) points out, "if human infants come to this world equipped with an evolved capacity to reason about physical objects, as the CK (core knowledge) theory contends, then one would predict that this knowledge should be shared with closely related primate species" (p. 167). The extent to which animals may share the same kind of common-sense understanding of the physical world as humans was first investigated by Köhler (1925) in his studies of chimpanzees and more recently re-examined by Povinelli (2000). In his investigation into what he terms 'naïve statics' (p. 130), Köhler looked at the behaviour of chimpanzees on a number of tasks requiring them to understand how objects behave and the effects of physical forces such as gravity on objects. For example, in one task, Köhler hung a banana from the ceiling and watched how the chimpanzees tried to retrieve the banana. Despite eventually managing to stack various boxes on top of one another in order to reach the banana, Köhler noted that they made numerous errors on the way to attaining a solution. For example, they would place boxes halfway up a wall with no support, or they would place one box diagonally against another box or even remove a box from a tower beneath them so that the tower (and the chimpanzee) would fall. In addition, Köhler reports that even after the chimpanzees succeeded at stacking boxes, their success was not easily repeated, despite modelling the correct solutions for them. As a result of these observations, Köhler concluded, "there is practically no statics to be noted in the chimpanzee" (Köhler, 1925; p. 130).

In addition to Köhler's reports of box stacking in chimpanzees, Visalberghi and colleagues have carried out a number of experiments in which they exploited the natural tool using behaviours of capuchin monkeys and chimpanzees to see if they could use a stick to retrieve a food reward from inside a narrow tube. The tube contained a trap in the middle, which meant that if the animals pushed the reward towards the trap, the reward would fall and be lost. If the chimpanzees pushed the reward away from the trap, they could obtain it. They wanted to know whether these animals could reason about the effect of the lack of support afforded by the trap. However, neither capuchins nor chimpanzees appeared to appreciate the function of the trap, and at least in the case of the capuchins, they initially just inserted the stick into the end that the reward was closest to (Visalberghi & Limongelli, 1994; Limongelli, Boysen, & Visalberghi, 1995; Visalberghi, Fragaszy, & Savage-Rumbaugh, 1995; Povinelli, 2000). Even when the animals finally managed to solve the task by pushing the food away from the trap, when the tube was inverted such that the trap was on the top of the tube and so would have no effect on the object, they continued to try to move the food away from the trap, suggesting that they did not really understand the causal nature of the trap (Visalberghi & Limongelli, 1994; Povinelli, 2000).[1]

In studies similar to those carried out with children, Hauser and colleagues have explored how much monkeys understand about contact and support. When cotton-top tamarins were presented with Piaget's cloth-pulling experiment, they appeared to show an understanding of the causal nature of the problem, choosing more often than would be expected by chance the cloth that would yield the reward, rather than the one that would not (Hauser, Kralik, & Botto-Mahan, 1999). They appeared to understand that the cloth would only bring them the reward if the reward were actually *on* the cloth. However, in a later study with chimpanzees, Povinelli et al. (2000) included an additional condition in which the degree of contact was varied such that in both cases the reward was in contact with the cloth, but in only one case was there sufficient contact that pulling the cloth would yield the reward. Although chimpanzees could eventually learn which set-up would bring the reward if they pulled the cloth, their behaviour at the beginning of the experiment did not show that they understood the difference between the two different degrees of contact.

However, despite Köhler's conclusion, there is evidence to suggest that some animals do reason about the physical world in accord with the principles that Spelke contended are innate in humans, and as was the case for human infants, most of these findings come from experiments which have employed the looking-time paradigm. For example, Santos & Hauser (2002) found that monkeys, like four-month-old human infants, pay more attention to an event in which an object appeared to have

[1] However, a more recent study with another natural tool user, the woodpecker finch, appeared to show behaviour that surpassed even the chimpanzee (Tebbich & Bshary, 2004) When the woodpecker was presented with the inverted trap tube, it started to insert the stick from just one side, apparently appreciating that the trap was no longer relevant. It appears that the woodpecker finch learnt something causal about the effect of the trap, rather than simply to avoid it.

passed through another solid object than one in which the movement of an object appeared halted by another object – appearing to appreciate the principle of solidity and how it acts to constrain object movement. In other studies, rhesus monkeys appeared to find it surprising that an inanimate object could start moving on its own, without first being contacted by another object – demonstrating that they can apparently reason about objects in accord with the principle of contact (Hauser, 1998; Santos, Flombaum, & Hauser, 2002).

Furthermore, a recent study by Cacchione & Krist (2004) suggests that chimpanzees do appreciate the need for support to prevent an object falling. The authors presented chimpanzees with video footage of events in which an object had adequate or inadequate support and found that their subjects looked longer at a display in which an object remained stable but was inadequately supported, than one in which the object was adequately supported. Interestingly however, in a subsequent experiment they found that although chimpanzees were able to discriminate between adequate and inadequate support, they did not show the same appreciation for the orientation of this support. Chimpanzees looked equally long at a display in which an apple appeared stuck to the side of another object as they did to a display in which the apple was supported from below. They did not seem to appreciate that only the display in which the apple was supported from beneath was actually possible.

* *

Thus, it appears that the same principles that Spelke and colleagues contend guide human adult commonsense reasoning about the physical world, might, to some extent, also guide the reasoning of non-human primates. For example, non-human primates appear to appreciate that one object cannot pass through another and that an inanimate object requires contact from another object in order to move. Non-human primates may even go beyond these core principles and develop some understanding of physical principles that are thought to develop later in human infants, like gravity and inertia. Non-human primates, it appears, do have naïve physical intuitions. With regard to such naïve physical intuitions, two questions are important with respect to the work to be presented in this thesis. Firstly, to what extent might such naïve physical intuitions impinge on a subject's ability to solve an invisible displacement task, by manifesting as a prepotent response? Secondly, the evidence for core knowledge in non-human primates and young children comes primarily from looking-time studies with sometimes contradictory findings emerging from studies in which subjects are required to make manual responses. It is unclear what kind of knowledge is tapped by this paradigm and it is possible that this kind of knowledge is not available for explicit reasoning and so is not available for solving the kind of manual search tasks that Piaget's theory was based on. What sort of form could knowledge in young children and animals take?

3.4 Procedural Responses and Modular Macros

As Povinelli writes, "chimpanzees' efforts with tools ultimately force them to cope with gravity, space, force, shape, and so on – but this may have no bearing on whether such concepts are explicitly present in their minds" (Povinelli, 2000; p. 77). Considering the multitude of sophisticated biological adaptations that various species appear to have been endowed with as a result of selective pressures (Hauser, 2000), it is not unthinkable that some species have evolved adaptations for making sense of their physical environments. Shepard (1984) has proposed that pervasive dynamic constraints in the physical world, such as the effect of gravity, are inherent in human motion processing mechanisms. Recently, Hauser (2003) has proposed that the same may be true for a non-human species, the cotton-top tamarin, proposing that "the mind of a tamarin has been designed with …knowledge" about gravity (p. 8).

Presumably, if some naïve physics is inherent in the design of the human or animal brain, it serves an adaptive function. For example, we know from the visual cliff paradigm that as soon as animals are able to move about on their own, that they are able to perceive and avoid drops. Even chicks of one day old will avoid a drop (Gibson & Walk, 1960). However, we would not want to argue that a one-day-old chick has a concept of gravity. Does the evidence from non-human primates discussed in the previous section allow us to attribute to them a more sophisticated understanding of the physical world than the kind of 'knowledge' that is revealed in a chick's reaction to depth cues?

Physical laws produce regular, learnable effects or statistical regularities and for every causal concept, there is a perceptual invariant that guarantees the same behavioural outcome (Hauser, 2002; Povinelli, 2002). For example, in the vast majority of cases, a dropped or unsupported object will fall downwards and in order to predict this we need not necessarily evoke any explicit causal concept of gravity. All we need do is evoke the end result that is most commonly associated with the beginning point; a simple association. Kummer (1995) argues that the causal knowledge of some animals may result only from repetitive observations and associations and does not reflect true understanding of physical principles. An animal may know that an object that loses support will tend to fall downwards, but they may not know *why*. Karmiloff-Smith (1991) describes this kind of knowledge as 'procedural knowledge' and proposes that it is "run as procedures within specific input systems, given appropriate *external* stimuli" (p. 177). According to Karmiloff-Smith, the knowledge is *implicit*, and it is not available for conscious reasoning. Understanding *that* something happens may simply be a case of evoking learnt statistical regularities and it is now well established that even the simplest of animals are competent associationists (Shettleworth, 1998). Understanding *why* something happens is entirely different and it is not even clear that the majority of non-physics trained humans possess explicit knowledge about why something happens. If you were asked why an object falls down, you are more likely to say 'because it is unsupported' than to respond with a physical description of Newton's law. This distinction between knowing what happens and why something happens has been explicitly stated by Povinelli who has proposed two systems responsible for extracting statistical regularities. On the one had, there is the 'what?' system that is solely responsible for the extraction of statistical regularities and is present in humans as well as non-human species. On the other hand, there is the 'why?' system that is concerned with extracting causal structures and this system is solely present in humans (Povinelli, 2002). According to these authors then, the kind of naïve physical knowledge possessed by non-human primates may be nothing more than rather sophisticated associations.

In a slightly more extreme hypothesis, Hauser (2003) has proposed that where there are statistical regularities in the world, natural selection favours innate mechanisms that respond adaptively to such regularities. From an evolutionary point of view, it would seem that the effects of gravity would be a useful constraint to have evolved a sensitivity to. For example, when foraging for food, it would be useful to know the likely landing place of falling fruits. Hauser has called these adaptive mechanisms 'modular macros' and proposed that they may be rather like the kind of habitual responses described by Graybiel (1998), which are subserved by the basal ganglia (Hauser, 2002, 2003).

Irrespective of whether the physical knowledge that animals have is hard-wired as Hauser has proposed may be the case for knowledge about gravity (Hauser, 2003), or comes about through repetitive observations as Kummer has suggested, the resulting appreciation of such principles may be very useful to the animal that possesses it. However, the efficiency of procedural knowledge may come at the expense of cognitive flexibility. Hardwiring particular behaviours in response to particular external stimuli is a double-edged sword because although these behaviours may allow for efficient problem solving, they may also result in responses that are not always appropriate to the situation. For reasons that will be made clear in the next section, in a recent review of the literature, Call & Tomasello (in press) conclude that procedural knowledge of physical principles may actually impair an animal's search for hidden objects, and interfere with the solving of various invisible displacement problems.

3.5 Prepotent Responses, Perseveration and Inhibition

Our review of the literature has now taken us full-circle to our starting point where our discussion began with the proposal that human infants may have more knowledge about physical principles than their performance on some tasks leads us to believe, and that limits in executive functioning may mask this knowledge.

Why would naïve or folk physical expectations impair a subject's search for hidden objects? If knowledge about some physical phenomena does take the form of procedural responses, then according to Hauser, young children and animals may be unable to override the responses that the activation of such mechanisms dictate

(Hauser, 2003). Modular macros, according to Hauser, are fast, automatic and unconscious action sequences that are immune to counter evidence. Because of this, the responses that they dictate will occur whenever the stimuli that evoke them are present. In behavioural terms, this will manifest as perseveration – repetition of the same behavioural response – despite the fact that this response may not be appropriate.

With this view, Hauser adopts Diamond's position that some subjects, namely animals and young children, because of weak inhibitory control, may be unable to suppress responses that the firing of such macros dictate, despite the fact that they may well comprehend the task at hand, and have the appropriate conceptual knowledge required to solve the task. Specifically, both Hood (1995) and Hauser (2003) have argued that on some invisible displacement tasks, to be discussed in more detail in the following chapters, it is not a failure to understand the task, or an inability to represent the hidden movement of an object that results in failure, but a failure to inhibit prepotent responses of the "modular macro" type, that are inappropriate considering the task at hand. According to Hauser, these responses stem from naïve physical theories, that in most cases suffice to allow the individual to function on a daily basis and interpret events in the physical environment appropriately, but in some cases will be inappropriate (Hauser, 2000).

If this proposal is true, failure on some tasks does not result from a deficiency in the subjects' understanding of the physical world. On the contrary, it is almost as if they have too much knowledge to know what to do with. For example, in one task (the tubes task), to be discussed more extensively in Chapter 5, an object is dropped down an s-shaped opaque tube and subjects have the option of searching for the object either directly beneath the top of the tube (an impossible location) or at the end of the tube (a possible location). Two-year-old children and monkeys fail this task and show a bias towards searching in the location directly beneath the top of the tube (Hood, 1995; Hood, Hauser, Anderson, & Santos, 1999). According to Hood (1995) and Hauser (2003), it is not a lack of understanding of how tubes function to constrain object motion or an inability to represent the invisible movement of an object, that causes failure on this task. It is a pervasive theory about the consequences of a lack of support on an object's pathway that leads subjects to search in the straight-down location. So, although subjects may have knowledge both about the physical constraints of the tube (the principle of solidity) and about the effects of gravity on object trajectories, it is this knowledge about the effect of gravity that wins out in this task.

That such naïve physical beliefs may impair the search for hidden objects implies that non-human subjects may have the capacity to solve an invisible displacement task. The empirical chapters that follow explore how monkeys and young children understand the world of invisible displacement of objects and examine the claims made by authors like Hood (1995) and Hauser (2003) that young children and monkeys do understand some invisible displacement tasks and would be able to pass the task were it not for naïve physical responses, that they are unable to inhibit.

4

SUBJECTS AND GENERAL METHODOLOGY

4.1 MONKEYS

Two groups of macaques served as subjects for the experiments described in this thesis. The genus of Macaques are Old World monkey species and are, with the exception of humans, the most widely distributed of any primate species on the planet (Fa & Lindburg, 1996). They are also, according to Matsuzawa (2001), probably the most dexterous of all the non-human primates, which makes them particularly suitable for object manipulation tasks.

4.1.1 Subjects: Monkeys

The first group of macaques were rhesus macaques (*macaca mulatta*). The group comprised 8 adult monkeys who were all born and raised in captivity. They live in a breeding colony in the School of Psychology at the University of St Andrews. They live in small social groups of 2 or more monkeys and are provisioned daily with monkey chow and fruit and have *ad libitum* access to water.

The second group of macaques were stumptail macaques (*macaca artoides*). The test group comprised 6 adult monkeys who were chosen opportunistically from a large group of animals, all of which were born and raised in captivity. The stumpails live in a breeding colony at the Medical Research Council (MRC) facility at the University of Edinburgh.

Neither group of monkeys have had much experimental testing prior to the participating in the current set of studies, and certainly none of the testing involved finding hidden objects. Table 4.1 provides details about the sex and age of each subject and the tasks in which they participated.

4.1.2 General methodology: Monkeys

All experiments carried out with monkeys were done on a one-to-one basis in the monkey's home-cage. Monkeys were isolated for testing by inserting wooden dividers between them and the rest of the colony. Monkeys were tested at floor level and a wooden stage was constructed (measuring 50 cm in length x 40 cm in width x 16.5 cm in height) to place the apparatus on to bring the apparatus level with the bottom of the monkeys cage. Some monkeys developed a tendency to sit to one side of the cage once they had been isolated. Such behaviour could potentially influence the monkey's choice of search location as they may simply choose the location that is nearest to them. To ensure that these monkeys were centred for testing, objects were placed on both sides of the cage to force the monkey to sit in the middle of the cage (see figure 4.1 below for testing set-up).

The experimenter sat opposite the monkey on a small stool so that they were at roughly the same height as the monkey. A videocamera was set up above and behind the experimenter so that all trials could be recorded. Food rewards were used as the object to be hidden. These consisted of various high rewards foods such as chocolate raisins, smarties, m&m's, grapes and marshmallows and were varied throughout testing to maintain the monkeys interest in the task at hand. Table 4.1 displays all the monkeys who took part in the experiments described in this thesis, their ages and the order in which they took part in each task.

Figure 4.1 Photo of testing environment for studies with monkeys. Here, a monkey who has a tendency to sit to one side of the cage is prevented from doing so by two large plastic obstacles that are placed on either side of the cage. In this way, the monkey is forced to sit in the centre of the testing cage. The photo also shows the small wooden stage that was used throughout the experiments presented in this thesis in order to present the apparatus to the monkey.

4.2 CHILDREN

The experiments with children were carried out in two locations. The majority of child testing was carried out at the University of Lincoln Babylab. Some additional testing was carried out at the Baby & Child Lab at the University of St Andrews. In each case, children were recruited through local advertisements and were brought into the lab by their parents. Parents were required to sign a consent form prior to testing.

For the search studies, the child was seated at a small table and the experimenter sat opposite the child. The parent or caregiver always sat next to the child. A videocamera was set up behind the child and recorded all responses the child made. Children either received a gift for taking part in the study or their parents were offered travel expenses.

The participants for the studies described in this thesis were children aged between two years and three years of age. In order to maximise data collection, each child participated in a number of studies. However, due to the limited attention span of the young child, each child was asked to come into the laboratory on two visits and so data collection was spread over two sessions. Four different search tasks (reported in chapters 5, 6, 7 and 9) and six different looking events (described in chapter 11) were designed and each child received a pseudo-random ordering of these tasks over their two visits. As some tasks resembled each other more closely than others, the most similar tasks were separated by visit, primarily to prevent the child from getting bored. Again, as children participated in a number of different studies, tables 4.2 and 4.3 describe which study each child participated in.

Ethical approval for the studies to be carried out with children was obtained from the School of Psychology Ethics Committee.

Monkey	Species	Sex	Age at start of testing (in years)	Tubes Chapter 5	Cups Chapter 6	Ramp Chapter 7	Ramp II Chapter 8	Cups II Chapter 9
Nathan	Rhesus	M	6	✓	✓	✓	✓	✓
Cowan	Rhesus	M	5	✓	✓	✓	✓	✓
Pete	Rhesus	M	8	✓	✓	✓	✓	✓
Lizi	Rhesus	F	15	✓	✓		✓	
Alison	Rhesus	F	11	✓	✓	✓	✓	✓
Jenny	Rhesus	F	3		✓		✓	✓
Alex	Rhesus	M	2		✓		✓	✓
Bruno	Rhesus	M	2		✓		✓	
Bep	Stumptail	F	22	✓		✓		
Miriam	Stumptail	F	16	✓				
Noreen	Stumptail	F	11	✓		✓		
Kelly	Stumptail	F	8	✓		✓		
Jane	Stumptail	F	20	✓		✓		
Wendy	Stumptail	F	23	✓		✓		
Jo	Stumptail	M	3			✓		

Table 4.1 Table listing details of monkeys and the different tasks in which each subject participated.

		SEARCH TASKS						LOOKING EVENTS		
Child	**Sex**	**Tubes 1 Chapter 5**	**Tubes 2 Chapter 5**	**Tubes 3 Chapter 5**	**Cups 1 Chapter 6**	**Ramp Chapter 7**	**Cups 2 Chapter 9**	**Tubes 1**	**Tubes 2**	**Cups 2**
VB	M	✓				✓		✓	✓	✓
AC	M	✓			✓	✓	✓	✓	✓	✓
MH	M	✓	✓		✓	✓	✓	✓	✓	✓
FC	F	✓			✓	✓	✓	✓	✓	✓
BP	M					✓	✓	✓	✓	
SM	M	✓			✓	✓	✓	✓	✓	
LZ	M	✓			✓	✓	✓	✓	✓	✓
HO	F	✓			✓	✓	✓	✓	✓	✓
MA	M	✓			✓	✓	✓	✓	✓	✓
ED	M	✓	✓		✓	✓	✓	✓	✓	✓
MC	M	✓			✓	✓	✓	✓	✓	✓

Table 4.2 Table listing two-year-old participants and the tasks in which they participated.

Child	Sex	Tubes 1 Chapter 5	Tubes 2 Chapter 5	Tubes 3 Chapter 5	Cups 1 Chapter 6	Ramp Chapter 7	Cups 2 Chapter 9	Tubes 1	Tubes 2	Cups 2
KW	F		✓				✓	✓	✓	✓
JP	F				✓	✓		✓		
ES	F	✓			✓	✓	✓	✓	✓	✓
VC	F	✓			✓		✓	✓	✓	✓
JW	M	✓	✓		✓	✓	✓	✓	✓	✓
RP	M	✓	✓			✓		✓		✓
KL	M	✓				✓		✓		✓
JH	M	✓	✓		✓	✓	✓	✓	✓	✓
HW	M	✓				✓			✓	
BG	M	✓				✓				
EK	F	✓				✓				
GZ	F					✓	✓			

Table 4.2 cont'd

Child	Sex	Tubes 1 Chapter 5	Tubes 2 Chapter 5	Tubes 3 Chapter 5	Cups 1 Chapter 6	Ramp Chapter 7	Cups 2 Chapter 9	Tubes 1	Tubes 2	Cups 2
TW	F	-	✓	✓			✓			
EW	M		✓	✓			✓			
OW	M		✓	✓			✓			
KW	F		✓	✓			✓			
EK	F		✓	✓			✓			
IL	M		✓	✓	✓		✓			
AS	F		✓	✓	✓		✓			
KT	M		✓	✓			✓			
AM	M		✓	✓	✓		✓			
EC	M		✓	✓						

Table 4.2 cont'd

		SEARCH TASKS						LOOKING EVENTS		
Child	**Sex**	**Tubes 1** **Chapter 5**	**Tubes 2** **Chapter 5**	**Tubes 3** **Chapter 5**	**Cups 1** **Chapter 6**	**Ramp** **Chapter 7**	**Cups 2** **Chapter 9**	**Tubes 1**	**Tubes 2**	**Cups 2**
WH	M				✓	✓		✓	✓	✓
ST	M	✓			✓	✓		✓	✓	✓
KB	F	✓			✓	✓		✓	✓	✓
KH	F	✓			✓	✓		✓	✓	✓
SC	F	✓			✓	✓		✓	✓	✓
TH	M	✓			✓	✓		✓	✓	✓
JO	M	✓			✓	✓		✓	✓	✓
RO	M	✓			✓	✓		✓	✓	✓
IB	F	✓			✓	✓			✓	
VB	F	✓			✓	✓		✓	✓	✓
Child	**Sex**	**Tubes 1**	**Tubes 2**	**Tubes 3**	**Cups 1**	**Ramp**	**Cups 2**	**Tubes 1**	**Tubes 2**	**Cups 2**

Table 4.3 Table listing three-year-old participants and the tasks in which they participated.

		Chapter 5	Chapter 5	Chapter 5	Chapter 6	Chapter 7	Chapter 9			
GE	F	✓			✓	✓		✓	✓	✓
CB	F	✓			✓	✓				
ET	F				✓	✓		✓		
LC	M	✓			✓	✓		✓	✓	✓
JD	F	✓			✓	✓		✓	✓	✓
AF	M				✓	✓		✓		
LH	F				✓	✓		✓		
OB	M	✓			✓	✓		✓	✓	✓

Table 4.3 cont'd

5

EXPLORING THE GRAVITY ERROR: PART I

5.1 INTRODUCTION

The gravity error is joining the ranks of classic developmental errors that may be the consequence of failing to inhibit a prepotent response. First identified by Hood (1995) in two- to four-year-old children, and subsequently also shown to be present in cotton-top tamarins (Hood, Hauser, Anderson, & Santos, 1999), the error appears when an object or food reward is dropped into an opaque tube and participants are allowed to search in one of three opaque containers, one of which is attached to the end of the tube. Subjects tend to search in the container directly below the top of the tube, rather than in the one attached to the end of the tube. Findings that participants do not have this alignment bias when the same apparatus is presented horizontally and an object rolled into the tube, have been taken to suggest that expectations about falling objects may be so strong that some subjects are unable to overcome their urge to search directly below where the object was dropped. This response has been interpreted by some authors as a perseverative error, because children and tamarins continue to make the error despite receiving no positive feedback, and never obtaining the reward (Hood, 1995; Hauser, 2003). Recently, Hauser (2003) has suggested that knowledge about the effects of gravity may have evolved as a sensitivity to statistical regularities in the physical world. If we see unsupported objects fall enough times, we become sensitive to the regularity with which they fall straight down. Such a sensitivity may become manifested as a prepotent response or bias, and activated when participants are faced with falling objects. Expectancy violation studies with human infants suggest this bias could be in place by 5.5 months (Dan, Omori, & Tomiyasu, 2000). According to Hauser (2003), such a response bias has to be inhibited when it is inappropriate. This is what human adults would do, but young children and some non-human primates, may lack the necessary inhibitory capacities to suppress this prepotent response.

The current study aims to test the inhibitory failure explanation for the gravity error. According to Hood, this error constitutes a procedural response of searching in the straight-down location upon seeing an object fall (Hood, 1995). According to authors like Hauser (2003), as a result of many years of life on earth, the brains of species, such as the cotton-top tamarin, have become hard-wired to respond to instances of falling objects with this straight-down result. He considers that such stimulus-response action sequences are largely automatic and unconscious. However, inhibition makes possible the withholding of these prepotent responses in situations in which they are not appropriate, for example when other physical constraints apply, deflecting the object's trajectory.

Both Hood (1995) and Hauser (2003) have proposed that the gravity error reflects an instance where, despite understanding the task and being able to track an invisible displacement, both young children and monkeys fail the tubes task because they are unable to inhibit this procedural response. The aim of the current study is to explore further the inhibitory failure explanation for the gravity error. Firstly, if inhibiting a prepotent response *is* crucial to passing the tubes task, as it is believed to be for passing the A-not-B task, we might expect a species that shows better inhibitory capacities than the cotton-top tamarin, to do rather better on the tubes task.

The first aim then, was to extend the realm of species tested on this task. To date, human children, the New World cotton-top tamarin, and dogs have been tested on the tubes task (Hood, 1995; Hood et al., 1999; Osthaus, Slater, & Lea, 2003) and all exhibit the gravity error to a greater or lesser degree. However, it has been suggested that Old World monkeys may have superior inhibitory capacities compared with those of New World species like the cotton-top tamarin (Rumbaugh, 1997; Hauser, 1999). In a study by Santos et al. (Santos, Ericson, & Hauser, 1999), it was found that like young human infants, adult cotton-top tamarins were unable to pass the object retrieval task, in which a desired object is placed inside a transparent box and can only be accessed via an opening on the side of the box. When presented with this task, cotton-top tamarins are unable to stop themselves from reaching straight ahead towards the object rather than reaching around the side and in through the opening. However, when adult rhesus macaques are given this task, they are able to retrieve the reward in the correct way, reaching around through the side (Diamond & Goldman-Rakic, 1989). This difference in task performance suggests that Old World monkeys, like rhesus macaques, may be better able to inhibit inappropriate prepotent responses than New World monkeys like the cotton-top tamarin (Hauser, 1999).

If inhibition *is* key to successful performance on the tubes task, as both Hood (Hood, 1995; Hood et al., 1999) and Hauser (2003) suggest, perhaps an Old World monkey might not make the same error. The presence of the gravity error was therefore investigated in two species of Old World monkey: the rhesus macaque (*Macaca mulatta*) and the stumptail macaque (*Macaca artoides*). Despite suggestive evidence that rhesus macaques may be exhibiting something akin to a gravity bias on a different task (Hauser, 2001b; see following chapter), the gravity error has not been investigated in any Old World monkey species.

The second aim of the current study was to test the prediction, made by Hood (1995), that "participants should be capable of performing the correct response when the prepotent response is removed" (p. 595), if indeed the gravity error is the manifestation of an inhibitory failure. Hood's own operationalization of this problem was to analyse children's second search choice, where there are three possible choices, reasoning that if they made the gravity error on their first choice, by their second choice, the prepotent response option would have been removed, and therefore they should now choose the correct location.

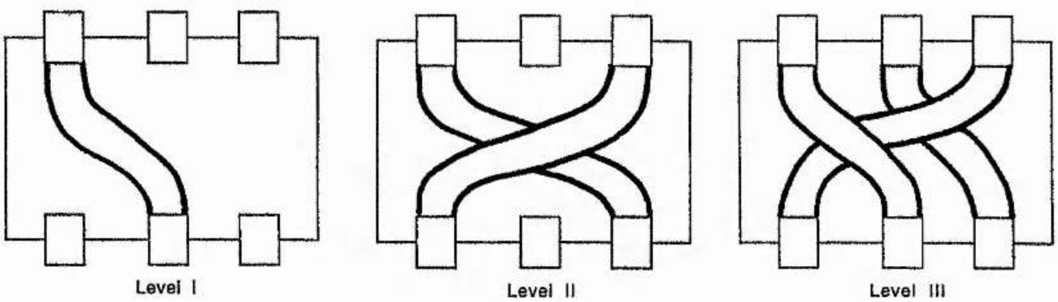


Figure 5.1 Taken from Hood (1995), the diagrams illustrate the different levels of the original tubes task, with one, two and three tubes. Those children who become able to pass level 1 move on to level 2 and those who become able to solve level 2, move on to level 3. When Hood analyzed children's second searches he found chance level responding on levels 1 and 3, but above chance responding on level 2. However, as acknowledged by Hood, this is likely to be because children have learnt that the ball is never found in a box unconnected by a tube. If this is the case, having initially searched in the straight-down location on their first search attempt on level 2, they then search in the only other location connected by a tube. The fact that second searches are not above chance on the other two levels suggests that correct second searching on level 2 does not reflect true knowledge about the location of the ball, contrary to the prediction of the inhibitory failure hypothesis.

However, the results of this analysis were inconclusive. Children who had shown an ability to pass the one-tube version of the test but who then failed the two-tube version on their first search, were often then correct on their second search attempt. This would appear to support the inhibitory failure hypothesis. However, as Hood acknowledges, the reason for this correct second searching may only be because children have learnt that the ball is always found in locations connected by a tube, but never in the third, tubeless location. Thus, with only two tubes, if they make the gravity error on the first search, then their second search will necessarily be correct. However, it is unclear whether this is because the prepotent response has been removed, or because they are choosing the only other location with a tube attached. Successful second searches therefore may not be due to any real understanding of the task.

To clarify this issue, I reasoned that if no search location was available beneath the point of release, participants who had previously failed the standard one-tube task should be able to solve this version, if indeed their problem had been an inability to inhibit a prepotent response. Specifically, I investigate whether, when the search locations are arranged such that both are misaligned in relation to the point of release of the object, the subject will search in the correct location, attached to the end of the tube, or in the incorrect location, on the opposite side, where both locations are an equal distance from the point of release. The inhibitory failure hypothesis would predict that, since search under the release point is not possible, no prepotent response needs to be inhibited and therefore the correct knowledge would be free to control participants' search behaviour.

Experiments 3 and 4 were designed to explore alternative explanations for the type of errors that have been described as gravity errors. In support of an inhibitory failure explanation, it has been claimed that it is not a lack of understanding of the constraining nature of the tubes that cause subjects to have difficulty with this task (Hauser, Kralik, Williams, & Moskovitz, 2001; Hauser, 2003) and that subjects do not have a problem understanding the function of the tubes. In their investigation into tamarins' abilities to pass the tubes task, Hauser et al. (2001) replaced the tube with an occluded ramp, reasoning that if there is something especially difficult about understanding the tubes, then animals should improve when presented with a ramp instead. However, tamarins continued to fail the task, and as a result, Hauser and colleagues concluded that it is not a failure to understand how tubes function that causes tamarins to fail the task.

Further evidence that is used to support the claim that tubes are not problematic is the fact that children and monkeys do not show similar biases when the task is presented in other ways. In one version of the task, the same apparatus is presented, but rather than standing vertically, it is placed horizontally in front of the subject and a desired object is dropped into one of the tubes. The beginning portion of the tube is slightly inclined to allow the object enough momentum to pass all the way through the horizontal tube and then the subject is allowed to search for the object as in the vertical version of the task (Hauser et al., 2001). Hauser (2003) argues that a misunderstanding of tubes *per se* cannot explain the problem because tamarins show a "marked improvement in their search patterns" (p. 7) when the tubes task is presented in this way. However, what this 'marked improvement' actually amounts to in tamarins is that three out of a sample of ten monkeys showed a convincing understanding of the task, managing to pass a generalization condition in which the tube was configured differently. Only two monkeys passed the generalization condition with the vertical task. Although seven out of ten monkeys did eventually reach criterion on the horizontal test, a comparison of the two reports suggests that by the time tamarins reached criterion, they had participated in many more trials than their counterparts on the vertical test. Moreover, although seven out of ten monkeys is slightly greater than the proportion who eventually reached criterion on the vertical task (five out of nine monkeys), this difference might be explained by an elimination of the alignment bias leading to a greater degree of random responding rather than a concentrated response pattern at one location. Similarly, when this test was carried out with two-year-old human children, again, although their performance improved relative to performance on the vertical condition, performance was not significantly above chance (Hood, Santos, & Fieselman, 2000). In sum, the horizontal tubes test does not provide convincing evidence that monkeys understand the function of the tubes.

Finally, Hood (1998) reports better performance by children in a version of the task in which children watch on a television screen as a ball appears magically sucked up the tube, suggesting that they do understand how tubes function to constrain object trajectories. In this version of the task, on half the trials children saw the ball being sucked up the tube and on the other half they saw the ball being dropped down the tube. Children performed significantly better on the trials in which the ball appeared to travel up the tube than on trials in which the ball was dropped down the tube. However, these same two-year-old children failed to commit the gravity error in the ball-dropped-down condition when tested with the same television screen, suggesting that the televised version, whilst still leading to erroneous searching, does not evoke the straight-down bias in the same way as the 'live' version. Because of this, it seems difficult to argue that it is the gravitational element that leads to erroneous searching rather than problems with the tubes, because children are not making the gravity error on this task anyway.

Experiments 3 and 4 of this chapter aim to clarify children's and monkey's understanding of the tubes. Experiment 3 was designed to examine Hood's claim that children are able to pass the tubes task when the motion is reversed and the object is pulled up the tube (Hood, 1998). In the experiment reported here, the apparatus is presented 'live' to two-year-old children, in a set up in which we already know that they exhibit a straight-down biased response. If children really do understand how the tube functions, then they should search correctly when the gravity element is removed and the ball disappears up the tube. Experiment 4 aims to investigate whether the same children are able to solve the tubes task if they are given some information about the initial trajectory of the object.

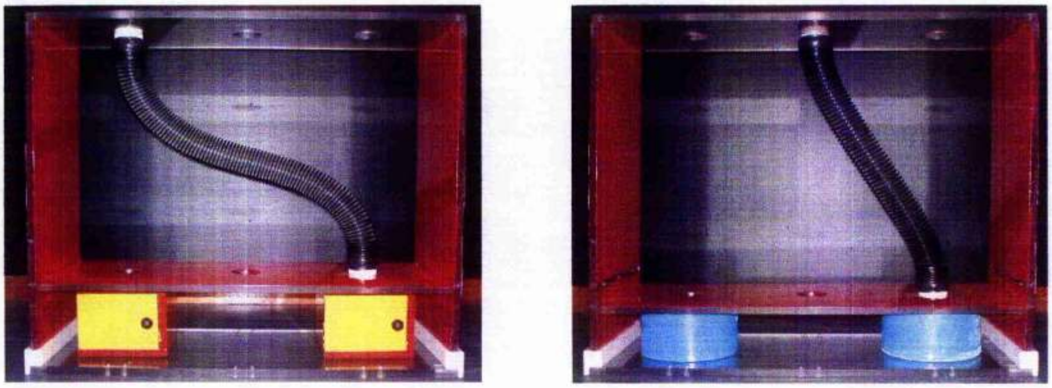
5.2 General Methods

5.2.1 Apparatus

The apparatus used in the studies described in the current chapter were designed to closely resemble those of Hood (1995). Figure 5.2 shows the apparatus used with both monkeys and children, configured for the two conditions presented in Experiments 1 and 2. Two types of search location were used: blue plastic rings for the monkeys (12 cm diameter, 6 cm height) and coloured boxes with doors for children (11 cm^3).

The rings used with monkeys were familiar to them as toys and contained wood shavings that they were familiar with foraging in. Research by Byrne & Suomi (1991) found that, in rhesus macaques, provision of wood shavings for foraging increases feeding, exploration, and motivation to search for food. The macaques in the current study regularly forage for food in wood shavings in their home cages, and so the provision of the same material during testing was hoped to increase motivation to search by exploiting 'natural' behaviours.

The tubes were made of flexible corrugated black plastic and were 50 cm long for the standard task and 37 cm long for the task in which the prepotent response was removed. For the monkeys, cotton-wool was placed a short way down each tube to stop the movement of the food reward as pilot testing had highlighted problems disguising the sound the food made as it travelled down the tube and landed in the wood shavings. Consequently, instead of allowing the food to pass down the tube, the correct location was pre-baited with the same reward. For children, small balls made of a soft material were used which made no noise within the tube or upon impact and so were allowed to travel down the tube. The tubes were held in place by a polycarbonate frame measuring 43cm x 50cm and three openings at the top with a distance between each of 12 cm that allowed the tube to be attached from the top to either the bottom left or right search location. For the monkeys, the polycarbonate frame was pulled back after the food reward had been released, to allow subjects access to the search locations. This design was adopted in light of a suggestion by Hood and colleagues, that tamarins in their study may have been avoiding the location with the tube attached (Hood et al., 1999). The current design removed any differences between the two locations at the time of search. This manipulation was not included in the design for children because the doors on each of the boxes meant that both locations were accessible without moving the frame away.



(A) (B)

Figure 5. 2 (A) Apparatus for use with children, presented in standard condition and (B) Apparatus for use with monkeys, presented in prepotent-removed condition.

5.3 EXPERIMENT 1: DO OLD WORLD MONKEYS EXHIBIT A GRAVITY BIAS?

5.3.1 Subjects

Five adult rhesus macaques (*macaca mulatta*) and six adult stumptail macaques (*macaca arctoides*) participated in this experiment. On session 2, one of the rhesus macaques was unable to be tested and so was replaced with an additional stumptail macaque such that 4 rhesus macaques and 6 stumptails participated in session 2. None of these subjects had participated in any behavioural experiments prior to testing. Table 4.1 in Chapter 4 lists the age and sex of each monkey that participated in this experiment.

5.3.2 Procedure

Participants were tested on two familiarization phases to ensure they were able to search in the locations and that they understood that the tubes were hollow. A food reward was dropped into the tube on five trials in which a tube was held up at roughly a 45° angle above one container filled with wood shavings. The end of the tube was placed into the wood shavings, such that monkeys could not see the reward emerging from the tube. The tube was then placed next to the hiding well and the monkeys were free to search either in the tube or in the well. All monkeys searched in the well on every trial, their behaviour indicating that they understood the tube to be hollow, and that the food reward would not remain inside the tube. In addition, the apparatus was presented to the monkeys a further five times, without the addition of the tube, to ensure they could search in the correct well when they saw the food dropped into it. All monkeys always searched in the correct well. Each subject was presented with the experimental task over two sessions, carried out a few days apart. On session 1, the monkeys received the standard tubes task with the tube either attached from the top right to the bottom left, or from the top left to the bottom right. The position of the tube was alternated from trial to trial so that if the tubes were presented to the monkey in the left to right configuration on trial 1, they would be presented in the opposite, right to left configuration on trial 2. In addition, to prevent the monkey learning a left-right pattern, two control trials were inserted in between each pair of experimental trials. In control trials, the tube was still changed to the opposite configuration from the preceding trial, but the reward was dropped in front of the tube rather than into the tube. In this way, the reward on control trials fell straight down and was found in the container on the same side as it was dropped. Each monkey received up to 12 experimental trials.

On session 2, the monkeys received the modified tubes task with the prepotent response removed. Here, the tube was attached from a middle top location to either the bottom left or bottom right (see Figure 5.2b) so that no search location was available directly beneath the top of the tube. Again, the configuration of the tube was changed on each trial and each monkey received up to 12 trials.

5.3.3 Results and Discussion

As each macaque completed at least 10 trials on session 1, performance on the first 10 trials was analysed. On session 2, 1 subject was uncooperative and only completed 4 trials so was dropped from the analysis. Out of the remaining 9 subjects, 7 completed at least 10 trials and 2 completed 6 and 9 trials respectively. A mean percentage correct score was obtained for each subject for both standard and 'prepotent removed' trials. Figure 5.3 presents the mean percentage of correct responses for both the standard condition and the prepotent-removed condition. A repeated measures ANOVA with condition type (standard vs. prepotent-removed) and species (rhesus vs. stumptails) revealed no effect of species but did reveal a significant effect of condition [$F(1,7) = 15.38$, $p \leq 0.01$] indicating that subjects are performing significantly better on the prepotent-removed condition than on the standard tubes task. Since there was no effect of species, the data was then collapsed across species. A one-sample t-test revealed that monkeys were performing below chance on the standard tubes condition [$t(9) = 5.71$, $p \leq 0.001$] indicating that they searched predominantly in the incorrect, straight-down location. However, although the ANOVA showed that performance was significantly better on the prepotent-removed condition, a one-sample t-test revealed that this improvement was not above chance [$t(8) = 0.778$, n.s.]

Results from the first session of Experiment 1 indicate that, like cotton-top tamarins and two-year-old children, adult rhesus and stumptail macaques also commit the gravity error when presented with the tubes task. Results from the second session suggest that removing the prepotent response so that participants are not given the option to search in a straight down location does not improve performance above chance level. That is, although this manipulation leads to the disappearance of the gravity bias, this is not replaced by correct performance, but by chance performance.

Two species of Old World monkeys, therefore, do show a gravity bias despite their hypothesized superior inhibitory abilities (Hauser, 1999). However, it does not appear that this bias is masking a potentially correct performance despite Hood's prediction that removing the prepotent response should lead to correct performance if indeed the gravity bias does reflect an inhibitory failure.

In order to investigate whether this task manipulation could improve the performance of human children, Experiment 2 presented two-year-old children with a tubes task in which the prepotent response had been removed.

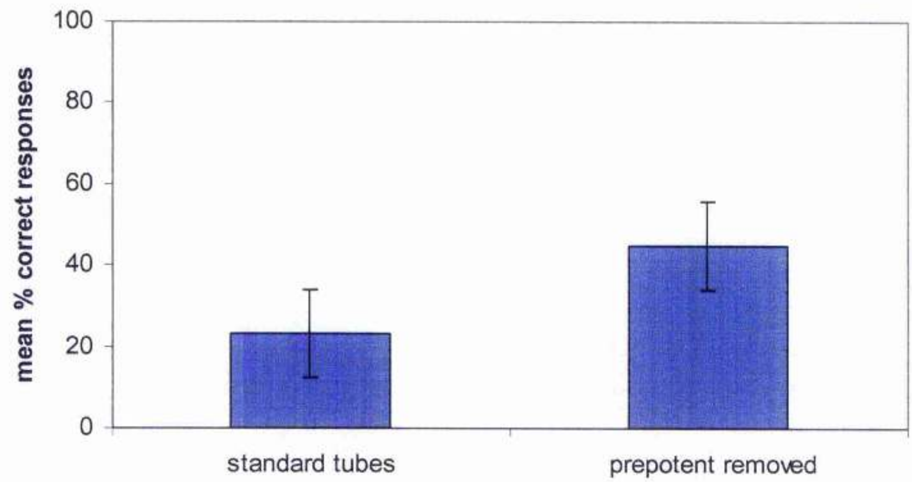


Figure 5.3 Mean (± *SE*) percentage of correct responses on each condition for monkeys.

5.4 EXPERIMENT 2: REMOVING THE PREPOTENT RESPONSE FOR CHILDREN

5.4.1 Subjects

20 24-month-old infants (M= 24.8 months, SD = 1.6 months) participated in the study. The sample consisted of 6 girls and 14 boys. Participants were recruited through a database of parents who had expressed an interest in their children participating in studies conducted at the infant lab. One child was excluded from analysis due to inattention and fussiness throughout testing. Table 4.2 in Chapter 4 lists the other studies that each of the children in the current study also took part in.

5.4.2 Procedure

The removal of the prepotent response for children was the same as for monkeys in that the tube was attached from the top middle to either the bottom left or right. The tube was again switched from left to right for each trial, and every two trials with the prepotent response removed were followed by two standard trials where the tube was attached from the top right to bottom left, or top left to bottom right. This was important to ensure that all two-year-olds who took part did indeed commit the gravity error on standard trials. Furthermore, it provided a baseline against which to compare performance on the 'prepotent removed' trials. Each child received up to 12 trials: 6 standard and 6 prepotent removed trials.

5.4.3 Results and Discussion

Of the remaining 19 children, 14 completed twelve trials and 6 completed between seven and eleven trials. A mean percentage correct score was obtained for each child for both standard and 'prepotent removed' trials. A paired-samples t-test revealed that performance on the prepotent-removed trials is significantly better than on standard tubes trials [$t(18) = 2.66$, $p \leq 0.05$]. However, one-sample t-tests showed that, as is the case for monkeys, this improvement only brings performance from below chance on standard trials ($t(18) = 3.64$, $p \leq 0.005$) to chance level on prepotent-removed trials ($t(18) = 0.54$, n.s). Results from Experiment 2 suggest that removing the possibility of committing the hypothesized prepotent response does not lead to successful searching in two-year-old children. The prepotent gravity bias therefore does not mask accurate knowledge about where the ball is. Figure 5.4 shows the mean percentage of correct responses on the standard tubes trials and the prepotent-removed trials.

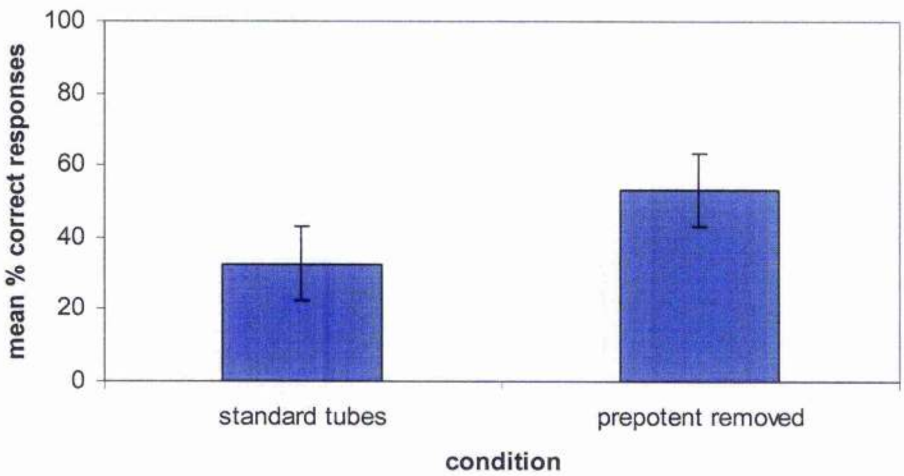


Figure 5.4 Mean (± *SE*) percentage of correct responses on each trial type for children.

5.4.4 Error Analysis

It has been suggested that first-trial performance may be the most important measure of true understanding in many search tasks because of the susceptibility that young children and non-human subjects may have to perseveration on subsequent trials (Suddendorf, 2003). That is, it may be difficult for these subjects to inhibit making a previously rewarded response even if the location towards which they are making this response is no longer appropriate. As such, performance on only the first and second trials was analyzed in order to explore whether there was evidence for perseveration of this type. Firstly, from this analysis, it appears that the gravity error was not predominant on the very first trial for 24-month-old children. 10 out of the 19 children made the incorrect 'gravity' response on the first trial, a proportion that is not greater than would be expected by chance ($p = 1.0$, 2-choice binomial).

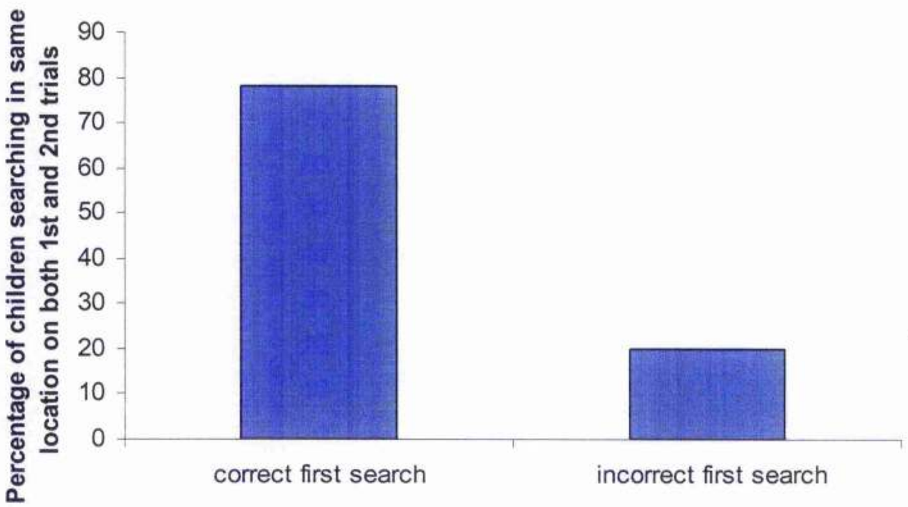


Figure 5.5 Percentage of 24-month-olds who searched in the same location on both first and second trials, as a function of whether or not they were correct on the first trial.

As figure 5.5 shows, the location of search on the second trial appears to be heavily dependent on whether or not the child successfully found the ball on the first trial. Seven out of the nine children who successfully found the ball on the first trial (i.e.

who did not commit the gravity error) searched for the ball in the same location on the second trial (and were therefore unsuccessful on the second trial because the location of the tube was switched from trial to trial). On the other hand, only two out of the ten children who failed to find the ball on the first trial continued to search at that location on the second trial. On the second trial, eight of these children switched their searching to the location that actually did contain the ball on the first trial (and were therefore also unsuccessful because by the second trial, this was no longer the correct location). Thus, it seems that children may be adopting a win-stay, lose-shift strategy whereby, on the second trial, location of search depends on where the object was found on the first trial.

Examining the initial search patterns of the monkeys reveals a different pattern. Only two of the monkeys searched correctly on the first trial, with eight monkeys exhibiting the gravity bias from the very first trial. Out of those eight monkeys who searched incorrectly on the first trial, six of these monkeys again searched incorrectly on the second trial. The two monkeys who did search correctly on the first trial also searched correctly on the second trial. However, it is difficult to compare these results with those of the children because the fact that 6 monkeys switched their search to the location that was shown to contain the reward on the first trial also fits with the contention that search reflects a gravity bias.

Figure 5.6 Two-year-old child (left) and rhesus macaque (right) searching incorrectly on the prepotent-removed condition.

5.5 EXPERIMENT 3: EXPLORING UNDERSTANDING OF TUBES IN YOUNG CHILDREN.

In Experiment 3, two-year-old children were presented with a version of the tubes task in which a ball travelled up the opaque tube. The aim of this experiment was to replicate findings by Hood (1998) that when gravity is removed, children are able to infer where the ball has gone based on a correct understanding of how tubes function. However, in that experiment (conducted via a television monitor), children did not actually commit the gravity error on downward motion trials and so it could be argued that the design was not comparable to the original tubes task and so inferences concerning children's understanding of tubes cannot be generalized to the actual tubes task. Experiment 3 presented trials in which the real tubes task was presented and a ball was drawn up the tube.

5.5.1 Subjects

10 two-year-old children took part in Experiment 3 (M = 24 months, range = 23 – 27 months). There were 4 girls and 6 boys. For this study, children were tested at the Baby & Child Laboratory at the University of St Andrews. Again, table 4.2 details which children took part in this study.

5.5.2 Apparatus

The same apparatus that was used in Experiment 2 was also used in Experiment 3. However, 2 additional boxes were used for the 'upward motion' trials such that there were two boxes on the top of the apparatus and two boxes at the bottom of the apparatus (see figure 5.8). The two additional boxes used in this condition served as launching boxes that contained the ball before it was drawn up the tube on 'up' trials. These additional boxes did not have a front, and were open so that the child could see the ball at the beginning of each trial. The two boxes with doors were placed at the top of the apparatus and held in place by velcro so that they could be easily removed in 'downward motion' trials. For trials in which the ball had to travel up the tube, invisible thread was attached to a number of small balls for use on the 'up' trials in order to draw the ball up the tube.

5.5.3 Design and Procedure

In order to be sure that these participants did commit the gravity error on the tubes task, standard trials where the ball is dropped down the tube were also included in the design. Children received 6 'up' trials and 6 'down' trials in blocks of three, i.e. they would first receive 3 up trials, followed by 3 down trials followed by another 3 up trials etc. The experimenter was seated opposite the child at a small table. The apparatus was placed on the table and the experimenter showed the child the ball, and then, out of view of the child, the experimenter hid the ball in one hand. The experimenter then placed one hand in each of the boxes and released the ball down the tube so that it appeared in one of the lower boxes. Because both hands were inserted into the two upper boxes simultaneously, children could not see which box the hand that contained the ball was inserted into. Once the ball had appeared in the lower box, the experimenter drew the attention of the child towards the ball. The child was permitted to touch the ball and take it out of the box. The experimenter then asked the child to put the ball back into the box, and to watch carefully what would happen to the ball. The ball was then drawn up the tube by the string. Children saw the ball for a small portion (about 8 cm) of its upward trajectory until it disappeared into the tube. The experimenter's hands were always kept at the bottom of the apparatus, in the centre, so as to avoid giving the child any cues as to where the ball was going. Once the ball had disappeared, the child was then encouraged to find the ball. During 'down' trials, the apparatus was configured as in Experiment 2 with the two boxes containing doors positioned at the bottom of the apparatus. As with Experiment 2, the direction of the tube was changed on each trial for both 'up' and 'down' trials.

5.5.4 Results and Discussion

Nine children completed at least 6 trials of each type but one child only completed two trials and was excluded from analysis because of inattention. The mean percentage of correct responses over the first 6 trials for each child was calculated for the 'up' trials and the 'down' trials. The mean percentage of correct responses for all children on 'up' trials was 30 % and the mean percentage of correct responses on 'down' trials was 24 %. A paired-samples t-test comparing performance on 'up' trials with performance on 'down' trials did not reveal a significant difference. One-sample t-tests comparing performance on both trial types with chance revealed that performance on both was significantly below chance [UP: $t(9) = 3.50$, $p \leq 0.01$; DOWN: $t(9) = 3.40$, $p \leq 0.01$].

The results from Experiment 3 show that removing the effect of gravity does not improve the performance of two-year-olds on an invisible displacement task involving tubes. Contrary to the findings of Hood (1998), the children in this study showed a bias both with the upward motion trials and with the downward motion trials. The bias was to search in the location immediately above or below the launching point.

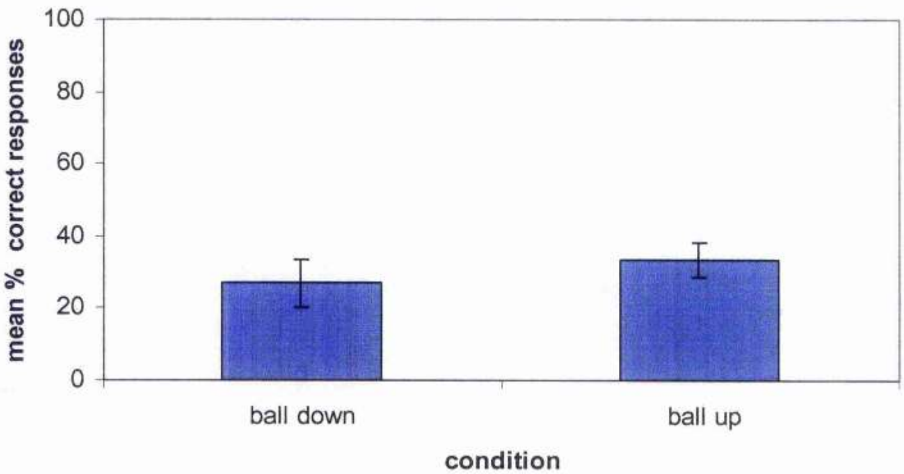


Figure 5.7 Mean (± *SE*) percentage of correct searches on both the downward and the upward motion trials.

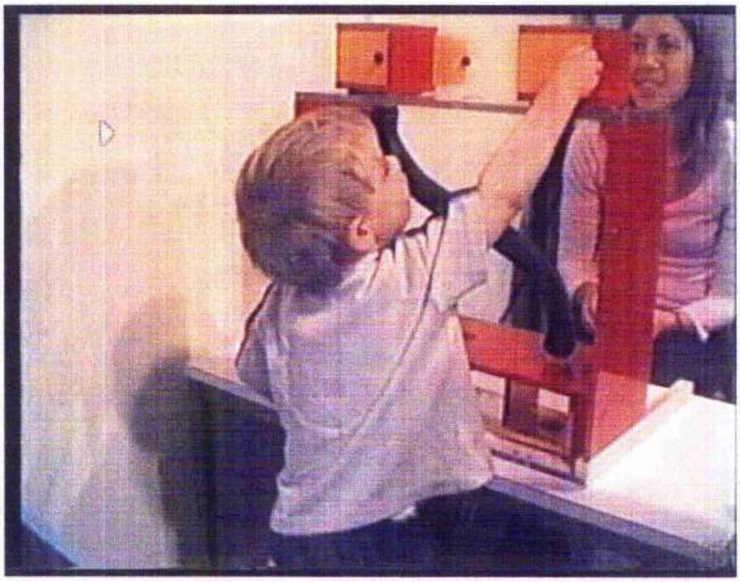


Figure 5.8 Two-year-old child searching in the incorrect aligned location on upward motion trials in Experiment 3.

5.6 EXPERIMENT 4: EXPLORING THE EFFECT OF VIEWING PART OF THE OBJECT'S TRAJECTORY.

Considering that two-year-old children appear to show no understanding of the function of the tubes irrespective of the type of motion involved (i.e. upward or downward), it seems likely that it is not a naïve theory of gravity *per se* that results in failure on this task but a lack of understanding of how objects move invisibly through a tube, that might be related to the more general problem of tracking invisible displacements of objects. It is unclear what kind of strategy or basis children are using when they search in the aligned location on both upward and downward motion trials. This kind of searching could result from a proximity strategy i.e. children could be using a 'search in location closest to where the object disappeared' rule. When both locations are equally close, as when the prepotent response was removed, random searching would be expected if children were indeed using such a strategy.

However, an alternative explanation is that subjects are extrapolating the invisible portion of the objects trajectory from the visible portion. So, when they see the object dropping, the only part of the motion they see is linear (before the object disappears into the tube) and likewise when they see the object being drawn up the tube. The aim of Experiment 4 was to present a situation in which the portion of the object's motion that the child saw was not straight-down, but maintain a situation in which the point of disappearance of the object was equally close to the two possible search locations. If children are indeed utilizing a proximity or alignment strategy of search, then allowing them to view the object trajectory within the tube to a point that is midway between the two-search locations should again yield random searching between the two locations. On the other hand, if children are extrapolating the continued trajectory of the object from a portion of movement that they are allowed to witness, then viewing the diagonal trajectory of the object until the point of disappearance should lead them to search preferentially in the correct location.

To this end, a partially transparent tube replaced the previously opaque tube so that the initial trajectory of the object was visible. The child therefore saw that the object did not fall straight down but followed a pathway imposed by the tube. The tube became opaque midway between the two search locations (see figure 5.9). If children are simply using a proximity strategy, one might expect random searching when the object disappears midway between the two locations. On the other hand, if children are extrapolating the pathway that the object takes based on the portion of object motion that they are permitted to witness, one might expect improved performance on this task.

5.6.1 Subjects

16 two-year-old children participated in Experiment 4. The same 10 children that participated in Experiment 3, plus another 6 who had previously participated in Experiment 2 were subjects for this experiment (see table 4.2 for list of which subjects participated in which studies). There were 11 boys and 5 girls and the mean age of children was 24.4 months (s.d. = 1.1 months).

5.6.2 Apparatus

The same apparatus that was used in Experiment 2 was used in the current experiment. The only difference was that the previously opaque tube was replaced with a semi-transparent tube. This bottom half of the tube was covered with red tape that was wrapped around the tube to render it opaque.

Figure 5.9 Two-year-old child searching correctly on the semi-transparent version of the tubes task.

5.6.3 Procedure

The procedure for the current experiment was exactly the same as for Experiment 2, with the configuration of the tube being switched on each trial. Children were given a maximum of 12 trials but no subjects completed this many trials.

5.6.4 Results and Discussion

14 subjects completed 6 trials, 1 subject completed 5 trials and 1 subject completed 4 trials. The mean percentage of correct responses for each subject was calculated. A one-sample t-test revealed that subjects were performing significantly above chance [$t(15) = 2.55$, $p \leq 0.05$]. Thus it appears that showing two-year-olds part of the object's trajectory down the tube does facilitate search, despite a portion of that trajectory still being invisible.

This result suggests that children are not using the simple strategy of searching in the location closest to the point of disappearance. If they were using such a strategy, we would expect to see random searching as the point of disappearance was at an equal distance from both search locations. An alternative possibility is that subjects extrapolate the remaining unseen portion of an objects trajectory from the information they could gather from the initial visible portion. Research has shown that children as young as nine-months are able to extrapolate unseen segments of object motion based on viewing the initial pathway (Berthier et al., 2001). Furthermore, extrapolating object pathways may in itself constitute a bias or prepotent response and the resulting behaviour on this task of correct search may have no bearing on whether the subject understands *why* the object must be in the box at the end of the tube. As has been shown by recent studies in the field of eye gaze perception, even newborn infants are sensitive to dynamic eye movements and orient correctly towards the direction that an adult attends (Farroni, Massaccesi, Pividori, & Johnson, 2004), but this is most likely because infants are cued by the direction of motion rather than by eye gaze *per se* (Farroni, Johnson, Brockbank, & Simion, 2000). Even though infants are sensitive to direction of motion and so can follow dynamic eye movements, this does not indicate that they understand the relationship between eye gaze and attending to objects (Woodward, 2003). Infants and young children may therefore be extremely sensitive to movement events and react appropriately (by extrapolating object trajectories or orienting in the direction of eye movements) without inferring that the object must be at the end of the tube as a consequence of the solid nature of the tube, or that the person whose eyes are moving is attending to a particular object. The observed response (of orienting or searching in the correct location) might be a reaction upon which the infant or child may have little control.

5.7 GENERAL DISCUSSION

Results from the experiments described in this chapter clearly establish that, like human children and cotton-top tamarins, rhesus and stumptail macaques also commit the gravity error on the standard tubes task. In the standard task, where a search container is available directly below the top of the tube, as well as at the end of the tube, these two macaque species show a bias towards searching in the container directly below. In order to investigate the response-inhibition failure hypothesis for the gravity error, subjects were given a version of the task in which the prepotent response was removed. Both children and monkeys stopped committing a biased error. However, rather than making the correct response, they chose randomly between the two locations. These results suggest that, contrary to the contentions of Hood (1995) and Hauser (2003), the prepotent, but erroneous gravity response does not mask a correct understanding of the object's location at the end of the tube. Participants do not demonstrate any correct knowledge of the location of the object in their manual responses once the prepotent response has been removed.

How should we think about these results, if not as a problem of response inhibition? Over the past decade, a number of authors have drawn a distinction between two types of inhibition. Harnishfeger (1995) has made a distinction between cognitive inhibition and behavioural inhibition and Zelazo and colleagues between inhibition at the response level and inhibition at the level of representations (Zelazo, Reznick, & Pinon, 1995; Zelazo, Reznick, & Spinazzola, 1998; Jacques, Zelazo, Kirkham, & Semcesen, 1999). According to Zelazo et al. (1995) "Executive errors due to a representational inflexibility or to forgetting can be contrasted with failures of response control, which occur when one cannot inhibit an incorrect response despite establishing and remembering a correct alternative" (p. 509). Thus, one possibility is that children and monkeys fail to suppress the inappropriate gravity-biased *representation* of the objects being underneath the release point. If participants were failing to inhibit dominant representations, the removal of the prepotent response would not necessarily improve performance. For example, in the current study with the prepotent response removed, if monkeys fail to inhibit the representation of the target falling straight down, they should look at the place under the release point and see that the object is not there. As a result, they refrain from actually searching in the gravity location. However, not having an alternative representation of the whereabouts of the target, they engage in random search among the available locations. Similar conclusions were drawn by O'Sullivan et al. (2001) in their investigation into DeLoache's model-room task (DeLoache, 1987). Believing perseveration to be the cause of failure in 2.5-year-olds, they removed the possibility of perseverative responding yet found no improvement in performance. They concluded that inhibition at the representational level, not response level, was crucial in this task. In the case of the tubes task, a strong representation concerning falling object trajectories might override participants' ability to appropriately consider mediating factors like the presence of the tube, but participants may nonetheless have the ability to represent objects moving through tubes correctly.

Another possibility is that inhibitory failures —whether at the response or representational level— do not contribute to the so-called gravity error. If this is the case, a number of strategies could lead subjects to an error that is ostensibly the same as the gravity error. Firstly, subjects may simply be relying on a default gravity-biased expectation because they lack an effective understanding of the object's behaviour in this task. If they do not understand how a tube constrains the trajectory of an object, they may guide their search with a default expectation that objects fall straight down. The difference between this explanation and one based on inhibitory control is that here participants are not failing to employ the correct understanding or response because they cannot inhibit an incorrect understanding or response. They are unable to form the correct representation of the task, and as a consequence they actively employ the gravitational strategy as a means to find an object (rather than being governed by a bias over which they have no control). The gravity bias is not masking a correct representation, but rather filling in the gap of a lack of understanding of tubes and their relation to moving objects. The proposal that the gravity error might reflect an active recruitment of a strategy when subjects do not understand the task would accurately predict that when the straight-down response option is removed, a randomised response pattern is seen.

Not understanding how tubes work would obviously lead to a misrepresentation of the task. However, as described earlier, some authors contend that both monkeys and children do not have problems understanding the function of the tube (Hood, 1998; Hauser, 2003). Results from Experiment 3 suggest that, contrary to Hood's (1998) finding, removing the gravitational element from the task does not enable children to solve the task. Results from this experiment, like those from the standard tubes task, are significantly below chance, indicating not only that children still fail the task but also that they continue to show a straight-line bias. Children search in the box on the same side of the apparatus as the ball disappeared, showing complete disregard for the tube. If the bias exhibited on the standard tubes task *was* the result of a naïve theory of gravity, this linear bias should not be present when gravity is removed – as it is when the motion is reversed. Furthermore, throughout testing there were many occasions where both children and monkeys appeared flummoxed by the disappearance of the object into the tube. In some cases, both groups of subjects would either attempt to reach their fingers into the top of the tube as if trying to retrieve the object and in other cases they would stand up to try to look into the top of the tube (see figure 5.10). Such behaviour suggests that participants do not fully comprehend that gravity will cause objects to fall all the way down the tube.

The results from Experiment 3 point to two things. Firstly, children do not take into account how tubes constrain object movement. This contention is supported not only by findings from this experiment but also by findings that both children and monkeys do not pass the tubes task when it is presented horizontally either (Hood et al., 2000; Hauser et al., 2001). Secondly, children show what is better described as an *alignment* bias rather than a *gravity* bias. An alignment bias better explains behaviour because it exists in the absence of gravity as well as in its presence. An alignment bias may be prepotent, which, having discounted response inhibition as an explanation, may suggest that failure on the task stems from an inability to inhibit an inappropriate 'aligned' representation of the task. On the other hand, an alignment bias may reflect the active recruitment of an alignment strategy, as described above. The current study is cannot distinguish between these two possibilities.

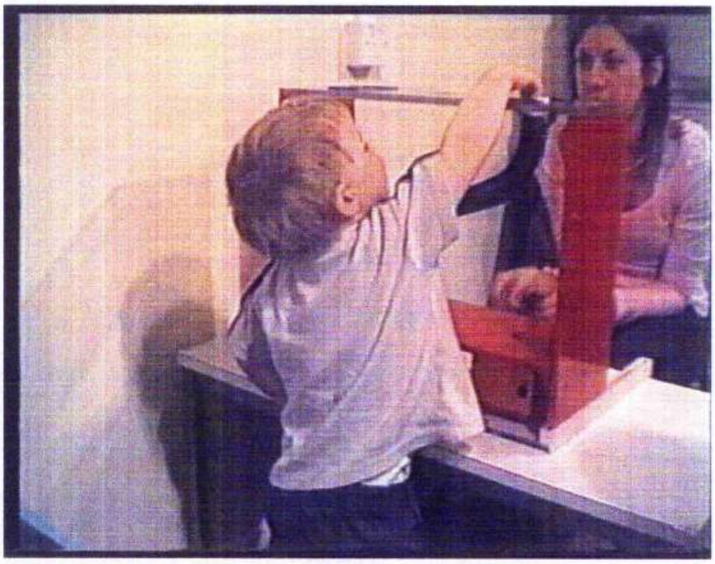


Figure 5.10 Two-year-old child reaching into the top of the tube after the ball has been dropped.

The trial-by-trial analysis of behaviour revealed that half of the children did not make the gravity error on the very first trial. In addition, although by the second trial, most children were making the error, this behaviour appears to be determined by the true location of the reward on the first trial. The emergence of the bias over the course of trials fits with Hood's finding that the percentage of incorrect responses increased with the number of completed trials (Hood, 1998). One possibility is that alignment biased search patterns reflect the active recruitment of a strategy *once* children have realised they do not understand the task.

Overall, the results from this chapter suggest that, contrary to the contentions of authors like Hood (1995) and Hauser (2003), an inhibitory failure at the response level does not explain the error on the tubes task. A number of alternative explanations may account for the observed responses in monkeys and two-year-old children. Taken together with the results from Experiment 3, it seems most likely that both groups of subjects have difficulty representing how the tubes constrain the pathway of an object, either because they do not have this knowledge or because they cannot recruit such knowledge. When given some information about how the tube functions, as in Experiment 4, children's performance improves, but this may not reflect any real understanding of the task. Finally, although the conclusions from this group of experiments have played down the role of gravity in favour of a more general alignment or proximity bias, there is another set of experiments by Hauser (2001b) which claim to have found a gravity bias in monkeys. In Chapters 6 and 7, I explore these experiments further and address some unanswered questions that have arisen.

6

GRAVITY ERROR EXPLORED: PART II

6.1 INTRODUCTION

The previous chapter proposed that the so-called 'gravity error' (Hood, 1995) of searching in the location directly beneath where an object was dropped was not dependent on gravity, and was also present when an object moved on an upwards trajectory, against gravity. In addition, it was proposed that the behaviour exhibited on the tubes task might reflect the extrapolation of the visible portion of an object's trajectory. This chapter addresses a related proposal by Hauser (2001b) that a gravity bias is also evident on a different task that both 2-year-old children and monkeys fail. This task, originally designed by Spelke et al. (1992), involves presenting participants with two search containers, one above and one beneath a solid shelf. A screen is erected in front of the apparatus and an object is dropped from above. Originally presented as a looking task, Spelke and colleagues (1992) found that 4-month-old infants looked longer at a result in which the ball would have had to pass through the solid shelf – i.e. an impossible outcome. However, in a study by Hood et al. (2003), it was found that even two-and-a-half-year-old children did not search in the correct location on top of the shelf when presented with a similar event but where a manual search response was required instead of a looking reaction. Instead, search appeared dependent on the location of the object during familiarization. If the object were presented in a lower window during familiarization, children would search in that window during a test phase even though there was now a shelf in between that would obstruct the pathway of the ball. The authors interpreted the results as evidence that even children as old as two-and-a-half years are not able to take into account the constraint of solidity on object motion in a search task.

In a more recent study with semi-free-ranging rhesus macaques, Hauser (2001b) has found that monkeys search predominantly in the lower search location on the same task. This bias towards the lower search container has led Hauser to propose that this preference reflects another dimension of the gravity bias. Not only is there an expectation that all falling objects will fall in a straight line, but there is also an expectation that falling objects will fall to the lowest possible point. According to Hauser, this prepotent expectation can override knowledge about physical constraints (in this case solidity) that the monkeys do possess. In a control condition, two boxes were placed horizontally side-by-side and a screen was placed in front of the boxes such that the monkeys could no longer see them. A reward was then rolled from one side behind the screen. Hauser found that monkeys searched predominantly in the first box, and he concludes that this provides evidence that monkeys do have the ability to take into account physical constraints. They reason correctly that the reward could not have passed through the first box and into the second, and so they direct their search towards the first box. It is the additional element of gravity that is introduced when the task is presented vertically that leads to the monkeys' failure on the vertical task.

The experiments reported in this chapter sought to elucidate the reasons why monkeys might choose to search under the shelf. I ask whether it is likely that this is a search bias based on a naïve theory of gravity that all falling objects fall to the lowest point (Hauser, 2001b) or whether monkeys might have a more general bias to search under a shelf irrespective of what kind of movement they encounter. Based on a proposal by Karin D'Arcy & Povinelli (2002) that evolutionary pressures have led monkeys to prefer to forage for food in sheltered places in order to avoid competition from conspecifics and predation, I raise the possibility that monkeys may approach a task like this with a pre-existing bias to search below the shelf for a food reward. If this were the case, the preference that monkeys exhibit for choosing the cup beneath the shelf does not reflect a naïve theory about gravity, but rather a long history of competition and predation that has led animals to develop a bias towards feeding in 'safer' locations.

Although Hauser's group of experiments does employ a number of controls to try to ensure that monkeys do not simply have a preference for a location underneath a shelf, I argue that none of these controls is sufficient. In the first control, an object is dropped from above but no screen is present so the monkey can see where the object goes (see figure 6.1a). It is possible that when the monkey sees the ultimate location of an object, any bias towards the beneath-shelf location is suppressed or that a beneath-shelf bias only arises when the monkey does not see the final destination of the food reward and where the monkey does not have an alternative representation of the food's location. This control is an instance of visible displacement and it may be that biases such as gravity or sheltered location preferences would emerge only in conditions of invisible displacement, when participants need to infer the movement of the object. Second, a control was included in which no bottom location was presented at all (see figure 6.1b), and monkeys searched entirely in the upper location. Hauser argues that if they did have a beneath-shelf bias, they should search beneath the shelf regardless of whether or not a box is present. However, this prediction seems tenuous because presumably as monkeys approach the apparatus, they can see that there is nothing beneath the shelf and by this point have probably learnt that on this task, food will be found in boxes. Third, a control was included in which two boxes were placed, one above and one below a shelf, but no reward was dropped at all (see figure 6.1c). Hauser argues that if they had a bottom box bias, they should search in the bottom box even when nothing has been dropped. However, as no food reward is dropped, monkeys have no reason to expect to find a food reward in one of the boxes and so search in this case may reflect curiosity rather than a genuine attempt to retrieve a food reward. If it is competition that leads monkeys to search preferentially beneath the shelf, the element of competition might be removed in this condition and so a bias may not emerge. The aim of Experiment 1 of this chapter was simply to explore whether, all things being equal, monkeys would exhibit a preference for the beneath-shelf location.

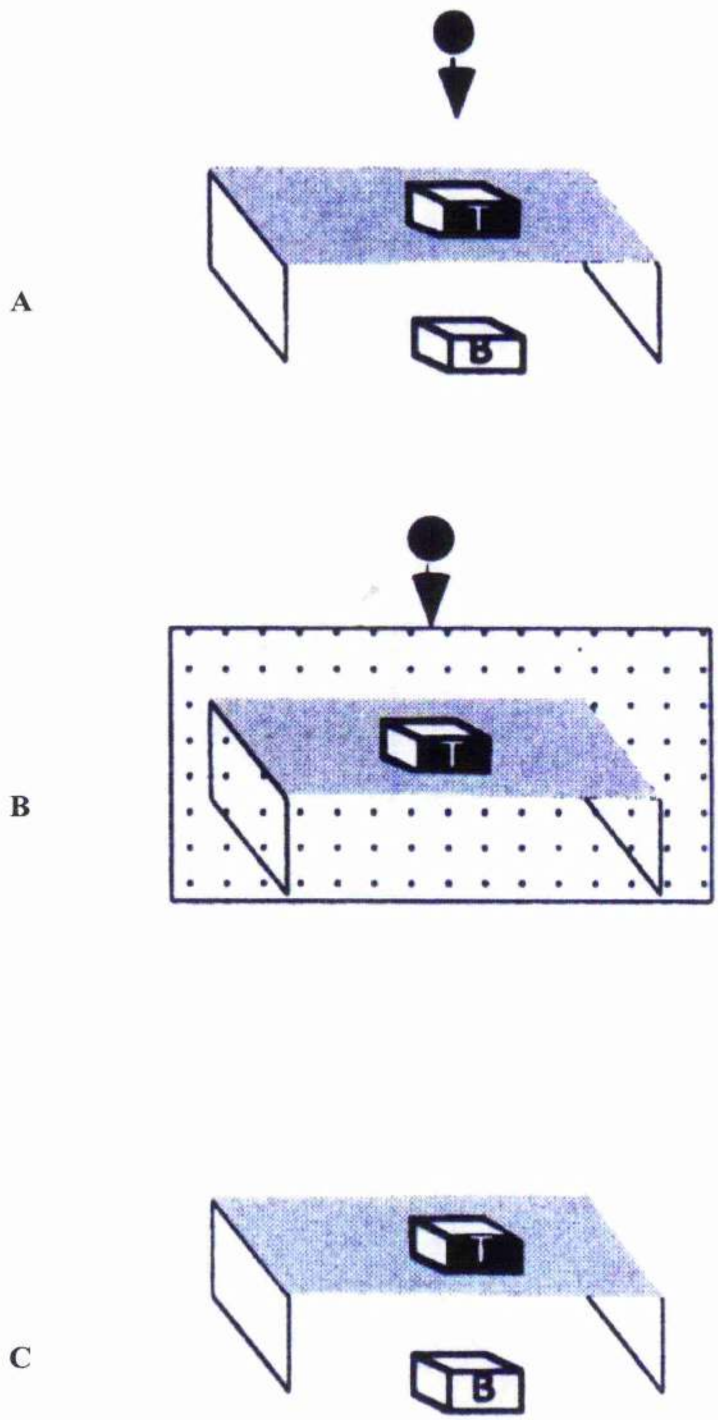


Figure 6.1 Controls employed by Hauser (2001b) to rule out intrinsic preference for lower box. (A) Ball is dropped into top box in full view of monkey (visible displacement); (B) Only one box available on top of shelf, no bottom box at all (invisible displacement); (C) Both boxes available but no object dropped.

From Hauser's work, it is clear that if a beneath-shelf bias exists, is not present when monkeys have exploitable information about where an object is hidden. In Experiments 3 and 4, Hauser demonstrated that, given sufficient spatial cues to an object's location, monkeys could find an object that was dropped behind an opaque screen.

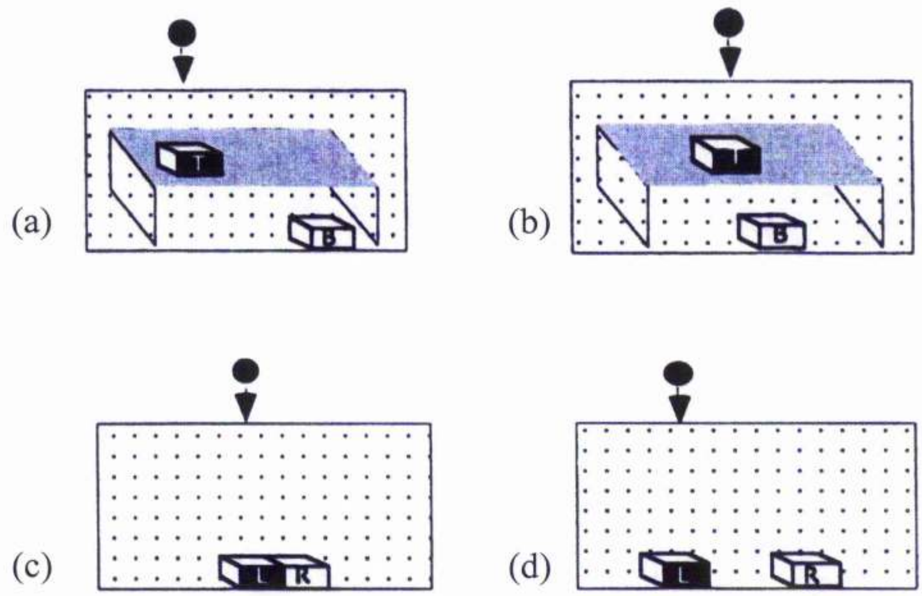


Figure 6.2 Controls employed by Hauser (2001b) in Experiments 3 and 4: (a) and (d) respectively: conditions in which two boxes are spatially distinct both with and without the shelf. (b) and (c) respectively: conditions in which boxes are spatially indistinct both with and without shelf.

In two conditions in which an object was dropped behind an opaque screen into one of two spatially distinct boxes (see figure 6.2a and 6.2d), monkeys searched correctly for the food reward, searching in the box on top of the shelf on one condition (6.2a) and in the left hand box on the other (6.2d). However, when the two boxes are not spatially distinct (as in figures 6.2b and 6.2c), monkeys' performance worsens and they search predominantly in the bottom box on one condition (6.2b) and randomly between the two boxes on the other (6.2c). It appears therefore that if there is a spatial distinction between two search locations, monkeys can use this as a cue to find a reward and if one location is beneath a solid shelf, then monkeys do not show a preference for this location if there are spatial cues available for them to use. It suggests that any beneath-shelf bias may only come into effect when monkeys do not have additional information as to the reward's location. Experiment 2 was designed to address the question of whether monkeys might have a bias towards a beneath-shelf location in an invisible displacement task in which gravity does not dictate one location to be more likely to contain the reward than the other, and in which the distance between the two locations was systematically varied. If monkeys continue to demonstrate a beneath-shelf bias when there is no difference in the gravitational plausibility of the two locations, then it would provide evidence that, given the choice, monkeys simply prefer to search beneath a shelf.

Given that Hood and colleagues have claimed an identical gravity bias in monkeys and young human children when they are presented with the tubes task (Hood, 1995; Hood et al., 1999), if performance of monkeys on the shelf task were due to a gravity bias, one would predict similar performance in children at the ages in which they manifest a gravity bias in the tubes task. However, findings by Hood et al. (2000) do not suggest a beneath-shelf bias in two-year-old human children. In that study, children did not display a preference for the bottom location, instead location preference appeared to be determined by the location where children had seen the ball appear during familiarization trials. One possible reason for the discrepancy between monkey and child performance on the shelf task is that the monkey's search pattern does not reflect a gravity bias but an intrinsic preference for the lower location. Experiment 3 investigated whether two-year-old children would display a beneath-shelf bias on a different shelf task, in which both locations are presented on the same laterality.

6.2 EXPERIMENT 1: PREFERENCE TEST WITH MONKEYS

Experiment 1 consisted of a simple preference test in which monkeys were presented with two identical food rewards, one placed on the shelf and one placed directly below. The preference test was designed to establish whether or not monkeys had any bias in the order in which they took the food rewards.

6.2.1 Subjects

The same five rhesus monkeys that took part in the experiment described in the previous chapter took part in the preference test. Additionally another three rhesus macaques also participated (Jenny, Alex and Bruno).

6.2.2 Apparatus

A wooden shelf measuring 27 cm in height by 40 cm in width was used as well as an opaque black screen that could occlude the apparatus (measuring 47 cm by 25 cm). The same small wooden stage used in the previous chapter's experiments was used in the current test in order to present the apparatus to the monkeys.

6.2.3 Procedure

The experimenter placed the wooden shelf on the stage and placed the opaque screen in front of the apparatus so that the edges of the shelf were still visible to the subject (see figure 6.3)

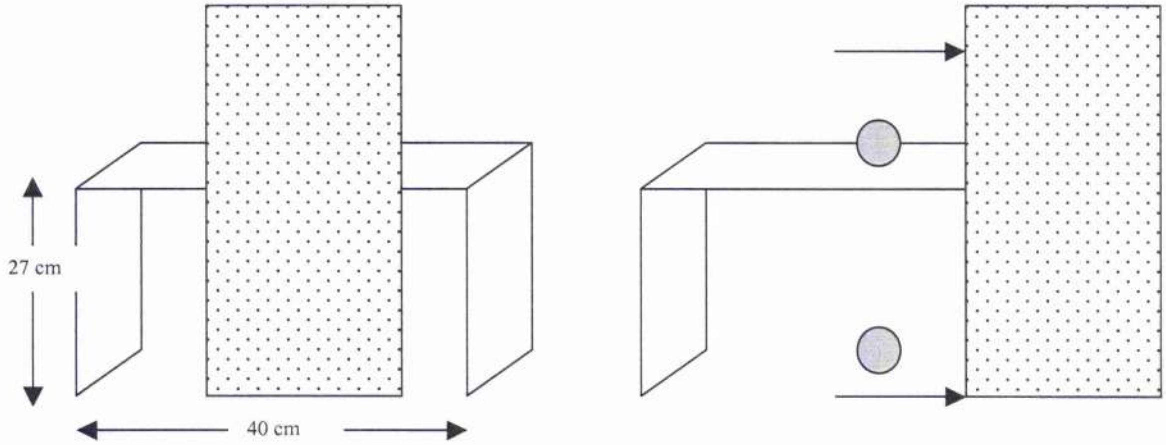


Figure 6.3 Diagram showing apparatus used in preference test.

The experimenter, sitting opposite the monkey and behind the apparatus then placed two identical food rewards behind the screen, one above the shelf and one below (see figure 6.3 above). The screen was then removed and the monkey was able to take the fully visible food rewards. Each monkey participated in up to 12 trials.

6.2.4 Results and Discussion

The food reward that the monkey took first was the variable of interest. The percentage of 'above-shelf first' versus 'beneath-shelf first' responses per monkey was calculated. Seven out of eight monkeys took the food reward beneath the shelf first more often than taking the food reward above the shelf. One monkey showed the reverse pattern of search. A one-sampled t-test shows that monkeys prefer to take the food reward beneath the shelf before taking the reward above the shelf, more often than would be expected by chance [$t(7) = 2.69$, $p \leq 0.05$].

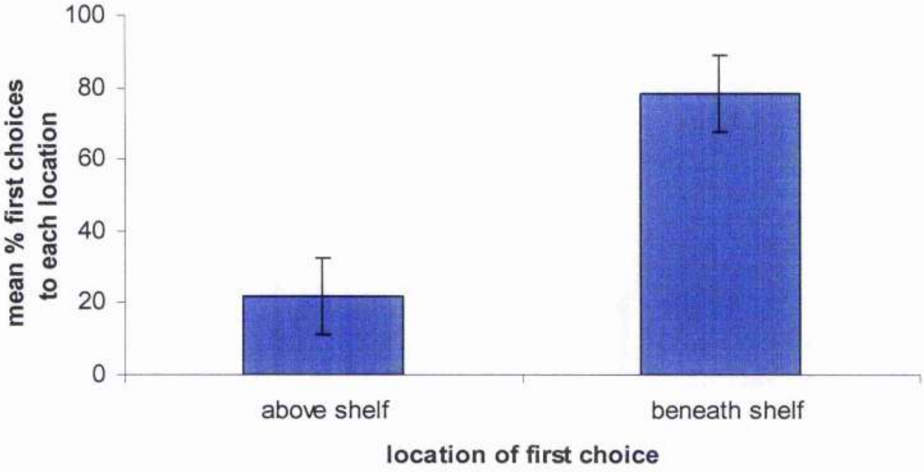


Figure 6.4 Mean percentage of first choices (± *SE*) directed at the above-shelf and beneath-shelf location.

No monkey avoided taking the food reward located on top of the shelf (after the food under the shelf had been taken), indicating that there was nothing aversive about this location. The results suggest that, all things being equal, rhesus monkeys have a bias towards taking a food reward from beneath a solid shelf. Two things can create a situation in which neither location is perceived as intrinsically more likely to contain the reward than the other. First, as is the case in this preference test, the fact that the two rewards are identical meant that only the monkey's location preference would determine their first search. Secondly, if the reward is not visible, as is the case in an invisible displacement, an inability to represent the invisible displacement of the reward may create a situation in which neither location is perceived as more likely than the other to contain the food reward. Experiment 2 presents the same subjects with an invisible displacement test in which one of the two search locations could not contain the object because it is located underneath the solid shelf.

6.3 EXPERIMENT 2: IS BENEATH-SHELF SEARCHING GRAVITY INFLUENCED?

If the monkey understands that a solid shelf constrains the falling object's pathway, then this would render the top cup a more likely location to contain the reward and therefore create an inequality between the two search locations. On the other hand, if the monkey is unable to correctly reason about the effect of a solid shelf on the object's trajectory, both locations may be perceived as equally likely to contain the reward. However, the presence of discernable spatial cues may provide the monkey with an alternative cue to the reward's location and, even if unable to reason about physical constraints, the information provided by spatial cues may create an inequality between the two locations such that the monkey now perceives one location as more likely to contain the food reward than the other.

Considering monkey performance on Hauser's controls, it is likely that the beneath-shelf bias revealed in Experiment 1 is only exhibited when monkeys cannot decipher where the food reward has gone or where there is nothing that makes one location more likely to contain the reward than the other. Experiment 2 of the current study was designed to investigate whether a beneath-shelf bias is exhibited in an invisible displacement task in which there is no difference between the two search locations in terms of gravitational plausibility. In other words, if monkeys do have a naïve theory of gravity in which they expect all falling objects to fall to the lowest point, then, if both search locations are on the same level, both are equally plausible. If monkeys continue to display a preference for a search location beneath a solid shelf even when both locations fit equally with an expectation that falling objects fall to the lowest point, then, it is unlikely that a beneath-shelf bias is attributable to a naïve theory of gravity.

An experiment was designed in which two cups were placed either side of a solid shelf, so that one cup was underneath the shelf and the other cup was on the outside of the shelf (see figure 6.5). The distance between the outside cup and the inside cup was varied systematically. Based on Hauser's findings and the findings in Experiment 1 of the current chapter, it was predicted that monkeys would show a beneath-shelf bias in the absence of sufficient spatial cues to delineate the two search locations (i.e. when the two search locations are very close together) but that this bias would disappear when spatial cues became useful (i.e. when the cups are further apart). A control condition involved the shelf being removed so that there were no differences in the appeal of either cup. The control condition was included to ensure that there was no intrinsic preference for the outside, as opposed to, the inside cup. In the absence of the shelf, when the two search locations are close together and there are therefore no spatial cues available as to the location of the object, search should be random.

6.3.1 Subjects

The same eight rhesus macaques that took part in Experiment 1 also took part in Experiment 2.

6.3.2 Apparatus

The same shelf and opaque screen used in Experiment 1 were also used in Experiment 2. In addition, two plastic coloured cups were used as hiding containers. These cups measured 15.5 cm in height and cotton-wool was placed inside each cup to eliminate any auditory cues as the food reward fell into the cup.

6.3.3 Design and Procedure

With the experimenter sitting opposite, subjects were again presented with the same wooden shelf on top of a low wooden stage. The factor differentiating the two search locations in Experiment 2 was horizontal position and so the monkey's position in the cage was important. Experiment 2 comprised four possible paired-container configurations (see figure 6.5). In the first configuration (1), the two cups were placed directly adjacent to each other, separated only by one of the walls of the shelf and thus spatially undifferentiated. In the second (2), third (3) and fourth (4) configurations, the cup placed under the shelf was increasingly further away from the cup on the outside of the shelf. The distances between cups, measured from the centre of one cup to the centre of the other cup were 11 cm, 18 cm, 27 cm, and 35 cm for configurations 1, 2, 3 and 4 respectively. These spatial positions were marked on the table so the experimenter knew where to place the cups. Monkeys were presented with each of these four configurations once from the right (i.e. the outside cup was placed on the right side of the shelf and each of the inside cups moved further to the left depending on the configuration chosen) and once from the left (i.e. the outside cup was placed on the left side of the shelf and each of the inside cups moved further to the right depending on the configuration chosen). Subjects might choose a particular location because it is ipsilateral to their dominant hand and so presenting the task from both sides removes this potentially confounding variable.

There were two conditions: shelf-present and shelf-absent. In the shelf-present condition, monkeys were presented with the wooden shelf and any of the four configurations of cups described above. A black screen was placed in front of the shelf and a food reward dropped from above into the outside cup. The screen was then removed and monkeys were allowed to search in one cup. If they failed to find the reward on their first attempt, the second cup was removed. This aspect of the design was chosen to increase the monkey's motivation to search correctly rather than just relying on a 'search all containers' strategy. In the shelf-absent condition, the paired-cups configurations were as above but no shelf was present (see figure 6.5B). Each monkey received a total of 16 trials: 4 shelf-present trials (with 1 trial for each paired-configuration) from the right; 4 shelf-present trials from the left; 4 shelf-absent trials from the right; and 4 shelf-absent trials from the left. The order of presentation of the trials was randomised.

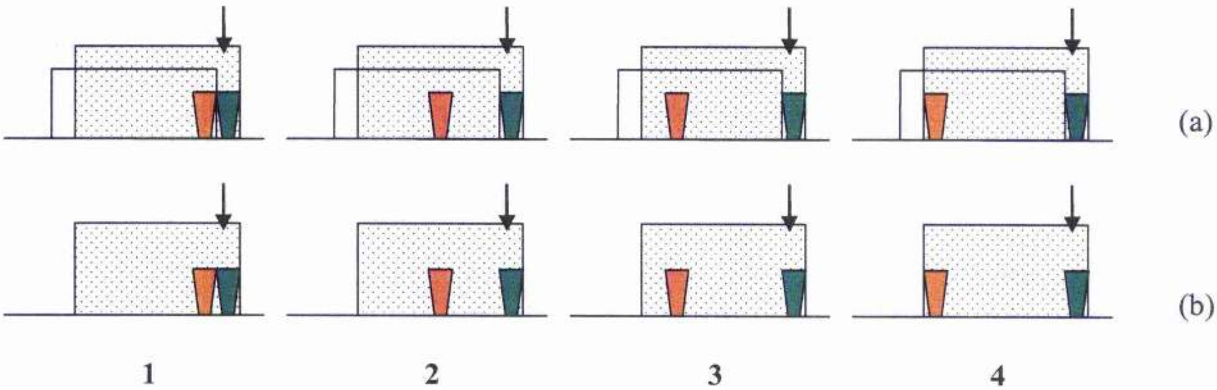


Figure 6.5 Apparatus and conditions for Experiment 2. The upper row indicates shelf-present condition (a), configurations 1 – 4 and the lower row indicates shelf-absent condition (b), configurations 1 – 4.

6.3.4 Results and Discussion

Each monkey completed 32 trials. A mean percentage correct score for each monkey was obtained for each of the 8 trial types (4 shelf-absent, 1 of each configuration and 4 shelf-present, 1 of each configuration).

A 2 x 4 x 2 repeated measures ANOVA with shelf (shelf present vs. shelf absent), configuration (positions 1, 2, 3 and 4) and side of presentation (left vs. right) all as within-subjects factors, revealed a significant effect of configuration [$F(3, 21) = 8.45$, $p \leq 0.001$] and an effect of 'shelf' that approached significance [$F(1, 7) = 4.57$, $p = 0.07$]. In addition, the interaction between 'shelf' and 'configuration' also approached significance [$F(3, 21) = 2.58$, $p = 0.08$]. Performance did not differ significantly with side of presentation [$F(1, 7) = 0.21$, *ns*]. Due to the fact that both the interaction and the factor 'shelf' were almost significant, comparisons were made between the different levels of the shelf and configuration factor, collapsing the data over side of presentation because there was no effect of this factor[1]. With an adjusted alpha of 0.99, two of the possible ten pair-wise comparisons were significant. There was a significant difference in performance between shelf-present configuration 1 trials and shelf-absent configuration 1 trials [$t(7) = 3.27$, $p \leq 0.01$), with monkeys performing significantly better on shelf-absent configuration 1 trials. There was also a significant difference between performance on shelf-present configuration 3 trials and shelf-present configuration 2 trials ($t(7) = 3.74$, $p \leq 0.01$), with monkeys performing better on configuration 3 trials.

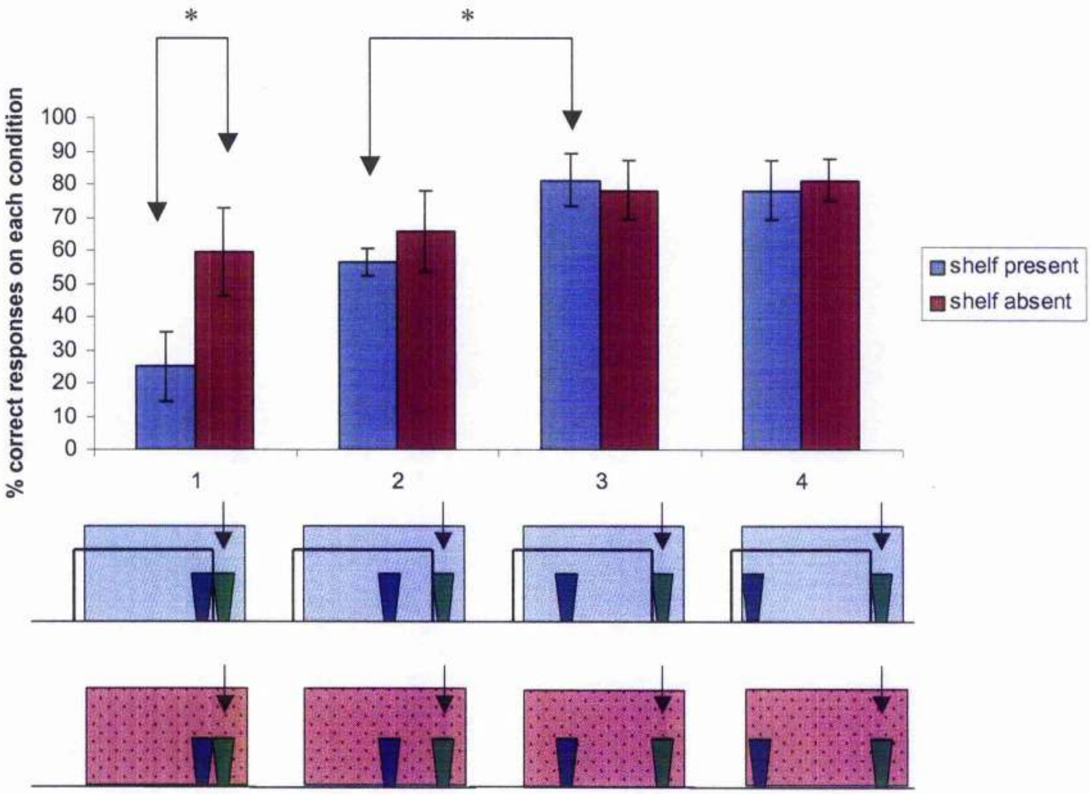
Using one-sample t-tests, performance on shelf-absent config.1 trials was not better than would be expected by chance [$t(7) = 0.7$, n.s.] but performance on shelf-present configuration 1 trials was significantly worse than would be expected by chance [$t(7) = 2.37$, $p \leq 0.05$] indicating that monkeys chose the cup beneath the shelf more than would be expected by chance. These results suggest that when containers are in close proximity such that monitoring the position from which the reward is dropped is unhelpful in providing a cue to the correct container, monkeys choose randomly between the two containers. However, with the addition of a solid shelf, so that one container is now underneath the shelf but still in close proximity to the other

[1] A Sidak test procedure was carried out in order to adjust the comparison alpha to take into account 8 possible paired comparisons. With 10 comparisons, this means that the null hypothesis is only rejected if $\alpha = 0.99$ or $p \leq 0.01$.

container, performance drops below chance because monkeys prefer to take the container underneath the shelf. Although the sidak test stipulated an alpha level of 0.99, it should be noted that one other paired-comparison nevertheless revealed an effect at the 0.05 level: monkeys performed better on shelf-present configuration 2 trials than shelf-present configuration 1 trials [$t(7) = 2.76$, $p = 0.03$].

These results indicate that as distance between containers increases, monkeys performance improves, but only in the shelf-present condition. However, when spatial cues are unambiguous (i.e. in configurations 3 and 4), it appears that the temptation to choose the container beneath the shelf can easily be overridden. This ability to override the temptation to choose the container beneath the shelf is also evident in Hauser's third experiment showing that when the top and bottom containers are significantly misaligned relative to one another, monkeys do not show a bottom box bias (Hauser, 2001b).

The results from this experiment clearly demonstrate that rhesus monkeys have a preference for searching for food in a beneath-shelf location, and this does not seem to be related to a naïve theory of gravity. Rather, in the absence of useable information as to the reward's location, monkeys will choose a cup based on their preference for location, and not on the possibility of that location containing the reward. Moreover, these results demonstrate another situation in which monkeys seem unable to take into account the constraint that the solid shelf has on the object's pathway. They appear not to understand that a falling object cannot pass through a solid shelf and into a cup beneath. The results from the control condition suggest that it is the presence of the shelf that creates a bias for the inside cup, and that when there are spatial cues to delineate the object's location, the presence of the shelf no longer exerts an influence on search.



* Significant difference at $p \leq 0.01$

Figure 6.6 Mean percentage of correct responses (± *SE*) for monkeys on each condition.

6.4 EXPERIMENT 3: DO CHILDREN SHOW A BENEATH-SHELF BIAS?

Considering the preference that monkeys appear to have for searching beneath a solid shelf both when the cup pairs are configured vertically and horizontally, it was thought fruitful to explore whether two-year-old children might also show such a preference. If the preference shown by monkeys is indeed due to a foraging adaptation to cope with competition, it is possible that such an adaptation might also be present in humans. On the other hand, if a preference for 'sheltered foraging' is a behaviour which develops as a result of monkey's foraging experiences, we might not expect children to show the same bias since human children do not have to cope with competition for food resources or predation to the same extent as monkeys. Experiment 3 aims to explore whether two-year-old children do exhibit the same bias on a task similar to that given to monkeys in Experiment 2. Experiment 3 was a modified version of Experiment 2 adapted to be more suitable for testing children. Based on pilot testing, the design employed in Experiment 2 for use with monkeys was deemed to be too lengthy and monotonous for use with young children and so a design incorporating the most important elements of Experiment 2 and Hauser's main experiment was used. In the 'shelf' task employed by Hood et al. (2000), it was found that children's choice of search location depended heavily on where they saw a toy during familiarization trials and when no familiarization trials were included, children showed no preference for searching above or beneath the shelf. These trials (hereafter called 'vertical' trials) in which a cup is presented above and beneath a solid shelf, were incorporated into the design of Experiment 3, along with trials based on Experiment 2 (hereafter called 'horizontal trials), in order to have similar data for both monkeys and children and to have vertical data against which to compare the horizontal data obtained from children. See figure 6.7 below for diagram of horizontal and vertical trials.

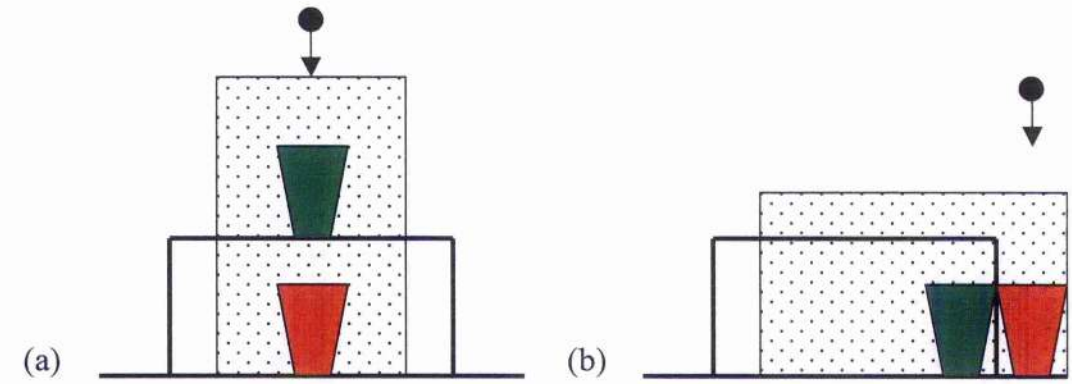


Figure 6.7 Trial types employed for use with children in Experiment 3. (a) vertical trials and (b) horizontal trials.

In addition, data was collected not only from two-year-olds but also from three-year-olds. As this is a new test, I was interested to see at what age children could solve this task and whether the ability to take into account the constraint of solidity in an invisible displacement test is something that develops generally at around three years, as was the case for both the tubes task (Hood, 1995) and the ramp task (Berthier, DeBlois, Poirier, Novak, & Clifton, 2000). It was predicted that, based on the failings of two-year-olds on these other invisible displacement tasks, they would also not be successful on this task. The aim of testing two- and three-year-olds was to explore whether they too exhibited a location bias.

6.4.1 Subjects

17 two-year-olds (11 boys, 6 girls, mean age = 25.4 months, s.d. = 1.3 months) and 18 three-year-olds (8 boys, 10 girls, mean age = 37.5 months, s.d. = 1.7 months) participated in Experiment 2. Parents were recruited through advertising and were tested in the Lincoln Babylab and the Baby & Child Lab at the University of St Andrews.

6.4.2 Apparatus

The same shelf, cups and screen used with the monkeys in Experiment 2 were used with children in Experiment 3.

6.4.3 Procedure

The child was seated at a small table opposite the experimenter. Children were tested on both horizontal trials, where the two cups were placed next to each other but separated by the shelf wall (as in configuration 1 of Experiment 2) either on the left or right of the shelf, and vertical trials where the two cups were placed one below the shelf and one directly above, on top of the shelf. Children were given up to four blocks of three trials (horizontal left, horizontal right, vertical) depending on how willing they were to cooperate. Small soft balls were used as the hiding objects and once the child was seated and the screen placed in front of the apparatus, the ball was dropped from above. The screen was then removed and the child was allowed to search until they found the ball.

6.4.4 Results and Discussion

Both two- and three-year-olds completed an average of 8 trials in the horizontal condition and an average of 3 trials in the vertical condition. Performance for each child was calculated as the proportion of correct first searches in each condition. A 2 x 2 repeated measures ANOVA with condition (vertical vs. horizontal) as a within-subjects factor and age (2 years vs. 3 years) as a between-subjects factor was carried out and revealed a significant effect of condition [$F(1, 33) = 3.97$, $p \leq 0.05$], with children performing significantly better on horizontal than vertical trials and a significant effect of age [$F(1, 33) = 12.6$, $p \leq 0.01$], with three year olds performing better than two-year-olds, but no significant interaction between condition x age [$F(1, 33) = 0.33$, *ns*].

	2 year olds	3 year olds
Horizontal trials	37.1	62.7
Vertical trials	21.5	54.2

Table 6.1 Mean percentage of correct responses on both horizontal and vertical trials for each age group.

One-sample t-tests were used to individually assess whether performance of two- and three-year-olds was above chance on either the horizontal or vertical conditions. These t-tests indicate that whereas two-year-olds are performing significantly below chance on the horizontal condition ($t(16) = 3.27$, $p \leq 0.005$], three-year-olds are performing significantly above chance ($t(17) = 2.25$, $p \leq 0.05$]. For the vertical condition, t-tests indicate that whereas two-year-olds are performing significantly below chance ($t(16) = 4.73$, $p \leq 0.001$), preferring to search beneath the shelf for the hidden object, three-year-olds performed at chance [$t(17) = 0.39$, ns].

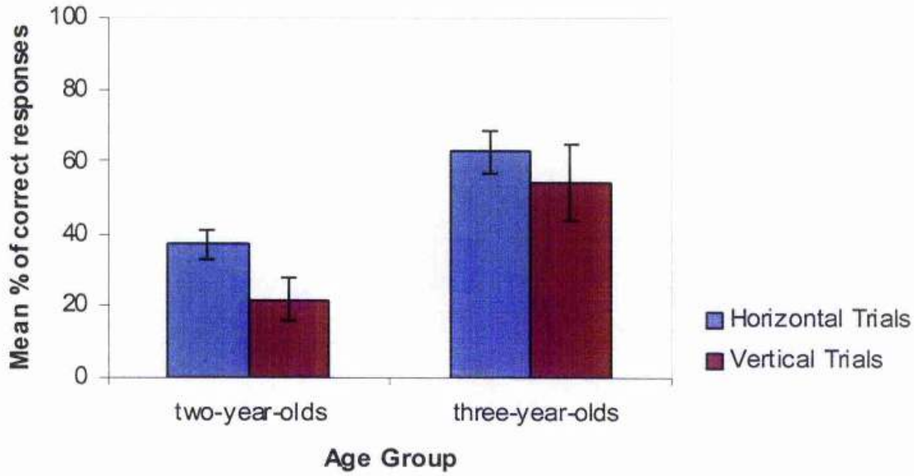


Figure 6.8 Graph showing mean percentage of correct responses (± *SE*) of two- and three-year-olds on both horizontal and vertical trials.

As with the monkeys, in the vertical condition the apparatus was presented to children from both the right and left in order to investigate whether there was any effect of handedness. Unlike with the monkeys however, a 2 x 2 repeated measures ANOVA with side (left vs. right) and age (two-years vs. three-years) as factors revealed a significant effect of side [$F(1, 33) = 3.90$, $p \leq 0.05$]. Specifically, performance on this task was significantly better when the apparatus was presented from the right rather than the left. Although two-year-olds generally performed below chance and three-year-olds generally performed above chance, when the results are separated for side of presentation, it appears that children of both ages perform better when the apparatus is presented from the right and worse when it is presented from the left.

	2-year-olds	3-year-olds
Left	24.0	57.9
Right	50.8	66.9

Table 6.2 Mean percentage of correct responses on horizontal trials presented from both the left and right, for each age group.

One-sample t-tests show that two-year-olds perform significantly below chance when the apparatus is presented from the left [t (16) = 3.68, p $\leq$0.005] but perform at chance when it is presented from the right. Three-year-olds show a similar pattern but they perform at chance when the apparatus is presented from the left, but significantly above chance when it is presented from the right [t (17) = 2.19, p $\leq$0.05]. This effect of side makes interpretation of the results difficult. On the one hand, two-year-old children demonstrate the same beneath-shelf bias as monkeys. However, this effect is only present when the apparatus is presented from the left, and when it is presented from the right, children perform at chance.

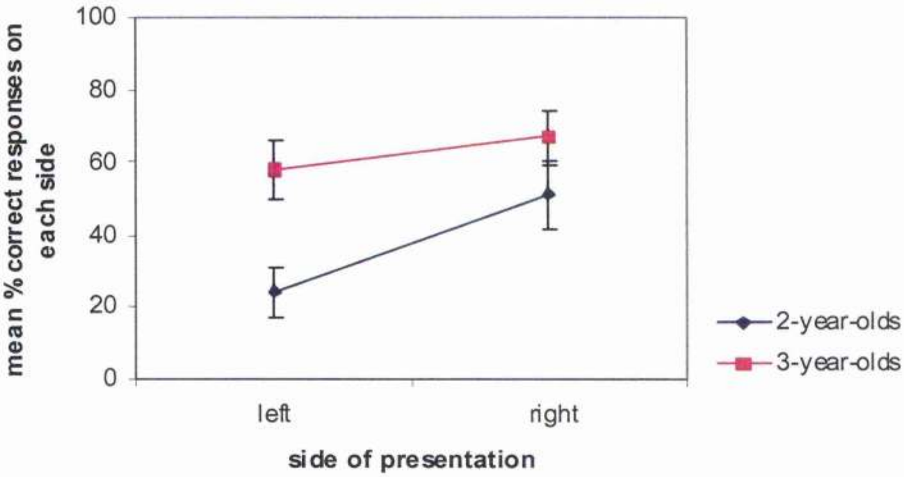


Figure 6.9 Mean percentage of correct responses (± *SE*) as a function of side of presentation.

However, a closer inspection of the results shows a differentiation within the three-year-old group on vertical trials, where 8 of the 18 children chose the correct container on every vertical trial. So, although overall the result of a one-sample t-test indicated that three-year-olds did not perform above chance on vertical trials, the data show that 8 of these children performed perfectly. An analysis of age within the three-year-old group showed that children who performed perfectly on the vertical condition (i.e. had 100% correct responses) had a higher mean age (38.1 months) than those who 'failed' (i.e. who had less than 100 % correct responses) (36.7 months). A t-test showed that this difference was significant [$t(8) = 2.80$, $p \leq 0.05$]. If a comparison is made between these 3-year-olds who perform perfectly on the vertical task and these same children's performance on the horizontal task, it seems that they make less errors on the horizontal task than do those children who failed the vertical task. The proportion of correct responses on horizontal trials for 3-year-olds who score 100% on vertical trials is 71.4 %, yet for those 3-year-olds who score less than

100% on vertical trials, the proportion of correct responses on horizontal trials is only 54 %. The correlation between subject's performance on the vertical and horizontal condition does not reach significance, yet the trend reported above does point towards a more general differentiation between children who do well on the horizontal and vertical conditions and children who perform poorly on both the horizontal and vertical conditions.

The results from Experiment 3 show that two-year-old children fail to take into account the solidity constraint imposed on object motion by the presence of a solid shelf, both in vertical and horizontal trials. However, the bias towards searching underneath the shelf on horizontal trials is only present when the apparatus is presented to them from the left. When the apparatus is presented from the right, search is at chance. The bias towards searching underneath the shelf on vertical trials is in contrast to the findings of Hood et al. (2000) in which it was shown that two-year-olds did not display a strong preference for either the top or bottom location in a similar design. By the time children reach three years however, this preference for choosing the cup underneath the shelf has disappeared and children seem able to correctly take into account the solidity constraint and choose the outside or top container. It is puzzling why some three-year-olds still display a bottom cup bias on the vertical task, but the fact that those three-year-olds who perform poorly on the vertical trials also perform poorly on horizontal trials (and those three-year-olds performing well on vertical trials also perform well on horizontal trials) suggests that failure comes out of a general inability to consider physical constraints on object motion and that this difficulty is not the result of a gravity bias.

6.5 General Discussion

The results from the experiments presented in this chapter suggest that monkeys have a bias towards searching underneath a solid shelf that is ostensibly also present in the search behaviour of two-year-old human children. The results from the monkeys point towards a bias that is easily overcome when, for example, the monkey has sufficient spatial cues as to the location of the reward.

There are a number of possible reasons why subjects show a preference for searching or taking a reward from underneath a solid shelf. Firstly, Karin D'Arcy & Povinelli (2002) have argued that subjects' (in their case, chimpanzees) initial choices concerning where to look for food rewards are "driven by several factors to which they have become sensitised in their extensive experience in coping with competition over food resources. These include (a) avoiding food that is out in the open...."(p.23 of manuscript). In the shelf paradigm, the beneath-shelf location is the more sheltered, less out-in-the-open location and it may be this that biases subjects to prefer to take a reward from beneath the shelf. Recent work by Flombaum & Santos (2004) suggests that even rhesus macaques who are well habituated to the presence of, and provisioned by humans, do still view humans as 'competitors' in situations involving food and prefer to steal food from a human whose gaze is directed away from the desired food item than the human whose gaze is not. This suggests that the visibility of food to others might influence a primate's disposition to search for it. It is possible that the food hidden in a cup underneath the shelf is perceived by the monkey as less visible to the human experimenter.

An alternative explanation concerns the relative perceptual salience of the two locations. The lower box is framed by the three walls of the shelf, which possibly make it perceptually more salient than the top box, which is not framed by any walls.

If the subject perceives a location as more salient, this may be enough to drive search to that location. Other authors have noted that young children display a centre-response bias (Benson, DeBlois, Bottani, & Hansen, 2000; Mash, Keen, & Berthier, 2003) in some search tasks and the framing of the lower box in the shelf task may highlight its centrality more than the top box. If this is indeed the case, then it may account for differences in performance of the two-year-olds in our study on those vertical trials and those in the Hood et al. (2000) study. Hood et al. found that although children failed to search correctly in their version of the shelf task, there was no inherent preference for the lower location. However, in their task, the difference in the salience of the two locations is less obvious as the two side walls continue above the shelf so that they also frame the top cup.

However, it is puzzling why two-year-old children show the beneath-shelf bias on the horizontal task (Experiment 3 of current chapter) only when it is presented on the left. I believe the most likely explanation for this pattern of search is that the majority of our child sample, like the majority of the population, are right-hand dominant (Annett, 1985; Carlson & Harris, 1985). Handedness in children emerges by about eight months of age (Ramsay, 1980; Butterworth & Hopkins, 1993) and although it was not possible to know for sure whether the majority of the children in our sample were right handed (many parents reported that they did not know whether their children were right or left handed yet), it seems a fairly safe assumption. If this is indeed the case then in the absence of any understanding of the task (i.e. a lack of appreciation for the constraints of the solid shelf on object movement) one can see how the outside container on the left of the child might become less attractive as a search option by virtue of it being a more awkward reach.

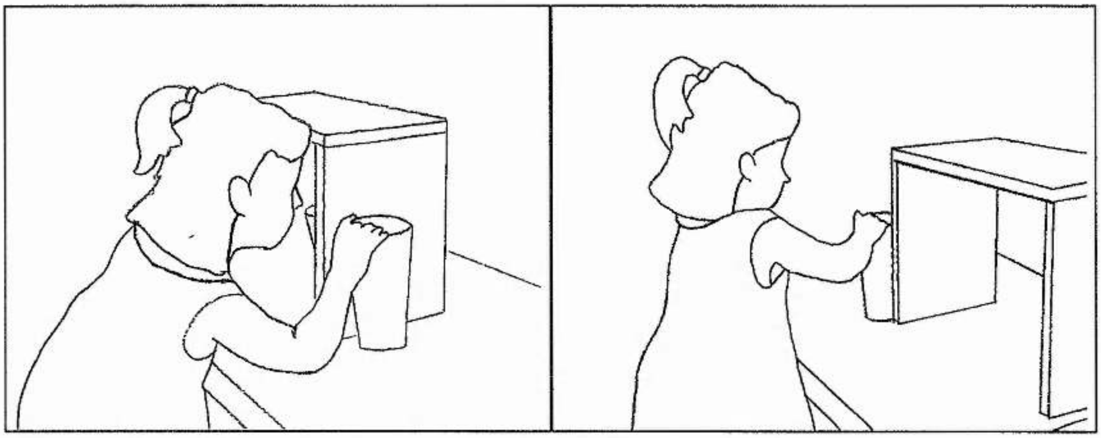


Figure 6.10 Diagram of child searching on the task presented in Experiment 3, (a) using right hand to reach ipsilaterally and (b) using right hand to reach contralaterally.

If the child is right-hand dominant and they do not alternate which hand they use depending on the side of presentation, reaching to the contralateral side when the apparatus is presented on the left might be awkward enough to create a bias towards choosing the nearer cup (which will be the cup underneath the shelf). In fact, not a single response to the correct, outside cup when the apparatus was presented to the left, was made with the right hand. However, the majority of reaches made by 24-month-old children were with the right hand (67 %). It seems likely then that this inflexible, preferred use of the dominant hand, may have lead to a bias towards the more accessible (beneath-shelf) cup when the apparatus is presented from the left. The absence of an effect of side of presentation in rhesus monkeys may be due to the fact that nonhuman primates in general show less pervasive handedness than humans (Annett, 1985; King, 1995). Specifically, in one observation of rhesus monkeys, Warren (1953) found that 45 % of subjects did not demonstrate handedness and so can be classed as ambidextrous. Whereas young human children may be resistant to using their less dominant hand, it is possible that this less pervasive hand preference in monkeys allows them to switch between hands and use the hand which is ipsilateral to the side of presentation more easily than if they had pervasive handedness.

It seems likely then that the ostensibly similar beneath-shelf bias that is shared by young human children and rhesus monkeys does not share a common aetiology. The most parsimonious explanation for the bias seen in children only when the apparatus is presented on the left is that is in an artefact of handedness, namely that children usually reach with their dominant hand and this gives rise to a preference for the less awkward-to-reach-to cup. Monkeys show this preference for searching underneath the shelf irrespective of which side the apparatus is presented on, and so it would seem that the beneath-shelf bias in monkeys reflects a real bias towards searching underneath a solid shelf. The existence of this bias in monkeys but not in human children could support the evolutionary 'peripheral feeding hypothesis' proposed by Karin D'Arcy & Povinelli (2002). When they are unsure of the location of a food reward, monkeys resort to a beneath-shelf bias that probably has its origins in a history of competing for food with other more dominant animals, something that is equally applicable to life in captivity as it is to life in the wild.

Most importantly however, the results from the current chapter argue against Hauser's contention that the bias that his monkeys exhibited on the shelf task reflects another example of naïve expectations about gravity (Hauser, 2001b). The results of this chapter suggest that there is no need to posit a gravity bias as an explanation for why monkeys prefer to search beneath a solid shelf for a falling object, since the bias exists regardless of whether there are any falling objects involved and regardless of whether there are any differences between locations in terms of gravitational plausibility. It seems more likely that neither monkeys nor children are able to take into account the presence of the shelf and the effect that this would have on the movement of a falling object. As a result, children search randomly except when it is awkward to do so (i.e. when the apparatus is presented to the left of the child) and monkeys are predisposed to prefer searching underneath a solid shelf when there is no information that would cause this bias to be overridden. However, Hauser (2001) claims that when the apparatus is presented in a horizontal orientation, such that two boxes lay side by side and a reward is rolled from the side, monkeys are able to take into account the presence of a solid wall, bolstering his claim that erroneous searching reflects an inability to inhibit a prepotent response rather than misconception of the problem. This claim will be examined in the following chapter.

7

UNDERSTANDING SOLIDITY

7.1 INTRODUCTION

The experiments presented in Chapter 6 suggest that the bias monkeys have for searching in a box underneath a solid shelf need not be explained by a naïve theory of gravity in which they expect all falling objects to fall to the lowest point (Hauser, 2001b). Rather, it appears that monkeys approach the task with a general preference for searching underneath a shelf. I proposed that the bias exhibited by monkeys and the more or less random searching of young children reflected a lack of understanding of the effect of a solid barrier on object movements that they do not perceive.

However, Hauser (2001b) proposes that monkeys are able to take into account the solid nature of a barrier if the gravitational aspect of the task is removed and that it is an inability to deal effectively with movements involving gravity that leads to a failure on some invisible displacement tasks. This claim that monkeys can pass an invisible displacement task in the absence of gravity is intriguing considering that most studies to date have concluded that monkeys are unable to solve invisible displacement tasks.

Evidence for Hauser's claim that monkeys "can solve an invisible displacement problem that involves solid containers" (Hauser, 2001b p.84) comes from the fifth experiment in his series of investigations into monkey's abilities to find hidden food rewards (Hauser, 2001b). In this particular experiment, monkeys were presented with two horizontally adjacent boxes open on their right sides and a screen erected in front of the boxes (see figure 7.1 below). A food reward is then rolled from the left, behind the screen and by necessity comes to rest in the first (near) box. Hauser found that monkeys searched significantly more in the near (correct) box than in the far (incorrect) box apparently demonstrating an appreciation for the solid constraint imposed on the object's motion by the first box. This is in direct contrast to their inability to consider the role of a solid barrier in the equivalent vertical configuration in the shelf experiment (experiment 1 of that series).

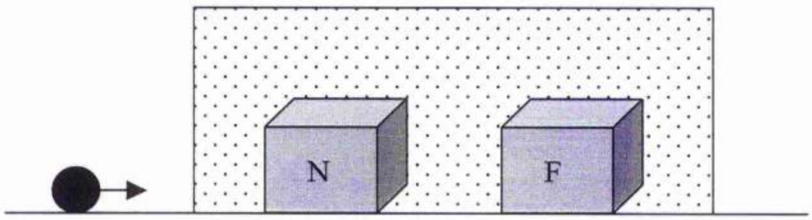


Figure 7.1 The design employed by Hauser to test understanding of solidity on the horizontal plane. When the food reward is rolled it will come to rest in the near (N) box rather than the far (F) box.

As the claims made in chapters 5 and 6 are centrally dependent on the proposition that monkeys and young children do not correctly conceptualise these tasks, it is necessary to address claims to the contrary. Although monkeys clearly do exhibit an ability to find a food reward when it is rolled behind a screen in this way, correctly conceptualising the task, reasoning about solidity and representing the invisible trajectory of the moving object is not the only way to solve such a task. An alternative means of solving it is for monkeys to simply search in the box closest to where they saw the food reward disappear. This box is the near box, the box that monkeys would also search in if they were really taking into account the constraint of solidity. Experiment 1 of the current chapter was designed to address whether monkeys do have an understanding of solidity in a slightly different task in which it was possible to alternate which of two locations, a near location and a far location, a reward ends up in. The design was chosen because it would clearly allow an assessment of whether monkeys used a 'search nearest box' strategy irrespective of physical constraints. Experiment 2 presented the same task to two-year-old children. Most of Hauser's task variations have to date not been run on young children, but considering the children's results from the previous chapter, it was predicted that children would also be unable to solve this horizontal invisible displacement.

7.2 EXPERIMENT 1: CAN MONKEYS SOLVE A HORIZONTALLY PRESENTED INVISIBLE DISPLACEMENT TASK?

7.2.1 Subjects

A total of 10 adult monkeys participated: 4 rhesus macaques and 6 stumptail macaques. See table 4.1 in Chapter 4 for details of which other experiments these monkeys also participated in.

7.2.2 Apparatus

The same blue plastic rings containing wood-shavings were used as the search locations for the current experiment as were used in the tubes experiment described in Chapter 5. A rectangular piece of wood measuring 50 cm by 40 cm served as the base for the search containers. Metal slots for holding in place an opaque black screen (30 cm x 25 cm) and a ramp ran along each side of the rectangular base, as well as a piece that connected the two longer sides together in the middle. Again, to prevent monkeys using the sound made by the object as it fell into the wood shavings, the correct location was pre-baited before each trial. The food reward that the monkey saw rolling down the ramp instead rolled into a concealed tray on the back of the opaque screen (see figure 7.2). The tray contained cotton-wool to mask any sound. A removable sloping shelf/ramp made out of polycarbonate and painted black, could slot into the base. The ramp measured 20 cm at its highest point, 15 cm at its lowest point and had a width of 15 cm. The ramp had a groove running its entire length so that the food reward would roll straight. The apparatus for monkeys had secure fastenings in place that screwed into the plastic search rings to prevent the monkey from removing them. These could also easily be moved from trial to trial so that the blue plastic rings could be correctly placed for each trial.

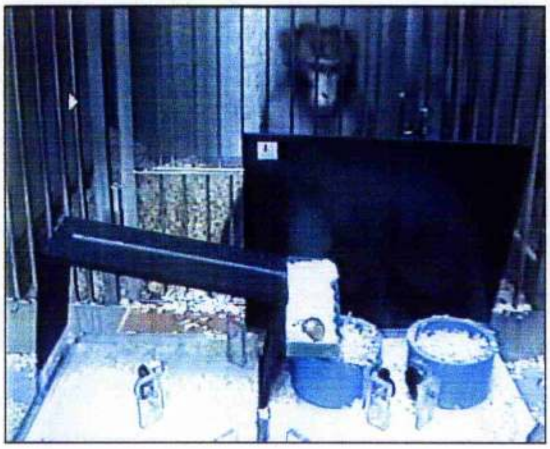


Figure 7.2 Apparatus used with monkeys in Experiment 1: 'under' trials (left) and 'after' trials (right), presented from the monkey's right and left respectively.

7.2.3 Design

There were two types of trials: 'after' trials in which both hiding containers were placed, one after the other at the end of the ramp, either from the left side or the right side of the ramp (figure 7.3 a & b) and 'under' trials in which one container was placed at the end of the ramp and the other was placed directly underneath the ramp, again with the ramp positioned from left to right or from right to left (figure 7.3 c &

d). A maximum of 12 trials were carried out per subject in three blocks of 4 trials: 'under' trial, left; 'under' trial, right; 'after' trial, left; and 'after' trial, right. The event was designed to be presented from either the left or right to avoid the potentially confounding effects of handedness.

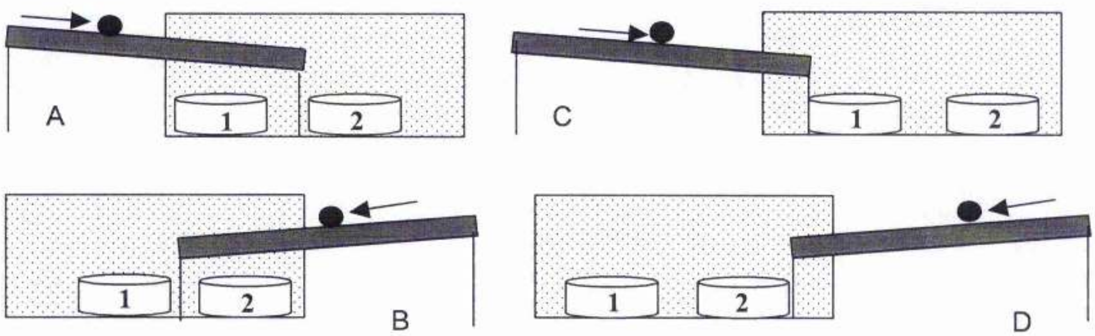


Figure 7.3 A & B: 'Under' trials from the left and right respectively. C & D: 'After' trials from left and right.

7.2.4 Procedure

The test monkey was isolated and the experimenter was seated opposite the monkey as in the general testing procedure described in Chapter 4. A number of familiarization trials preceded testing to encourage the monkeys to search in each location. In full view of the monkey and without the ramp in place, the experimenter hid a food reward in each of the plastic rings and allowed the monkey to retrieve the reward. When testing commenced, the opaque screen was then slid into place in order to occlude the two search containers but leaving the top half of the ramp unoccluded. A food reward was placed at the top of the ramp and after the experimenter had drawn the subject's attention to the object, it was released and rolled down the ramp, disappearing behind the screen. The screen was then removed and, in the case of 'under' trials, the experimenter slid back the ramp to allow the monkey equal access to both search locations (see figure 7.3b). The subjects could then search for the object.

On 'after' trials, the correct location is always the nearest box to the point of disappearance of the object, and so if subjects are using a 'search nearest box' rule, they should choose the first box significantly more often than the second. On 'under' trials, the correct location is always the furthest box (since the object could not be in the first box without passing through the solid shelf) but if subjects are using this 'search nearest box' rule, they should fail 'under' trials.

7.2.5 Results and Discussion

Seven monkeys completed 12 trials (6 'after' trials and 6 'under' trials), 2 completed 11 trials and 1 completed 9 trials. The mean proportion of correct first searches on both 'after' and 'under' trials was calculated. The mean proportion of correct first searches on 'under' trials was 17.6 % and on 'after' trials was 81.9 %. The proportion of correct searches on after and under trials was then subdivided into side of presentation. A 2 x 2 x 2 repeated measures ANOVA with condition (after trials vs. under trials) and side (left vs. right presentation) as within-subjects factors, and species (rhesus vs. stumptail macaque) as a between subjects factor, showed that there was a significant main effect of condition [$F(1, 8) = 27.3$, $p \leq 0.001$]. Monkeys performed better on 'after' trials than 'under' trials. However, there was no significant effect of side of presentation [$F(1, 8) = 3.10$, *ns*] and no significant effect of species [$F(1, 8) = 0.74$, *ns*]. Further one-sampled t-tests indicate that monkeys are performing significantly below chance on 'under' trials [$t(9) = 6.20$, $p \leq 0.001$] and significantly above chance on 'after' trials [t (9) = 5.98, p < 0.001] suggesting that search is not random.

Looking at performance on both 'after' and 'under' trials, the results strongly suggest that the superior performance of monkeys on 'after' trials is not due to any real understanding of the task, but rather due to a propensity for searching in the location closest to where a food reward disappears, irrespective of whether or not this location happens to be one that is physically possible. The fact that monkeys search predominantly in the ring that is under the solid shelf on 'under' trials indicates that they do not take into account solidity even in a horizontal invisible displacement test. Together, the results from under and after trials point towards the reliance on a proximity strategy or bias.

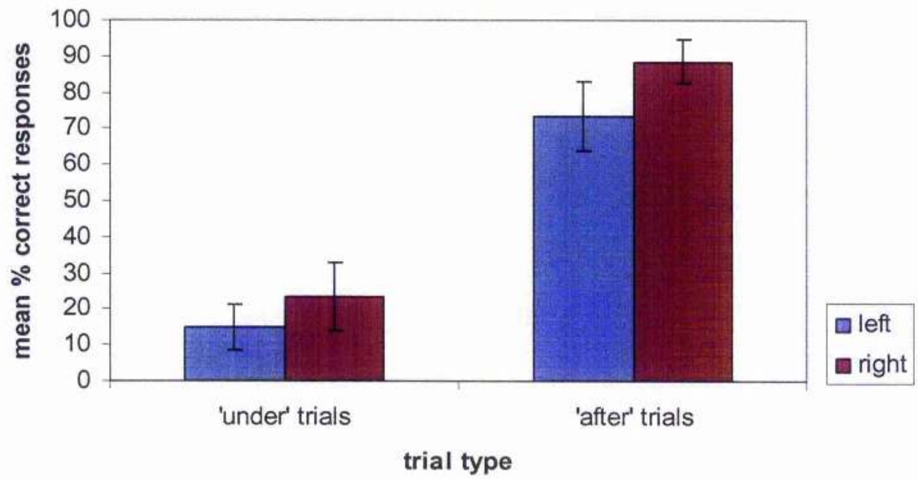


Figure 7.4 Graph showing mean percentage of correct responses (± *SE*) for monkeys, as a function of trial type and side of presentation.

Figure 7.5 Left: monkey searching correctly on 'after' trial and right: monkey searching incorrectly on 'under' trial.

7.3 EXPERIMENT 2: DO CHILDREN SHOW AN UNDERSTANDING OF SOLIDITY ON A HORIZONTAL INVISIBLE DISPLACEMENT TASK?

There exist data on two different horizontal invisible displacement tasks that two-year-old children appear to fail. Firstly, in a task devised by Berthier et al. (2000), children are presented with an opaque panel containing four doors that is placed in front of a ramp. A solid barrier is placed next to one of the doors and a ball is rolled down the ramp. The ball, by necessity, has to stop when it hits the wall and is found at whichever door is to the left of the wall. Secondly, in an experiment described by Hood et al. (2000), children are presented with a stage in which there are two compartments that can be separated by inserting a solid wall in between them. When a screen is erected and a ball rolled from one side, if the wall is present the ball will stop in the first compartment but if not, it will continue and come to rest in the second compartment. Two-year-old children fail both of these tasks. In the Berthier et al. task, children search randomly between the doors, not appreciating that the ball can only be behind the door adjacent to the solid wall and in the Hood et al. study, children chose both sides of the stage equally, regardless of the presence and location of the barrier. However, in neither of these tasks do children appear to exhibit the same proximity bias displayed by monkeys on the task described in Experiment 1 of this chapter or in Hauser's task (Hauser, 2001b). In other words, children in these studies did not tend to search more in the location closest to the disappearance of the ball. On the other hand, children older than two years (three years for Berthier et al. task and two-and-a-half years for Hood et al. task) appear able to solve both of these tasks (Hood et al., 2000; Berthier et al., 2000). Based on these findings, it was predicted that two-year-old children would also fail the task that was presented to monkeys in Experiment 1. Unlike the monkeys however, it was not predicted that they would show a proximity bias.

7.3.1 Subjects

Children: 21 two-year-olds (15 boys and 6 girls, mean age = 24.9 months, s.d. = 1.5) and 18 three-year-olds (8 boys and 10 girls, mean age = 37.3 months, s.d. = 1.6) took part in Experiment 4. Testing took place at the University of Lincoln Babylab.

7.3.2 Apparatus

The apparatus for use with children was very similar to that described in experiment 1 with monkeys. A polycarbonate base was used (67 x 41 cm) instead of wood and the search containers were small brightly coloured polycarbonate boxes (14 x 11 x 11 cm) with doors measuring 10 cm x 9 cm. These boxes were lined with layers of felt which prevented any audible cues as the ball rolled into the box. The apparatus for the children had strips of Velcro placed in each location where the boxes were to be placed so that the position of the boxes could easily be moved from trial to trial. A blue polycarbonate ramp measuring 23 cm at its highest point and 35 cm long and an opaque screen measuring 27 cm by 23 cm were also used. See figure 7.6 for photograph of the apparatus.

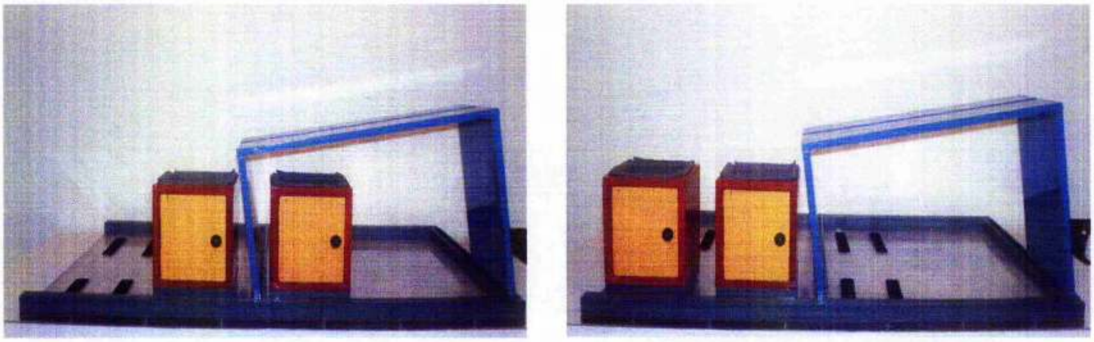


Figure 7.6 Apparatus set up for both 'under' trials (left) and 'after' trials (right), presented from the right.

7.3.3 Design

The design used for children was identical to that used for monkeys in experiment 1. A maximum of 12 trials were carried out per subject in three blocks of four trials: 'under' trial, left; 'under' trial, right; 'after' trial, left; and 'after' trial, right.

7.3.4 Procedure

The procedure with children was the same as for monkeys. Children were seated at a small table opposite the experimenter with the apparatus on the table. The only difference between the two procedures was that in the case of children, the experimenter did not slide the ramp back before allowing the child to search for the object. This was because the search containers had doors and so they were just as easily accessible without removing the ramp.

7.3.5 Results and Discussion

The mean proportion of correct first searches on both 'under' and 'after' trials was calculated for each subject. For 24-month-olds, the mean proportion of correct first searches on 'after' trials was 70.8 % and for 36-month olds it was 80.6 %. On the other hand, the mean proportion of correct first searches on 'under' trials was just 43.7 % for two-year-olds and 44.2 % for three-year-olds. A 2 x 2 x 2 repeated measures ANOVA with condition ('under' trials vs. 'after' trials) and side of presentation (left vs. right) as repeated measures factors and age (24 months vs. 36 months) as a between subjects factor revealed a significant main effect of condition [$F (1, 37) = 30.1$, $p \leq 0.001$]. There were no other significant main effects or interactions, indicating that children of both two-years and three-years performed similarly better on 'after' trials than 'under' trials.

As there were no main effects of age or side of presentation, the data were collapsed over these two factors (figure 7.7). The box plot presented below (figure 7.8) indicates that the distribution for the two-year-old group on the 'under' trials is particularly skewed to the right, as the majority of children in this group had low percentage correct scores. However, the small number of children who had higher scores on this condition led to an inflation of the mean relative to the median. As a way of transforming the data into a more meaningful distribution, the raw percentage scores for each subject were converted into a binomial distribution, by assigning each of the possible number of correct responses (out of 6) with a probability of occurring. This has the effect of lowering the overall mean (figure 7.9), bringing it closer to the median.

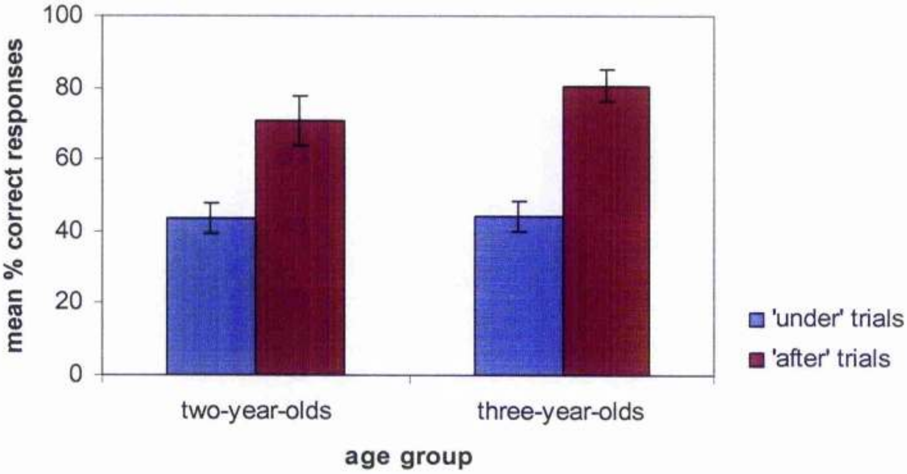


Figure 7.7 Graph showing mean percentage of correct responses (± *SE*) for both two- and three-year-old children on 'under' trials and 'after' trials.

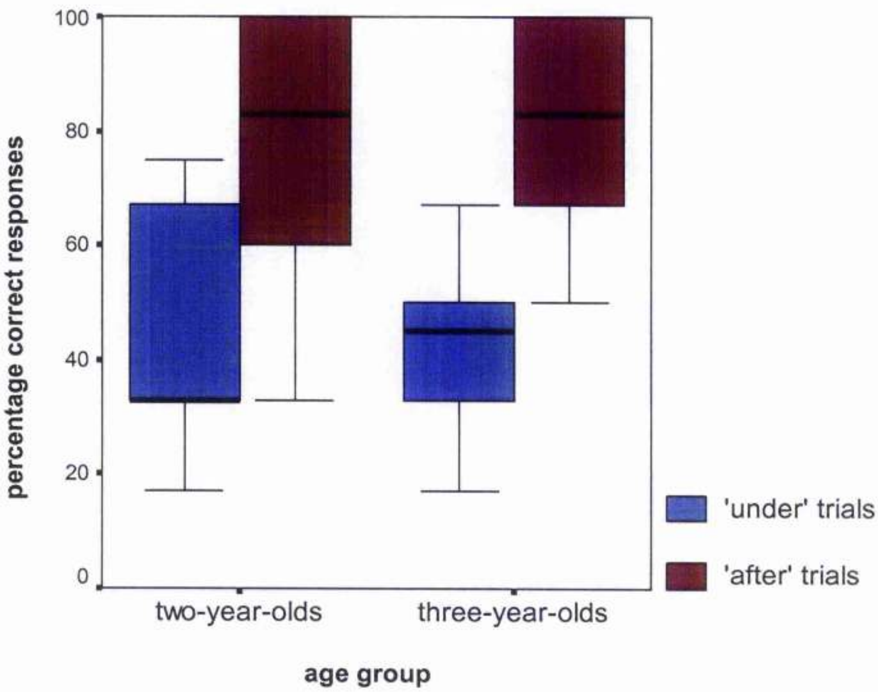


Figure 7.8 Box plot indicating the median, range and inter-quartile range of correct responses for two- and three-year-olds on 'under' and 'after' trials. The median correct responses on 'under' trials is 33 % and 45 % for two- and three-year-olds respectively and on 'after' trials is 83 % for both age groups.

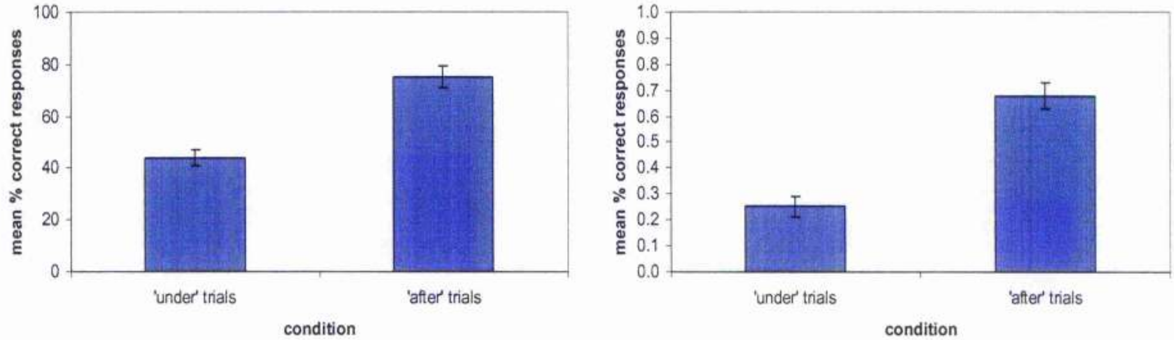


Figure 7.9 Graphs showing the performance of both two- and three-year-old children (data combined) on 'under' trials and 'after' trials. The graph on the left shows the mean percentage of correct responses (± *SE*) calculated from the raw percentage correct scores for each subject. The graph on the right shows the mean percentage of correct responses (± *SE*) after the raw data was converted to a binomial distribution.

The results from experiment 1 of this chapter indicated that monkeys were making a proximity error and searching in the location closest to the point of disappearance of the food reward. As a result, they searched below chance on 'under' trials and above chance on 'after' trials. One-sample t-tests comparing performance with chance were carried out to assess whether children also made this error of searching predominantly in the first location. These tests were carried out on the normalized data and revealed that children also performed significantly below chance on 'under' trials [$t\ (38) = 6.54$, $p \leq 0.0001$] and significantly above chance on 'after' trials [$t\ (38) = 3.58$, $p \leq 0.001$]. In this way, children's performance on this task mirrors that of monkeys.

Side of presentation	'under' trials		'after' trials	
	24 months	36 months	24 months	36 months
left	45.0	61.9	67.5	78.8
right	45.3	32.8	68.7	87.1

Table 7.1 Mean percentage correct scores for each age group as a function of trial type and side of presentation.

Table 7.1 above presents the mean percentage correct score for each age group, for each of the two trial types and depending on the side of presentation. Although the ANOVA revealed no effect of side of presentation and no significant interaction between side of presentation and age, the means suggest that three-year-olds are performing better on 'under' trials when the apparatus is presented from the left. A paired-samples t-test confirms this difference [t (17) = 2.33, p $\leq$0.05] and further indicates that it is only when the apparatus is presented from the right that three-year-old children show a significant preference for the first location on 'under' trials [t (17) = 2.1, p $\leq$0.05].

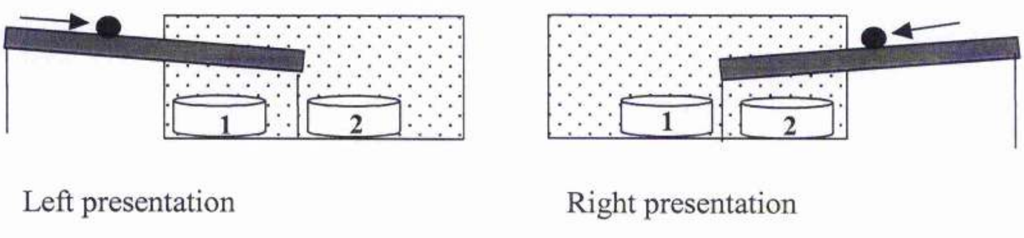


Figure 7.10 Apparatus configured for 'under' trials presented from left (left) and right (right) as designated by which side the ball rolls from.

Again, the fact that three-year-olds do better on 'under' trials when the apparatus is presented from the left is likely to be influenced by handedness. The diagram presented in figure 7.10 above is the child's view of the apparatus. When the apparatus is presented from the right, the correct location is ipsilateral to the child's left hand. Children who are right-hand dominant, as most probably are, may find it awkward to reach contralaterally with their right hand to the left box, leading to a greater degree of errors on trials in which the ball rolls from the right.

However, with such data, it is difficult to draw firm conclusions because on the one hand, it could be argued that three-year-olds do understand the task but because of an awkward reach to the contralateral side, they get lazy and just reach ipsilaterally instead, producing an error. On the other hand, perhaps the only reason why they do well when the apparatus is presented from the left is because the correct location is the right-hand location and this is ipsilateral to their dominant hand.

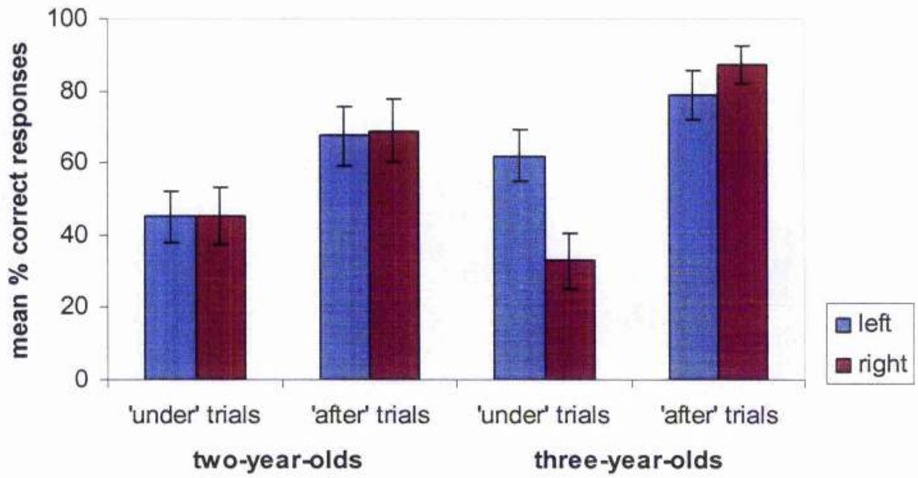


Figure 7.11 Graph showing mean percentage of correct responses (± *SE*) for both age groups as a function of trial type and side of presentation.

Figure 7.12 Two-year-old child searching incorrectly on 'under' trial (left) and correctly on 'after' trial (right).

7.4 GENERAL DISCUSSION

Both two- and three-year-old children and monkeys display a proximity error when presented with a task in which they can either search in a location closest to where a ball disappears or furthest from where a ball disappears. Rather than taking into account the effect of a solid shelf on the ball's movement, these results indicate that the search patterns of monkeys and children reflect a bias to search in the location closest to object disappearance. Whether this is a bias that children bring to the task or a strategy that they implement when the location of the object cannot be deciphered is unclear. However, what is clear is that the results of Hauser's study in which it is claimed that monkeys demonstrate an understanding of solidity, should be treated with caution. The results from the experiments presented in the current chapter not only demonstrate that our monkeys do not take into account solidity when searching for a hidden object, they are also biased towards searching in a location closest to an object's disappearance. Furthermore, this task demonstrates another occasion where two- and three-year-old children are unable to track the invisible displacement of a moving object and where the performance of monkeys closely mirrors that of young children.

In light of the findings presented in the previous chapter, one possible interpretation of the results presented in the current chapter is that searching in the first location on 'under' trials reflects a bias towards searching under a solid shelf. However, there is reason to suppose that search behaviour on this task really does reflect a different type of bias: a proximity bias. Firstly, two-year-old children exhibit the bias towards searching in the first location on 'under' trials on this task yet do not display the 'beneath-shelf' bias that monkeys display on the shelf task described in Chapter 6. Instead, the children's behaviour on the shelf task of Chapter 6 is more likely to be an artefact of handedness as it is only apparent when the apparatus is presented from the left. Secondly, three-year-old children perform fairly well on the shelf task, and do not exhibit a beneath-shelf bias despite still exhibiting a preference for the first box on 'under' trials in the experiment described in this chapter. As such, it seems more likely that the results presented in this chapter are best interpreted as a proximity bias.

Considering these results, it is intriguing that two-year-old children do not display behaviour characteristic of a proximity bias on other tasks involving horizontal object movement. For example, on the Berthier et al. (2000) task, they report no bias towards searching at the first door, which would be the location closest to the disappearance of the object. One possible reason for this difference is that in the task reported here, the apparatus was within reach of the subject as the event unfolded. In both the Berthier et al. task and the Hood et al. task, the apparatus was at a distance from the subject as the event unfolded. It has been argued by some authors that success on a task may be more likely if the subject actively participates rather than simply passively observes (Filion, Washburn, & Gulledge, 1996). It is possible then that the more participatory nature of a 'game' that is within reach of the subject evokes a different response to one that is not within reach and therefore less participatory. Chapter 8 tests this proposal with monkeys using the Berthier task that has so far only been presented out of reach of the subject (Berthier et al., 2000).

8

Is invisible displacement within reach?

The effect of involvement and apparatus movement on search

8.1 Introduction

Testing young children on manual search tasks requires a fine balance in order to obtain good data. On the one hand, the task must be interesting enough to engage the child's attention. On the other hand, it is often necessary that the child pay close attention to small details that might be missed if they are too actively involved in the 'game'. As a result, children are often seated some way from the event that the experimenter is presenting (Hood, Carey, & Prasada, 2000) or the apparatus is out of reach of the subject whilst the event unfolds and pushed towards them afterwards to allow them to search (Berthier, DeBlois, Poirier, Novak, & Clifton, 2000). This methodological problem is often magnified when testing non-human subjects because most often the object being hidden is a highly desired food reward and it is not possible to instruct the subject to wait until you tell them to search. This difficulty is reflected by the fact that the majority of Piagetian search tasks carried out with nonhuman primates have involved pushing the objects towards the animal after the experimenter has carried out all the necessary manipulations (e.g. Call, 2001; deBlois & Novak, 1994; deBlois & Novak, 1998; Dumas & Brunet, 1994; Mendes & Huber, 2004; Matthieu et al., 1976; Natale et al, 1986; Schino et al., 1990; Vaughter et al., 1972).

There are a number of potential problems that stem from this distance that is imposed in many search tasks. Firstly, it could be argued that when the apparatus is within reach of the subject, the task becomes more participatory. Participatory, in this sense, means that the subject is free to choose when to respond instead of having to wait for the experimenter's decision, and this could facilitate a better match between perception and action. Moreover, if the subject perceives their involvement to be greater, it could increase their motivation to attend to the task. Filion et al. (1996) have suggested that one of the reasons that monkeys may have succeeded on their invisible displacement task was because of the more participatory nature of the task relative to most standard invisible displacement tasks. In that study, monkeys played a computer game in which they watched moving targets disappearing behind an opaque portion of the screen. With a cursor, the monkey had to intercept the target and to do this, had to predict where on the screen the target would reappear. Because the monkey was actively involved in the task, it is possible that this higher level of participation contributed to the monkey's success on the task.

Secondly, one point that has been raised concerns the movement of the apparatus itself and the potentially distracting effect this might have on the subject's representation of the object's location (Spelke, 2002). This is of special concern when comparing performance on looking and search versions of the same task because the same movement of the apparatus does not to take place in looking tasks.

A number of different versions of the Berthier et al. (2000) task have been carried out, all with children between the ages of two- and three-years (see figure 8.1 below for task). In a version by Butler and colleagues (2002), the opaque panel was replaced by a transparent panel containing the four opaque doors. In this case, when the ball was released at the top of the ramp, children could see the ball passing between the doors and could use re-emergence or non re-emergence as cues to the ball's resting point, even if they did not take into account the solid wall. Despite this additional information, very few of the two-year-olds tested performed above chance, instead they either searched randomly or demonstrated specific door biases. This finding suggests that tracking invisible displacements is not the only factor that leads to successful searching on this task. The authors also looked at eye gaze throughout the task and found that if children broke their gaze before choosing a door, they were unlikely to choose the correct door. So, even if they tracked the ball to the right location after displacement, if they looked away from this location before opening a door, their performance was at chance. If they held their gaze, performance was better (Butler et al., 2002). Similar findings were reported by Mash et al. (2003). This result suggests that the representation that the child has of the task is very fragile and easily disrupted. It is possible that the subsequent movement of the apparatus towards the child after the ball has been rolled could lead to a disruption of gaze or of their working representation of the task.

This issue is particularly important considering that this task (the standard ramp task) has been compared to an identical looking version in the same children (Hood, Cole-Davis, & Dias, 2003). Hood and colleagues found that whilst two-and-a-half-year-old children failed to perform above chance on the standard search version of the Berthier task, when these same children were presented with outcomes in which the ball appeared at a possible location (i.e. to the left of the solid wall) or an impossible location (i.e. any of the other doors), they looked longer at an impossible outcome. Hood et al. interpret these findings as suggesting that children do show a sensitivity to solidity, but that this knowledge is not available for use in a manual search task. However, such conclusions should remain tentative because the two versions of the task are not identical. Specifically, the additional movement of the apparatus in the search task that is absent from the looking task could introduce a critical difference between the tasks. It is possible that the putative distracting effect of movement may be part of the explanation for why the perceptual knowledge demonstrated on looking tasks (e.g. Hood et al., 2003) fails to be recruited in ostensibly similar action tasks (Berthier et al. 2000).

The results from the previous chapter indicate that both monkeys and two-year-old children exhibit a proximity error or bias on a similar task involving an object rolling down a ramp and disappearing from view. The fact that two-year-olds show such a marked proximity preference on that task but do not show a similar search pattern on the Berthier et al. task is puzzling. As was noted however, the task presented in Chapter 7 was within reach of the subject. It is possible then that this difference is crucial to evoke a response based on proximity such that the proximity bias or strategy is only evoked when subjects perceive a certain level of involvement in the task. The experiment to be described in the current chapter examines this possibility by presenting the Berthier et al. task to monkeys, both within their reach and out of reach.

8.2 METHODS

8.2.1 Subjects

Eight monkeys were subjects for the current experiment and all were rhesus macaques. See table 4.1 in Chapter 4 for details of which monkeys participated, their sex and their age. The majority of these monkeys had already participated in Experiment 1 of Chapter 7, and so it was known that they made search responses based on proximity in that task.

8.2.2 Apparatus

The apparatus was designed to closely resemble that used by Berthier et al. (2000). A wooden base board measuring 87 cm in length and 23 cm in width held in place a polycarbonate ramp measuring 71 cm in length. The ramp was 10 cm wide and contained a groove down its entire length to enable an object to be rolled in a straight line. An opaque panel measuring 50 cm in length and 20 cm in height contained four doors. These doors measured 9.5 cm by 7.5 cm and were 2.5 cm apart. The doors were painted different colours as Keen (2003) has suggested that making the doors distinct from each other could aid successful searching. Each door contained a small knob and each door opened from the right. The panel was held in front of the ramp by two pieces of plastic attached to the wooden baseboard. Four different polycarbonate panels served as the walls to be inserted next to each of the doors. Each wall was designed to fit one of the four positions and so differed in length, but each wall extended 7 cm above the top of the opaque panel. The main opaque panel contained slots so that the front of each of the walls was visible all the way down the apparatus as well as from above. See figure 8.1 below for photo of apparatus.

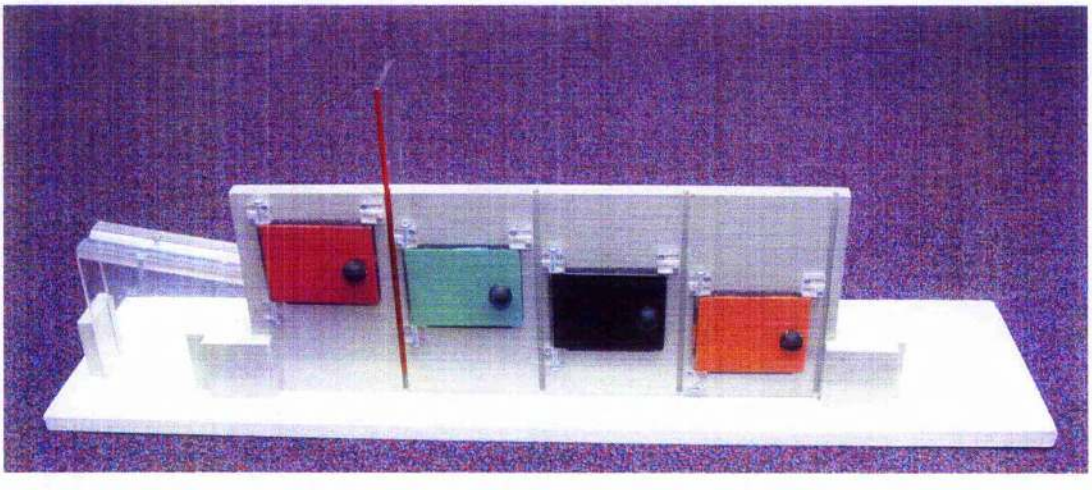


Figure 8.1 Apparatus used in current experiment.

8.2.3 Design

Each monkey participated in two conditions: within-reach and out-of-reach. In the within-reach condition, the subject could reach the apparatus throughout the event and no movement of the apparatus took place after the event. In the out-of-reach condition, the apparatus was out of the subject's reach during the event (at the back of the wooden stage – about 30 cm away from the monkey) and was pushed towards the subject to allow them to search. Each monkey participated in the within-reach condition before participating in the out-of-reach condition. The main reason for doing this is that, in the initial stages of testing with a new task, monkeys tend to be very wary and are often alarmed by the movement of apparatus. The out-of-reach condition was presented second to allow the monkeys to become familiarized with the apparatus before introducing this slightly more aversive condition. A maximum of five trials at each location were given to each monkey in each condition meaning that each monkey received a maximum of 20 trials on each condition.

8.2.4 Procedure

With the experimenter seated opposite the monkey, the apparatus was placed on the small wooden stage used in the previous experiments. A familiarization phase ensued in which a food reward was held above one of the closed doors and lowered behind the door. The monkey could then open whichever door they wanted to obtain the reward. This initial familiarization was included to ensure that monkeys could aptly open the doors and could obtain the reward without problems. All monkeys learned quickly how the doors operated and were usually able to open the doors after two or three familiarization trials, although one monkey required five familiarization trials before she managed to open the door on her own. After a monkey had demonstrated competent door opening abilities (i.e. had retrieved a food reward from behind a different door on four successive familiarization trials), a second familiarization phase ensued in which all doors were open and the solid wall was inserted next to one of the four doors. A food reward was then rolled from the top of the ramp so that the monkey could see how the apparatus functioned and could watch the reward hitting the wall and stopping. There were four of these familiarization trials; one for each door/location and the monkey was always allowed to retrieve the food reward.

The experimental trials began immediately after the familiarization phase. The experimenter closed all the doors and inserted a wall next to one of the doors. A food reward was then rolled from the top of the ramp. In the within-reach condition, monkeys could search immediately whereas in the out-of-reach condition, they could only search once the apparatus had been pushed towards them. The position of the wall was randomly determined. Monkeys were allowed to search for the reward until they found it.

8.2.5 Results

One monkey (Bruno) did not complete the out-of-reach condition as he would not tolerate the movement of the apparatus and would leave the testing area. Only three monkeys completed 20 trials in any condition. Two monkeys completed 20 trials in the within-reach condition (Pete and Cowan) and one monkey completed 20 trials in the out-of-reach condition (Nathan). Most monkeys became distracted or uncooperative before the experimenter was able to administer the full 20 trials. However, each monkey completed at least 13 trials in the within-reach condition and all but two monkeys completed at least 14 trials in the out-of-reach condition. These two monkeys (Jenny and Cowan) completed 11 trials and 8 trials in the out-of-reach condition respectively. Due to the distance of the apparatus from the monkey and their inability to fully engage in the task, it was more difficult to sustain their attention in the out-of-reach condition. The mean percentage of correct responses for each monkey was calculated. One-sample t-tests showed that neither performance on the within-reach condition nor the out-of-reach condition was above chance [$t(7) = 1.66$, n.s. and $t(6) = 0.45$, n.s. respectively]. This indicates that monkeys did not appreciate the function of the wall or the constraining nature that a solid wall has on an object's trajectory. In this sense they perform in the same way as two-year-old human children.

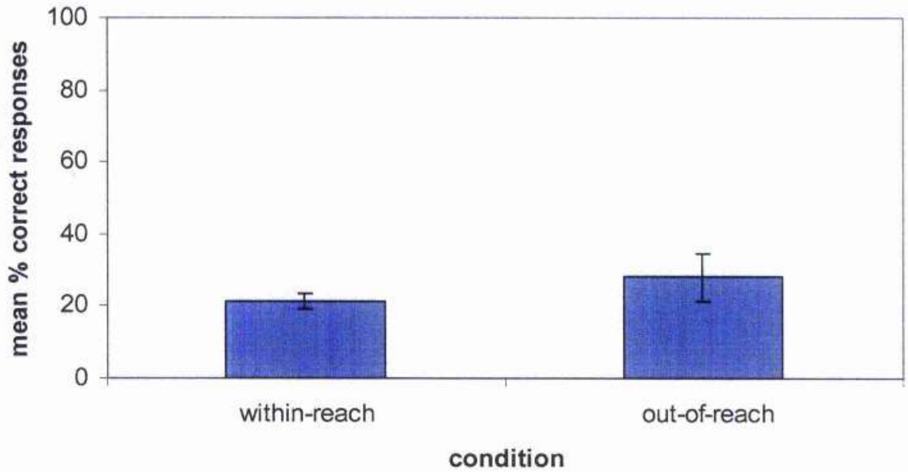


Figure 8.2 Graph showing mean percentage of correct responses (± *SE*) by monkeys on both the within-reach and the out-of-reach conditions.

8.2.6 Error Analysis

The principal aim of this study was to examine whether monkeys responses would differ as a function of whether or not the apparatus was within-reach during the event. Specifically, as the motivation for this study was the finding of a proximity bias in the somewhat similar task described in the previous chapter, the primary interest lay in whether or not there would be more responses to the first door (the door closest to where the reward disappeared from view) when the apparatus was within-reach of the subject. The mean percentage of correct responses to each location was calculated and these are displayed in the table below (table 8.1).

	Location of search			
Condition	**1**	**2**	**3**	**4**
Within reach	67	19	9	6
Out of reach	11	16	50	24

Table 8.1 Mean percentage of first searches at each location for both the within-reach condition and the out-of-reach condition.

As there were four possible search locations, chance performance on this task was 25 % correct responses. From the above table it can be seen that monkeys made many more first responses towards location 1 (the first door) on the within-reach condition compared with the out-of-reach condition. In the out-of-reach condition, the monkeys made more responses towards door 3 than any other door. The mean percentage of responses to door 1 on the within-reach condition was 67% compared with only 11% on the out-of-reach condition. If subjects were randomly selecting a door to open, each door should be selected with an equal probability of 25%. Clearly, when the apparatus is within-reach, they are not choosing randomly as the high percentage of first searches at door 1 (67%) indicates. A one-sample t-test confirms that the percentage of searches directed at door 1 is significantly greater than would be expected by chance [t (7) = 5.67, p $\leq$0.01, bonferroni corrected]. This result suggests that when the apparatus is within the subject's reach, monkeys do exhibit a proximity preference.

A one-way ANOVA with condition (within-reach or out-of-reach) as a within-subjects factor and choice of door as the dependent variable revealed three significant differences. Subjects searched significantly more at door 1 when the apparatus was within reach than when it was out-of-reach [F (1, 13) = 43.1, p $\leq$0.001, bonferroni corrected] and they searched significantly more at both door 3 when it was out-of-reach than when it was within-reach [F (1, 13) = 51.0, p $\leq$ 0.001, bonferroni corrected]. Individual one-sample t-tests comparing the mean percentage of searches at each location with chance (25%) revealed that monkeys searched significantly more often at door 3 in the out-of-reach condition than would be expected by chance [t (6) = 4.66, p $\leq$0.05, bonferroni corrected].

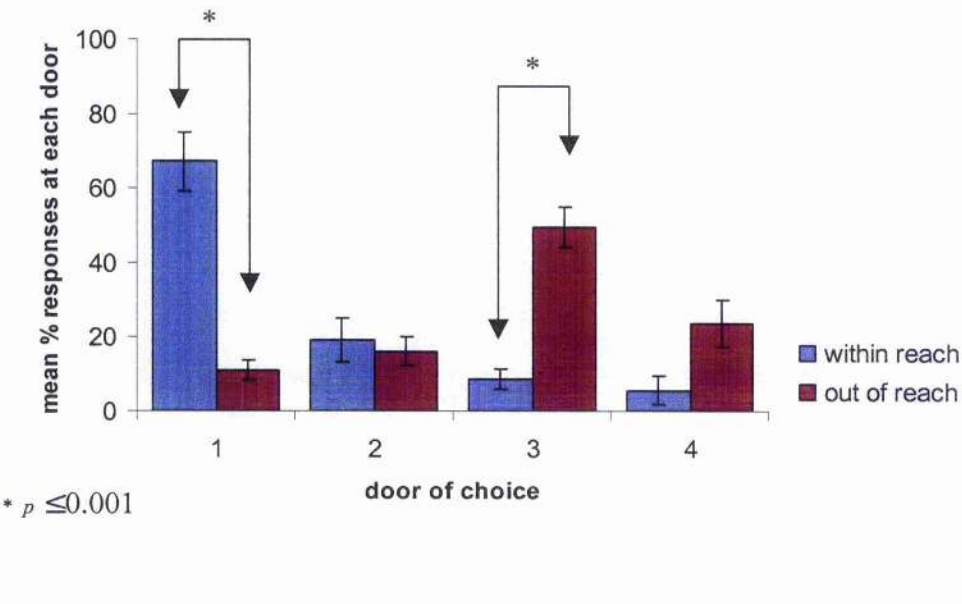


Figure 8.3 Mean percentage of searches (± *SE*) that were made to each door, on both the within-reach and the out-of-reach condition.

Finally, the question of whether or not monkeys have an appreciation that a moving object will continue to move from left to right on a linear pathway following disappearance (in accord with the principle of continuity) can be explored by looking at monkeys' second search attempts on trials where they initially make an error. On those trials where monkeys initially search erroneously at door 2 or 3, do they follow this search attempt with a further search attempt to the right rather than to the left? If monkeys search to the right of their first search rather than to the left, they are demonstrating an appreciation that the vanished object will continue moving in the same direction. An analysis of second search attempts was carried out on the data from the out-of-reach condition in which monkeys frequently directed their first search attempts to location 3 (although those trials where they initially search at location 2 were also included in analysis). Out of those trials on which monkeys initially search erroneously at either door 2 or 3 and where they make a second search attempt, this attempt was to the right on 89 % of trials. This is significantly greater than would be expected by chance [$t (6) = 9{,}23$, $p < 0.0001$] where chance is 50 % (since having searched first at doors 2 or 3, monkeys have the option of then searching to the right or to the left).

8.3 DISCUSSION

Firstly, the results from the current chapter constitute additional evidence that monkeys are not able to solve a horizontal invisible displacement task. This is true irrespective of whether the task is presented within-reach or out-of-reach of the subject. This finding is contrary to Hauser's claim that rhesus macaques are capable of taking into account a solid barrier in an invisible displacement task (Hauser, 2001). The results from the current study better fit with those from the previous chapter indicating that monkeys are not able to appreciate the constraint that a solid barrier has on unperceived object pathways, even if they have received demonstrations of the effect of the barrier. If monkeys are unable to take into account the critical element of the task that determines the object's location, what does guide their search?

Contrary to the findings of other authors who have carried out this task at a distance from the subject (Berthier et al. 2000; Hood et al., 2003), the results from the within-reach condition show a clear preference for searching in the location closest to the disappearance of the reward (door 1). When the apparatus is out of reach and then pushed towards the monkey to allow them to search, this preference for the first door disappears and monkeys appear to search predominantly at the third door.

The results from the current experiment support the findings from Chapter 7 suggesting that monkeys exhibit a proximity bias when faced with an object that has disappeared from sight. Why then do they not exhibit the same proximity bias when faced with the same task out of their reach? One explanation is that the preference for searching at the first door reflects the subject's attempt to intersect the object's pathway. If this is the case, perhaps presenting the apparatus within reach of the monkey prevents them from really considering where the object *could* be and leads them to act impulsively rather than thoughtfully. However, presenting the apparatus out of reach of the subject does not appear to facilitate successful searching either, as monkeys then appear to show a preference for searching at door three. Whilst their preference for searching at door one is explainable as a proximity bias, it is less easy to explain why they show a preference for door three. However, both Berthier et al. (2000) and Mash et al. (2003) report that children in their study searched more at the two centre doors (doors 2 and 3) than at doors one and four. Why should subjects exhibit a bias towards centre locations? Mash et al. (2003) suggest that children may have a "centre-response bias" leading them to search near the "geographic centre of a given space" (Mash, Keen & Berthier, 2003; p. 384). The authors leave open the question of whether or not this bias prevents children from considering another door or whether they simply resort to this preference when they do not understand the task.

The results from the current experiment do not suggest that moving the apparatus on this task adversely hinders the subject's searching since they do not demonstrate an ability to find the object when the apparatus is not moved. Nor do they suggest that increasing the subject's participation in the task leads to improved performance. The discrepancy seen between successful performance on the looking version of the task and unsuccessful performance on the manual search task (Hood et al., 2003) cannot therefore be solely due to the movement of the apparatus.

Finally, as noted in the general introduction, whilst we know a considerable amount about young children's understanding of continuity and object motion, we know very little about non-human species' understanding of these physical events. For example, a number of studies by von Hofsten and colleagues have shown that, by six months, infants are capable of extrapolating future object trajectories based on what they have already seen (von Hofsten, Vishton, Spelke, Feng, & Rosander, 1998; von Hofsten, Vishton, Spelke, Rosander, & Feng, 1998) and by nine months they appear able to infer the point of re-emergence of an invisibly displaced object based on its initial linear trajectory (Berthier et al., 2001; Spelke & von Hofsten, 2001). One study by Filion et al. (1996) does suggest that monkeys too can correctly extrapolate the future location of an invisibly displaced object based on its initial linear trajectory, and results from the study described in this chapter also alludes to this. That monkeys have an appreciation for the constraint of continuity on object motion – that they 'know' that the object will continue to move on a linear pathway –

is evidenced by the fact that after failing to find the object on their first search attempt, in most cases monkeys then search to the right of their first search in the direction that the object was travelling when it disappeared.

The results from this chapter may help to explain the discrepancy described at the end of Chapter 7 between the proximity preference exhibited on the experiment described in that chapter and the absence of a proximity preference on similar horizontal invisible displacement tasks (Berthier et al. 2000; Hood et al. 2000). It would seem that a proximity preference is most marked when a subject is more actively engaged in the task and it is possible that this preference reflects an attempt by the subject to intercept or chase the object as it rolls down the ramp. Although it is not possible to ascertain from these results whether it is the increased involvement of the subject in the task or the post-disappearance movement of the apparatus that generates the difference in search behaviour between the two conditions, these results highlight the large difference in search behaviour that can result from a seemingly unimportant difference between two ways of presenting a task. One way of trying to differentiate between these two possibilities might be to present the task within reach of the subject (so that no movement of the apparatus occurs before the subject can make a response) but have the subject less involved in the task by imposing a transparent screen in front of the apparatus. If, once the screen is removed, the monkey still searches predominantly in the first location, it would seem unlikely that it is 'involvement' in the task that evokes this proximity bias. In which case, when the apparatus is out of reach, the movement of the apparatus between the disappearance of the object and the time when the monkey is allowed to search may have the effect of disrupting the representation of the task that the monkey has in accord with proximity.

9

INVISIBLE DISPLACEMENTS INVOLVING GRAVITY

9.1 INTRODUCTION

The results described in the previous four chapters are testament to Piaget's claim that despite being able to solve his standard invisible displacement task by eighteen months, this "does not signify that this discovery is immediately generalized to include the whole universe." (Piaget, 1955, p 79). Clearly, there are several instances where children are unable to solve an invisible displacement task, even by two or three years of age. Moreover, these results add to the contention discussed in the introductory chapters, that adult monkeys are unable to solve invisible displacement tasks at all.

However, the tasks described in these chapters are clearly different from the standard invisible displacement task upon which Piaget's stage theory of object concept development was based. The ability to pass a standard invisible displacement, according to Piaget, signifies the emergence of symbolic mental representational abilities in young children. Once this ability emerges, children can supposedly recreate in their mind the pathway that an object took during an invisible displacement and hence are able to solve the task. So, if children have acquired the ability to mentally recreate invisible movements of objects and put it to good use in the standard Piagetian tasks, why are they unable to solve the invisible displacements described in the preceding chapters? One possibility is that these invisible displacement tasks involve the need to process and understand an additional type of information not required for solving the standard Piagetian task. The tasks presented in this thesis would seem to require an ability to process at least two different kinds of information. On the one hand, at the very least, subjects would need to have an ability to extrapolate future object trajectories from a portion of a visible object trajectory. So, for example, in order to solve the ramp task designed by Berthier and colleagues (2000), children and monkeys would need to know that when the rolling ball disappears behind the occluding panel, it continues to roll in the same linear downward trajectory that was visible before it was occluded. I will refer to this type of information as knowledge of natural object trajectories. In addition, these tasks require knowledge about the interaction of objects, what Leslie (1994) terms 'mechanical' knowledge. In order to solve the types of invisible displacements described in this thesis, subjects need both to understand natural object trajectories and those circumstances under which natural object trajectories are interrupted or modified by mechanical factors such as solid walls or tubes.

There is evidence that both young children and some monkeys do have the ability to extrapolate future object trajectories from a visible portion of that trajectory. As described in the introductory chapters, Filion and colleagues showed that rhesus monkeys can correctly intercept a moving object that has disappeared behind an occluder, as if they appreciate that the object will continue to move on its linear pathway (Filion, Washburn, & Gulledge, 1996). As described in the previous chapter, when presented with the Berthier ramp task (Berthier et al., 2000), monkeys generally tend to search from the top door to the bottom door when searching for an invisibly displaced food reward and rarely show successive searching *up* the ramp. This would suggest that they appreciate the continued downward trajectory of the now invisible object. In the case of young children, we know that by nine months infants appear able to infer the point of re-emergence of an invisibly displaced object based on its initial linear trajectory (Berthier et al., 2001; Spelke & von Hofsten, 2001).

It is possible that moving objects hold such interest for us that, while we can easily extrapolate the continued trajectory of a linearly moving object, we may focus so exclusively on the moving object that we fail to pay attention to other task-relevant features – like the presence of solid walls or tubes. This may be particularly difficult for young children or non-human primates who may have difficulty disengaging from salient features (Flavell, 1977).

On the one hand then, one of the differences between standard Piagetian tasks and those invisible displacement tasks presented in the previous chapters is that these latter tasks would appear to require the additional understanding of mechanical interactions between objects. On the other hand, these latter tasks also initially involve visible moving objects that may be so salient to a subject that they fail to take into account other task-relevant details. Either, or both, of these factors could make these types of invisible displacements more difficult.

As it appears that both monkeys and young children do have the ability to extrapolate even an invisible portion of an object's trajectory given the opportunity to witness a visible portion of this trajectory, the current experiment was designed to investigate whether monkeys and two-year-old children can go beyond this and infer the future position of an object whose initial trajectory is not visible. Although the results from the previous chapter call into question whether the bias exhibited on some tasks does result from a naïve theory of gravity *per se*, it seems that monkeys and young children do extrapolate the *continued* downward trajectory of an object that has disappeared from view. The current experiment questioned whether, in the absence of a visible portion of a downward trajectory, monkeys and young children could *infer* a downward trajectory.

9.2 General Methodology and Design

The invisible displacement task designed to address the question of whether or not monkeys and young children are able to infer a downward trajectory is depicted in figures 9.1 and 9.2. In this task, the subject is presented with three identically shaped cups, differing only in colour, and a food reward is dropped into one of the cups in full view of the subject. The experimenter then overturns the baited cup on to either one (single-displacement) or two (double-displacement) of the other cups. As the baited cup is overturned onto another cup, the object inside naturally falls into the second cup. In order to solve this task then, the subject needs to have some understanding that a) overturning the cup means that the object inside is no longer supported and so will not remain in the baited cup and b) an unsupported object will fall down. Instead of witnessing the initial trajectory of the object, subjects need to imagine the entire trajectory that the object will take. Whereas in some other tasks the initial visible portion of an object's trajectory could be argued to be enough to allow the subject to extrapolate the remaining portion of the pathway as a procedural response, the current design in which the initial trajectory needs to be inferred, requires a more explicit understanding of physical phenomena.

The study incorporated both single and double invisible displacement trials. Double invisible displacements also served as a control to the extent that if the monkey was using a strategy of searching in the last location touched, this would not suffice in order to solve double invisible displacement trials since, by necessity, the object will always be displaced into the first cup onto which the baited cup is overturned. Furthermore, a number of 'catch' trials were incorporated into the design in order to control for the possibility that subjects might solve the task by simply using a strategy of searching in the first cup touched. In catch trials, depicted in figure 9.3, the experimenter baits one cup and displaces the baited cup *upright* into another cup. In this case then, because there is no overturning, the object must still be in the baited cup and so a strategy of searching in the first cup touched by the baited cup will no longer work.

In addition, both adjacent and non-adjacent displacements were included in the design as this has also been identified as a factor that appears to influence successful performance, in both children and non-human primates (Call, 2001). Figure 9.4 depicts each of the possible adjacent and non-adjacent invisible displacements that are possible. An adjacent displacement is one in which the baited cup is overturned onto the next sequential cup in the line, whereas a non-adjacent invisible displacement is one in which the baited cup is overturned onto the cup that is not sequentially adjacent. One reason why non-adjacent invisible displacements may result in less successful searches is because in order to solve them, subjects need to bypass a middle container. This is most pertinent when the design incorporates what Dumas and Brunet called a 'comprehensive' procedure whereby the subject is not shown that the original baited container is empty after the displacement and so there may be a number of possible search locations (Dumas & Brunet, 1994). If the subject begins by searching in the originally baited container but does not find the object, they would then need to recall another visited box as an alternative search location. If this other location is not adjacent to the location of first search, the subject will need to bypass another box. Bypassing an empty location may be particularly difficult for some subjects because they may not possess the necessary inhibitory capacities. Indeed, Call (2001) concluded that this was the most likely explanation for failure of non-human primates and human children on his tests of invisible displacement. On the current task, non-adjacent trials were those in which the displacement was from cup 1 to cup 3 or vice versa. If the monkey made the error of searching in the originally baited cup first, they may then find it difficult to bypass the middle location (cup 2).

9.3 EXPERIMENT 1: MONKEYS

9.3.1 Subjects

Six monkeys participated in the current study. An additional monkey was initially tested but showed such a strong side bias that testing was stopped. Those monkeys that participated in the current study are listed in table 4.1 in Chapter 4. 4 males and 2 females ranging in age from 3 years to 8 years at the time of the experiment, took part. These monkeys had previously taken part in a number of other studies and again, these details are listed in table 4.2.

9.3.2 Apparatus

Three identical cups were employed as the hiding locations for the current study, differing only in colour (green, orange and blue). These cups measured 15.5 cm in height. The same cups had already been used in the experiment described in Chapter 6, and so the monkeys had already had experience retrieving a reward from these containers. However, monkeys would never retrieve a reward from the cups by overturning the cups themselves. The usual method of retrieval during the experiment described in Chapter 6 would involve the monkey knocking the cup over so that the reward would roll out, or tipping the cup towards them with one hand and taking the reward out with the other hand. To ensure complete opacity, coloured paper matching the colour of each cup was placed around the inside of each cup. Cotton-wool was placed at the bottom of each cup to mask any sound that the food reward might make as it fell from one cup to the other. In addition, a plastic board measuring 50 cm by 30 cm was used as a base to place the cups on so that the cups could be moved out of reach of the monkey if need be. Again, the apparatus was placed on the small wooden stage used throughout the experiments described in this thesis.

9.3.3 Design and Procedure

The experimenter sat opposite the monkey on a small stool behind the wooden stage. The three cups were placed equidistant apart (roughly 17cm apart from each other) on the plastic board, which had been placed on top of the wooden stage. The cups were placed within reach of the monkey and the monkey was permitted to handle the cups and to look inside each cup until they were satisfied that there was no reward inside. Initially they would remove the cotton-wool in their search, but most monkeys quickly stopped doing this. Once the monkey had stopped looking in the cups, they were again placed upright, equidistant apart. The experimenter then took a food reward, showed it to the monkey, and held it above one of the three cups. When the monkey was looking at the reward, the experimenter dropped the reward into one of the cups. On a single invisible displacement, the experimenter then overturned the baited cup onto one of the other two cups, such that the monkey could not see the transfer of the food reward from the baited cup to the empty cup. The experimenter then replaced the overturned cup in its original upright position and the monkey was allowed to search. The procedure for double invisible displacements was the same except that after the experimenter had overturned the baited cup onto one of the other two cups, she then moved the cup, still in its overturned position, onto the other

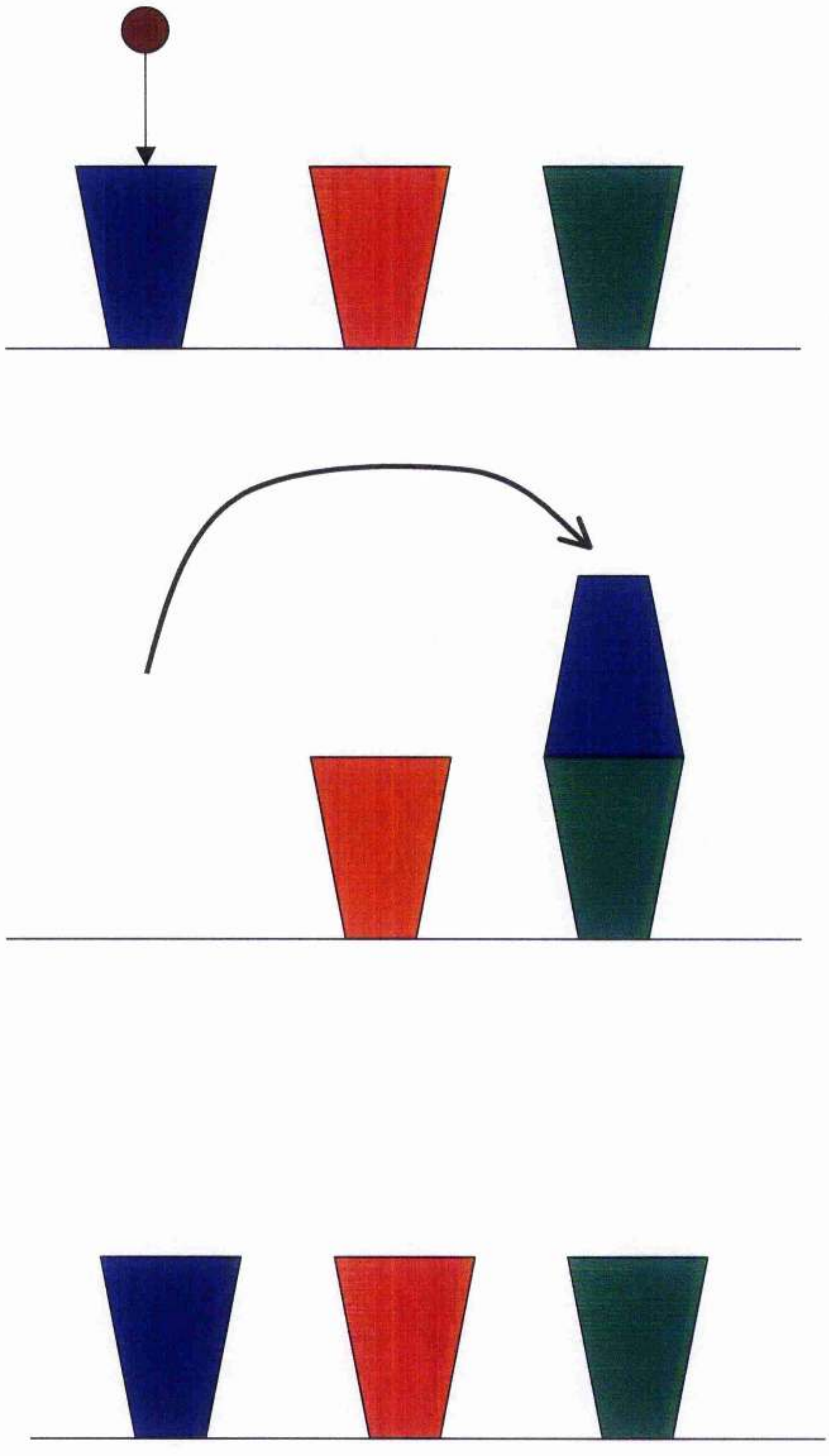


Figure 9.1 Diagram of single invisible displacement

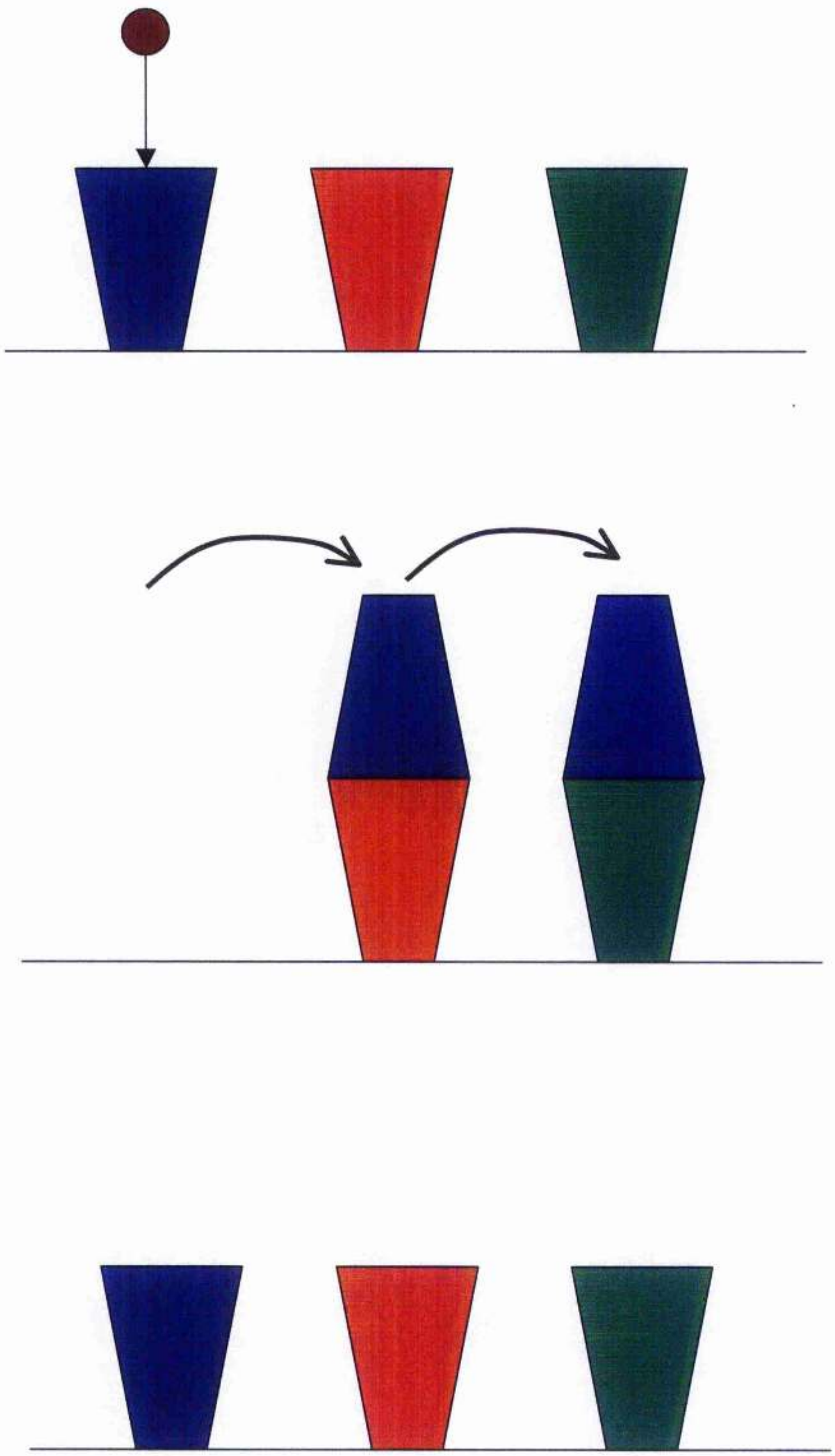


Figure 9.2 Diagram of double invisible displacement.

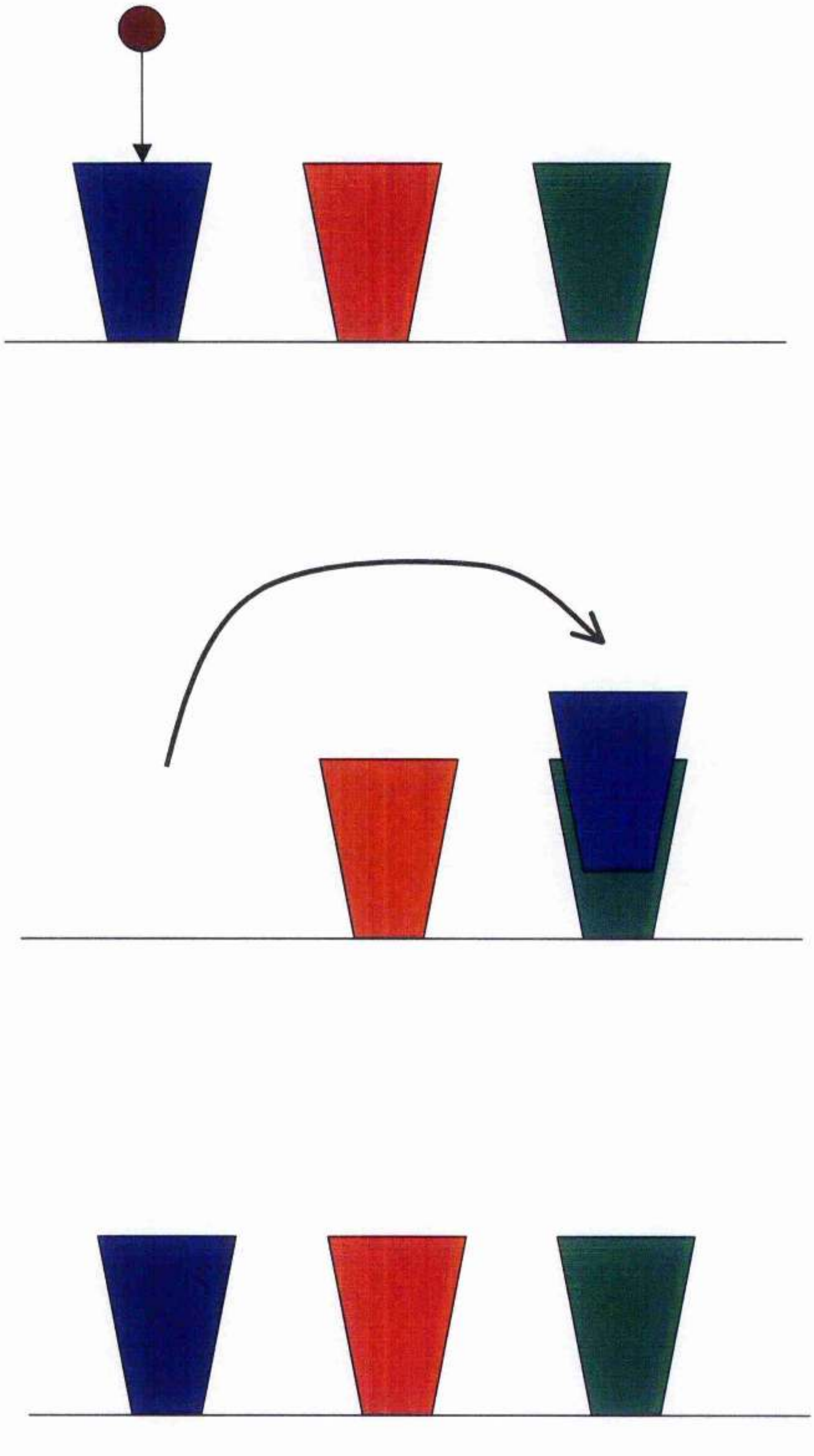


Figure 9.3 Diagram of catch trial

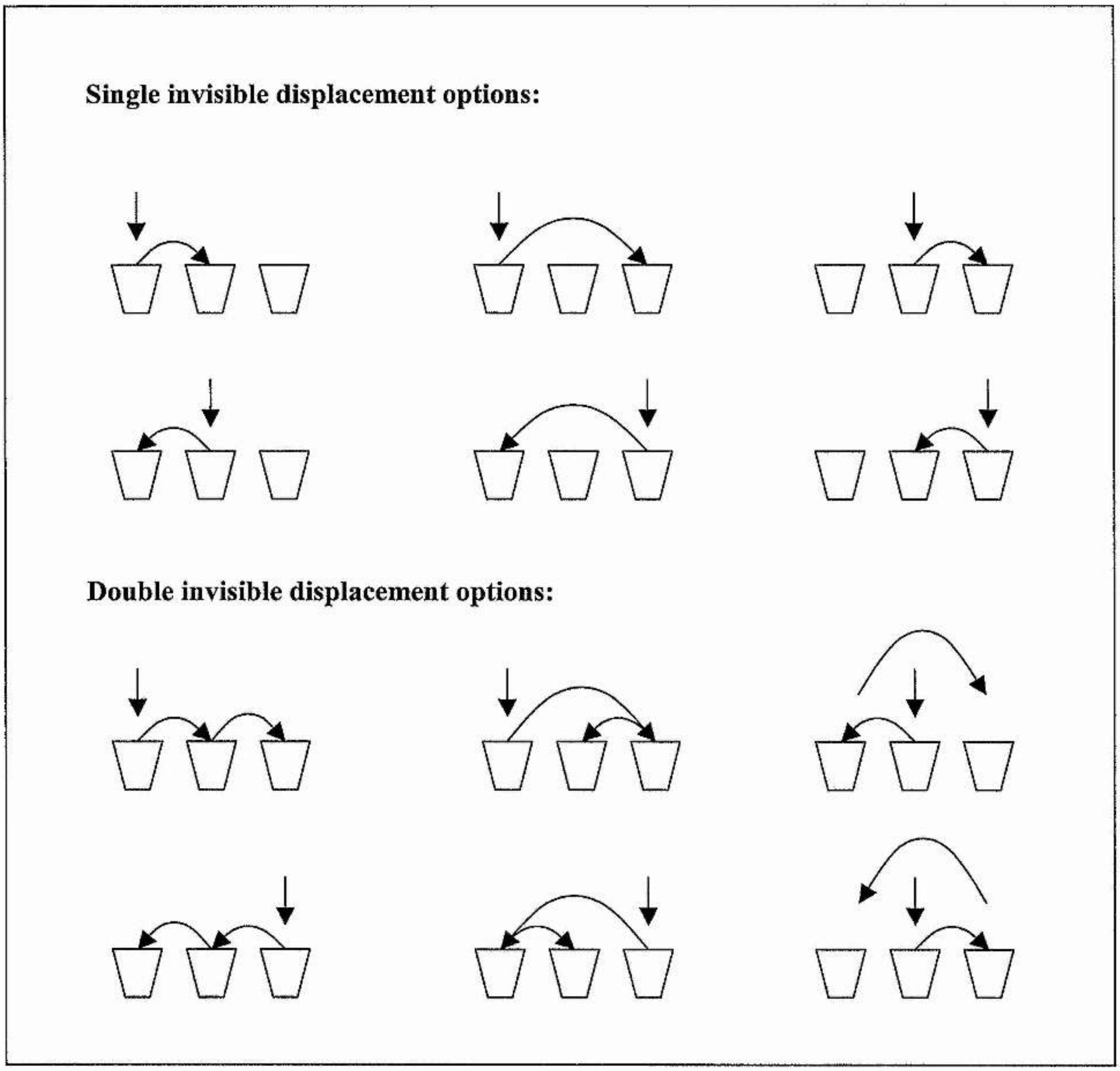


Figure 9.4 Diagram of all possible invisible displacements.

empty cup and then replaced the cup in its original upright position. In as far as was possible, the manipulations were carried out within reach of the monkey. Occasionally a monkey continued to try to take the upright cups even after they had already looked inside them at the beginning of each trial. In these cases, the experimenter would slide back the base so that the cups were just out of reach of the monkey during manipulations. This was the case for both Alex and Jenny.

At the beginning of their first session, four of the six monkeys (Pete, Alison, Alex and Jenny) appeared very preoccupied by the presence of the third cup. During manipulations, two cups were always engaged by the experimenter; the one being baited and the one onto which the baited cup would be overturned. For these three monkeys, the presence of the third cup that was not being manipulated seemed to engage their attention to such an extent that they would continue trying to reach for this third cup rather than observing the actions of the experimenter. Rather than losing the subjects completely, it was decided to remove the third cup and only test these monkeys on single invisible displacements during that session. Having participated in one session where they were only presented with two cups, all four monkeys were then tested again with three cups on double invisible displacements in a second session, where they did not appear to be preoccupied by the third cup.

A maximum of 20 trials were carried out per session consisting of both single and double invisible displacements, randomly ordered. The number of completed trials and the length of the testing session varied depending on the monkey's attentiveness and willingness to cooperate, as did the number of trials aborted due to monkeys either leaving the testing area before manipulations were complete or being distracted and not watching at the experimenter's actions. Monkeys were tested over the course of 2 or 3 sessions, depending on how many trials they were willing to complete in each session. Cowan, Pete and Alex were highly motivated and were willing to complete 20 trials per session in two sessions, whereas Nathan, Alison and Jenny were less willing and required an additional session of testing.

In addition, a total of four catch trials were inserted in between normal experimental trials during the second (Pete, Cowan and Alex) or third (Nathan, Alison and Jenny) session. During catch trials, the experimenter again dropped a food reward into one of the upright cups, but rather than overturning the baited cup *onto* one of the other cups, the baited cup was instead inserted upright *into* one of the other cups. The experimenter attempted to ensure that the amount of time that the baited cup was inserted into the other cup was roughly equivalent to the amount of time that the baited cup was overturned for during normal experimental trials (roughly 2 seconds). The baited cup was then returned to its original position and monkeys were allowed to search for the reward.

9.3.4 Results and Discussion

All monkeys completed at least eight single and seven double invisible displacement trials, over the course of the two sessions. 5 monkeys also completed 4 catch trials and 1 monkey completed 3 catch trials. Two monkeys (Jenny and Nathan) required three sessions as they had completed very few trials on one of their previous sessions due to either distraction or refusal to approach the apparatus. Percent correct responses for each monkey were calculated for performance on single and double invisible displacements and catch trials. As a consequence of having to remove the third cup during one session for four of the monkeys, there were a greater number of completed single invisible displacements than double invisible displacements (as having only 2 cups necessitates only single invisible displacements). An average of

20 single invisible displacements and an average of 13 double invisible displacements were completed per subject at the completion of testing.

A paired-sample t-test indicated that monkeys performed better on single invisible displacements than on double invisible displacements [$t\ (5) = 3.10$, $p \leq 0.05$]. In order to assess whether performance on either the single or double invisible displacements was above chance, two analyses were carried out against a hypothetical mean of 33% (3 possible search locations). However, a consequence of removing the third cup for some of the subjects on some of the trials is that these trials in which there are only two cups cannot then be included in an analysis that compares performance with chance-level responding at 33%. With these data omitted, one sample t-tests comparing performance on single and double invisible displacement trials with chance (33%) revealed that performance was significantly above chance on both types of displacement [single: $t\ (4) = 6.79$, $p \leq 0.005$, double: $t\ (5) = 7.54$, $p \leq 0.001$].

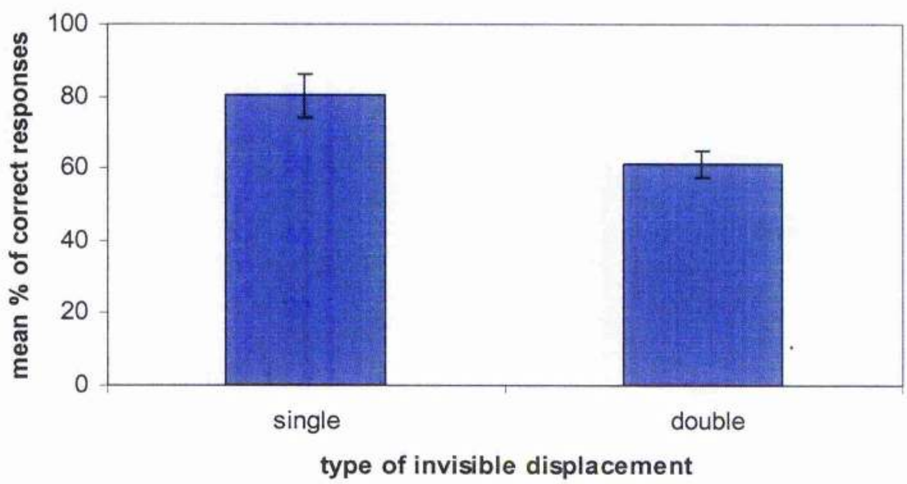


Figure 9.5 Mean percentage of correct responses (± *SE*) on both single and double invisible displacements for monkeys.

Monkey	% correct on single invisible displacements	% correct on double invisible displacements
Pete	76	71
Cowan	100	58
Nathan	68	67
Jenny	77	69
Alison	94	69
Alex	60	46

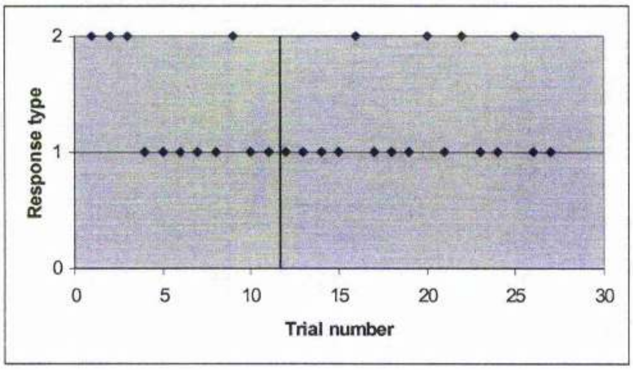
Table 9.1. Percentage of correct responses for each monkey for both single and double invisible displacements.

The above-chance performance of monkeys on both single and double invisible displacements suggests that they are not using a simple rule such as 'search in the last location touched' as the last location rule would only be a successful strategy for solving single invisible displacements. On double invisible displacements the last location touched is not the location where the reward will be found. Another relatively simple way of solving this task might be to always search in the first cup onto which the baited cup was overturned without appreciating the reason why the food reward has to be in this location.

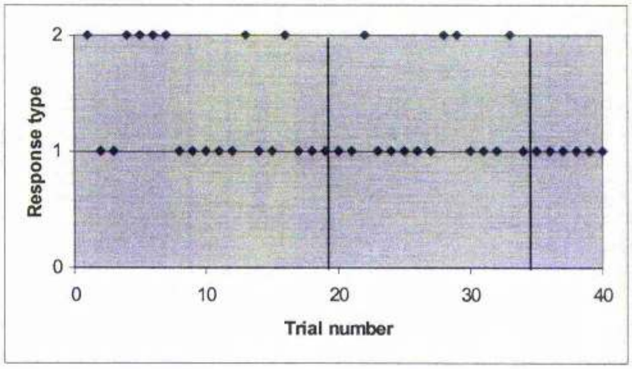
As a way to control for this strategy, catch trials were included in which the cup was not overturned onto but inserted into a second cup, such that the reward would remain in the originally baited cup. If subjects were simply searching in the first cup that the baited cup makes contact with, they would be expected to search in the second cup even on catch trials. Performance was generally poor on catch trials and a one-sample t-test showed that as a group, these monkeys did not perform above chance [t (5) = 0.42, n.s.]. However, there was considerable interindividual variability with Alex getting three of his four completed catch trials correct and Alison failing all three of the catch trials she completed. Out of a total of the 23 catch trials analysed, monkeys made mistakes on 16 of these trials. Out of these 16 trials, 14 of the errors were directed towards the cup that the baited cup was inserted into.

Performance on catch trials suggests that perhaps monkeys were simply searching in the first cup that the baited cup contacted, but did not understand the mechanics of the task – that by overturning the cup, the object inside loses support and must fall into the second cup, but that this is not the case when the baited cup is inserted upright into the second cup. Generally, searching according to a rule like this suggests a case of associative learning or a practice effect and performance tends to be characterized by a cluster of errors towards the beginning of testing and improvement over trials (Pepperberg, 2002). Such explanations are less easy to advance if errors are evenly spread throughout the trials.

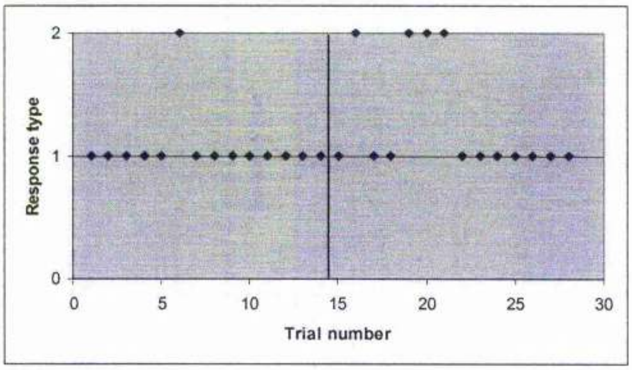
With this in mind, an assessment of the distribution of errors was carried out for each subject. Figure 9.6 presents, for each monkey, the distribution of errors that they made over the course of trials. Three out of the six monkeys responded correctly on the very first trial. Importantly however, there appears no cluster of errors at the initial stages of testing and the errors that monkeys do make appear to be distributed throughout trials. For each monkey, percentage correct performance was calculated for the first half of the experimental trials they completed and the second half of the experimental trials they completed. A paired-samples t-test indicated that performance on the second half of trials was not significantly better than performance on the first half, confirming that performance did not improve over trials [t (5) = 0.67, *ns*].



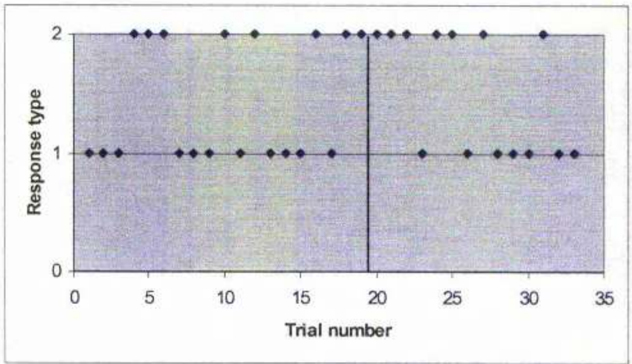
Cowan



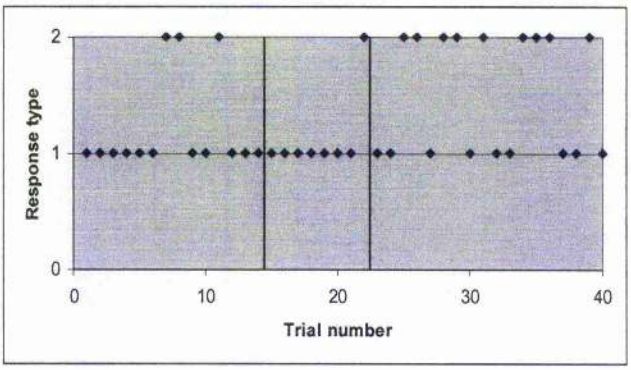
Nathan



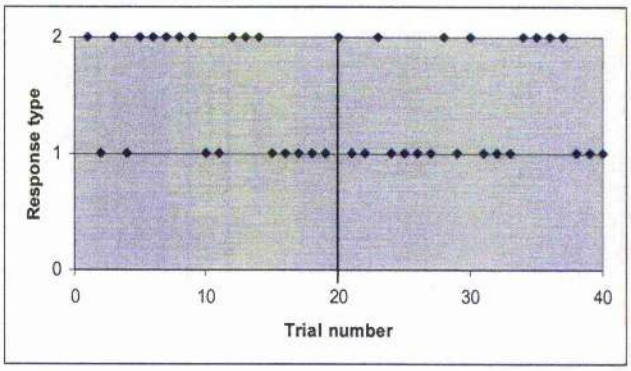
Alison



Alex



Jenny



Pete

Figure 9.6 Individual graphs of error distribution for each subject.

9.3.5 Error Analysis

Monkeys were above chance on both single and double invisible displacements, and so the number of failures with which to analyse the types of errors monkey's made is few. However, a few observations can be made from all the errors made on trials involving the presence of three cups[1]. Firstly, for two of the monkeys (Nathan and Alex), the majority of errors (82% and 86% for Nathan and Alex respectively) that they both made were directed towards the originally baited cup. For two more monkeys (Alison and Pete), when they make errors, these errors appeared to be directed more towards the centre cup (cup 2). 100% of Alison's errors were directed to this location and 60% of Pete's errors were directed towards this location, even though, for Pete, four of these errors (40%) were on single invisible displacements in which the experimenter did not engage this second cup. The errors committed by the other two monkeys (Cowan and Jenny) did not show any bias towards a particular location.

The second searches of the two monkeys who committed errors of searching in the baited cup were examined in order to establish whether there was any evidence that they could skip the middle empty location in trials in non-adjacent trials. If monkeys do make the error of searching in the originally baited cup, as both Nathan and Alex did on a number of trials, then a number of questions could be posed. Firstly, once the monkey has established that the reward is not in the baited cup, does he know that it has to be in another location that has been in contact with the baited cup? Secondly, if the only other location that has been touched is not adjacent to the

[1] Those trials in which the third cup was removed were not analysed for patterns of errors since, because there were only two cups present, if the subject made an error, by necessity they would be choosing the originally baited cup. Similarly, by necessity, second searches on erroneous trials would always be correct.

originally baited cup, is the monkey then able to skip over the untouched cup and go straight to the touched cup, or are they unable to resist the lure of the middle cup?

With only two monkeys making the error of searching in the originally baited cup, it is difficult to draw conclusions. However, in all 5 trials in which Nathan made the error of searching in the originally baited cup on his first search, he searched correctly on his second search attempt. Three of those five trials were non-adjacent trials and so required him to skip over a middle container having initially searched incorrectly. Alex, on the other hand, having initially chosen the incorrect baited cup did not show correct second searching on any of the 3 non-adjacent trials; instead choosing the next sequential cup in line.

9.4 EXPERIMENT 2: CHILDREN

9.4.1 Subjects

Participants were 20 two-year-old children, 13 boys and 7 girls (M = 25.1 months, SD = 1.4 months). An additional 5 children participated but failed to complete at least 6 trials and were eliminated from the analysis. Table 4.2 in Chapter 4 lists the children that participated in the current study and also the other studies in which they have also participated.

9.4.2 Apparatus

The apparatus for use with children were identical as those used with the monkeys, except that various small balls were used as the hiding object rather than food rewards.

9.4.3 Design and Procedure

Pilot testing with this task suggested that it would be difficult to engage children in many trials. Consequently, it was decided to divide children into two groups: a single invisible displacement and a double invisible displacement group. Originally, 15 children were assigned to the double invisible displacement group and 10 to the single invisible displacement group. After the five children that did not complete at least 6 trials were eliminated, 12 children remained in the double invisible displacement group and 8 children in the single invisible displacement group. As with the monkeys, the adjacent and non-adjacent displacements were randomly ordered and assigned for each child.

The experimenter and the child sat on opposite sides of a small table, with the parent or caregiver seated next to the child. The experimenter then introduced the three opaque cups to the child, and showed the child that each of the cups was empty, except for the cotton-wool at the base of each cup. A small soft ball was then dropped into one of the cups and either a single or a double invisible displacement was carried out, in the same way as for the monkeys, depending on which group the child was assigned to. A maximum of 12 trials were carried out per child, but few children completed 12 trials. In addition, up to 5 catch trials were carried out at the end of the experimental trials.

9.4.4 Results and Discussion

The mean percentage of correct responses per child were calculated and a Mann-Whitney test was carried out to compare the performance of children who participated in the single invisible displacement trials with those who participated in the double invisible displacements. Those children in the single invisible displacement group performed significantly better than those in the double invisible displacement group [t

(18) = 5.12, $p \leq 0.0001$]. The performance of each group was then compared with chance (chance is 33.3% as there are three possible search locations) which revealed that children in the single invisible displacement condition were performing significantly above chance [$t (7) = 10.5$, $p \leq 0.0001$] whereas children in the double invisible displacement condition performed at chance [$t (11) = 0.45$, *ns*].

Unfortunately the current task proved very difficult to engage the attention of two-year-olds. Out of the 20 two-year-olds who were willing to participate in this task, only a small number completed the additional catch trials. The purpose of catch trials was to assess whether or not children understand the effect of overturning the cup on the object inside and to check for the use of simple strategies like 'always search in the first cup that the baited cup touches'. For this reason, it is only useful to analyse the catch trials of the children who succeeded on the invisible displacement trials, which in this case was the single invisible displacement group since the double invisible displacement group performed at chance. Out of the eight children who were willing to participate in this task from the single invisible displacement group, only four completed catch trials. These children did very well on the catch trials that they did complete with three children passing all catch trials presented to them and one child passing four of the five catch trials.

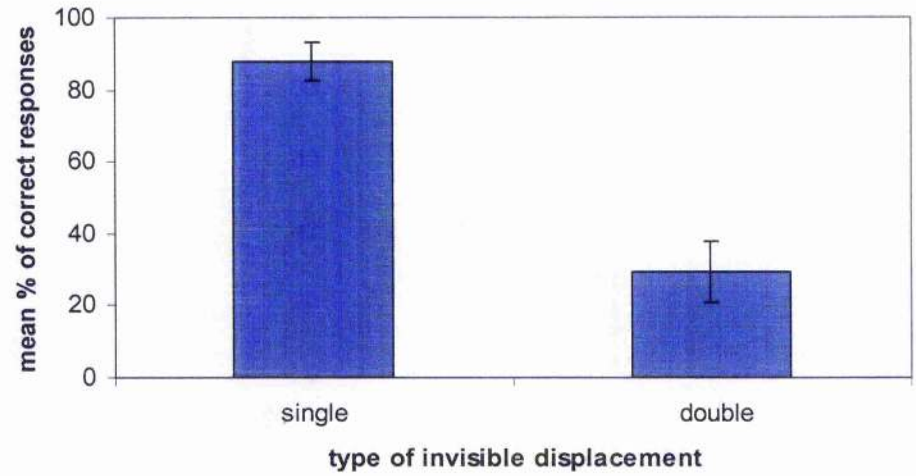


Figure 9.7 Mean percentage of correct responses (± *SE*) for children in both the single and double displacement conditions.

9.4.5 Error Analysis

For those children who received double invisible displacement trials, an analysis of the types of errors committed revealed that they were not random. Out of the twelve children in this group, 2 children (LZ and BP) only made 2 errors and so these children were not included in the error analysis. However, the other ten children made at least 5 errors each. For eight of these ten children, the preferred location of search appeared to be the cup that was originally baited by the experimenter. These errors accounted for at least 60 % of the total number of errors. For the two children that did not display this pattern of errors (JH and VC), their errors also did not appear to be random. Instead, they preferred to choose the centre location (cup 2). Both of these children made 9 errors, and of these 9 errors, 6 and 7 respectively were at location 2.

For those 8 children who showed a tendency to search in the originally baited cup on their first search attempt, there is little evidence that they are able to skip over the middle container on their second search attempt in those trials that required it. For each of these 'non-adjacent' trials on which children made the error of searching first in the originally baited cup, a percentage correct for second searches was calculated and compared with chance using a one-sample t-test. In this case, performance at chance (where, having searched initially in the incorrect baited cup, children then show no preference for either cup 2 or 3) would be 50 %. If children were indeed able to skip over the middle cup and search correctly in their second search attempt, above chance responding would be expected. Likewise, if children were not able to skip over the middle container and search predominantly in the next sequential location on their second searches, below chance responding would be expected. The one-sample t-test revealed indeed that children were not able to skip over the middle container, and searched significantly more at this middle location on non-adjacent trials than would be expected by chance [$t(7) = 3.89$, $p \leq 0.01$].

9.5 GENERAL DISCUSSION

Both two-year-old children and rhesus monkeys perform well on an invisible displacement task involving overturning a baited cup onto an empty cup, when the invisible displacement entails just one movement. However, although both species' performance worsens with double invisible displacements, monkeys still perform well whereas two-year-old children do not perform above chance on double invisible displacements.

Performance on catch trials, however, suggests that monkeys may not understand the critical role of overturning a cup and the consequent lack of support on the object inside the cup. Conversely, the good performance of the small number of children who completed catch trials suggests that their good performance on experimental trials reflects a true understanding of the task and a true appreciation of the critical action of overturning a cup, the resulting lack of support for the object and what happens to an object when it loses its support. It would therefore appear that children do well on the single invisible displacements because they are representing the invisible movement of the object from one location to the other, whereas monkeys are successful because they have learnt that they will find the reward in the first cup that the baited cup comes into contact with.

However, as the error analysis did not reveal the characteristic pattern that would be expected if monkeys were learning over the course of an experiment, perhaps monkeys approached the task with an existing rule. It is conceivable that these monkeys have already learnt something about what happens when a cup with a reward in it is overturned, as the same cups were used in the experiment described in Chapter 6, and although never overturned during experimental trials, it is inevitable that monkeys would have seen the experimenter overturn the cups to remove rewards that were not claimed or to give a reward to a monkey if the monkey had been unable to retrieve it on their own. In this way, monkeys may have learned an association without having any generalizable knowledge or expectations regarding objects that lose their support. However, a heuristic that would lead to the kind of behaviour seen in this experiment would involve something like 'search in the first cup which the baited cup comes into contact with' and this seems like an odd rule to have generated *a priori*.

Although performance on catch trials does suggest that monkeys are not solving the experimental trials in a representational way, this performance should not be taken as unequivocal evidence that monkeys do not understand the crucial causal element of a task. As in other tests of invisible displacement (e.g. Neiworth et al., 2003), the catch trials were presented towards the end of testing and it is possible that subjects had become so accustomed to the experimental type of invisible displacements that they had developed a procedural or habitual response by the point at which catch trials were administered and had stopped paying attention to the crucial element of the task. It is possible that true representational solving of a task may lead to rules that are simpler to execute, perhaps as a way of conserving cognitive power. Perhaps initially, monkeys do represent and reason about where the object has gone, but with experience develop automatic responses to specific situations that are more cognitively efficient. This in turn may make it more difficult for the monkey to reverse this newly developed response when the type of movement is slightly different (i.e. the cup is not overturned but maintained upright). It is interesting that despite having the ability to use a representational strategy when necessary, the gorilla tested in Natale et al.'s study used a simple practical rule-based strategy when this sufficed to solve the task (Natale et al., 1986). One possibility then is that the macaques in this study developed a practical rule after time and once this practical rule is in place it is difficult to reverse.

The ability of one monkey to skip over a middle empty container would suggest that rhesus macaques, in principle, are able to inhibit falling victim to sequential searching if the next container in line is never visited by the experimenter. In addition, on these particular trials, the fact that the monkey is able to skip over the middle location suggests that he knows the reward can only be in a location visited by the experimenter. One possible explanation for searching in the baited container on some trials is that monkeys are drawn to this location because it is the last location they focus attention on (as the cup is returned to its original location by the experimenter). In another study, Goldman-Rakic has noted the tendency of prefrontally-lesioned rhesus macaques to respond "to the first food well that catches its eye" (Goldman-Rakic, 1987). It is possible that on some trials, monkeys are unable to inhibit choosing the last location that they attend to, even though Nathan's ability to skip over the middle location on his second search attempt suggests that he may have some correct representation of the rewards location.

Ultimately, it is difficult to evaluate the importance of failure on catch trials, and with so few children completing these trials, it is difficult to draw any firm conclusions or compare the performance of monkeys and children. Based on the distribution of errors committed by the monkeys, it does however seem unlikely that monkeys' good performance on experimental trials results from learning over trials, and this leaves open the possibility that they are truly solving the experimental trials by representing the invisible movement of the object from one cup to another.

The performance on this task by two-year-old children, although ostensibly less accomplished than the monkeys, may be easier to account for. The children in the single invisible displacement group performed well on both normal trials and catch trials suggesting that they really did understand that when the cup was overturned, this meant that the object inside would fall into the other cup. The fact that children in the double invisible displacement group generally did not perform well fits with previous findings that double invisible displacements are more difficult than single invisible displacements (Call, 2001).

Furthermore, unlike monkeys, children in the double invisible displacement group showed a bias towards searching in the initially baited cup and when they failed to find the object in this cup, tended to direct their second search attempt towards the next sequential cup. Since both single and double invisible displacements require the same understanding that, when a cup containing an object is overturned, the object will not remain inside the cup, it seems unlikely that the bias that the double invisible displacement group displayed towards searching in the originally baited cup results from failing to understand the task. Searching in the originally baited cup – the most common error made by this group – might indicate that children are failing to disengage from the last location of their attention. Children may be more prone to this when their representation of the object's location is weaker. There are a number of possible reasons why children in the double invisible displacement group may have weaker representations than those in the single invisible displacement condition.

Firstly, the amount of time between overturning the baited cup and the point at which the child is allowed to search for the object may influence the strength of the representation that the child has - during a double displacement, this period of time will be longer. The length of delay between hiding and searching has been shown to be an important factor in determining success on the AB task in much younger infants (Diamond, 1991). For example, whereas a delay of 2 seconds induces the error in 9-month-old infants, 12-month-old's require a delay of 5 seconds before they make the A-not-B error (Diamond & Goldman-Rakic, 1989). It is conceivable therefore that this extra time required for the double invisible displacement is sufficient to cause children to forget where the object is and to resort to searching where they last saw the object deposited or at the location where they last attend. Although the children who are detrimentally affected by the time delay in the AB task were much younger, the AB task is a visible displacement task and it may be the case that representations in invisible displacement tasks are relatively weaker than in visible displacements, meaning that even a short increase in time delay may have a similar effect on a younger infant's representation of a visible displacement that is has on an older child's representation of an invisible displacement.

Another factor that has been shown to be an important determinant of success on some invisible displacement tasks is whether or not the child's gaze to the correct location is broken before they commence searching. Butler, Berthier & Clifton (2002) found that even if young children tracked a ball to the right location after displacement, if they looked away from this location before opening a door, their performance was at chance. Because in the current invisible displacement task the correct location is always the first cup onto which the baited cup is overturned, if the child is following the experimenter's actions, their gaze from the correct location will be broken when the experimenter executes the second displacement.

The results from the current study are intriguing. Although monkeys appear to do better than children on the experimental trials to the extent that they also solve double invisible displacements, the successful performance of those few children who completed catch trials suggests that the children's performance is actually superior.

Whilst the failure of children to pass the double invisible displacement condition may be explained by either of the above factors that children in the single invisible displacement condition do not have to cope with, it is less easy to explain why monkeys also do not fall prey to these factors? It should be remembered however that despite showing above chance performance on the double invisible displacement trials, this performance was at the same time significantly worse than performance on the single invisible displacement trials, showing that monkeys did find these double trials more difficult, perhaps for the same reasons as children. One could argue that because of the within-subjects design employed with monkeys, monkeys were subjected to more trials than children and it is perhaps this greater number of trials and hence experience that leads monkeys to be more successful than children. However, this seems unlikely since monkeys do not make fewer errors over time and errors appear evenly distributed. One possibility is that monkeys are so highly motivated by the food reward that they pay little attention to subsequent actions that bear no effect on the location of the reward. So, having correctly reasoned that the food reward must be in the first cup onto which the baited cup is overturned, monkeys become fixated on this cup and do not follow the additional displacement. On the other hand, children may be more interested in following what the experimenter is doing and less fixated by the object inside the cup. The fact that children receive verbal instructions to pay attention to what the experimenter is doing may contribute to this difference between monkeys and children.

In conclusion, although the monkeys used in this study appear able to solve the invisible displacement test trials, their failure to solve the catch trials must lead us to conclude that they are not solving the test trials in a representational way. However, it is an open question as to whether the issues raised above could account for failure on catch trials. Failure on catch trials should lead to the conclusion that the successful performance of subjects on test trials results from a simple rule (i.e. search in first cup that overturned cup comes into contact with) rather than representational solving. However, while this explanation can explain successful solving of the single invisible displacement trials, it cannot explain the solving of the double invisible displacement trials. If the monkeys were really using this rule, it should lead them to fail the double invisible displacement trials. With this in mind, and considering the possible reasons raised above for why monkeys may fail catch trials, I suggest that the monkeys' performance on this task goes beyond simple rule learning. One way to examine what effect the catch trials have would be to run the catch trials before the experimental trials, rather than at the end. In this way, if it is the order of presentation that effects performance (as proposed above), and monkeys do have the representational capacities needed to solve invisible displacements, they should be able to demonstrate this by solving the catch trials that are presented first.

10

THE LOOKING-SEARCHING DISSOCIATION

10.1 INTRODUCTION

Andrew Meltzoff commented recently that as our methodology has become more sensitive, infants and young children appear to have become more competent (Meltzoff, 2000) and he probably would not disagree that this point could now be extended to include non-human species as well. Based on a wealth of studies carried out using looking time as the measure, rather than search, young infants and non-human primates have shown remarkable sensitivity to the constraints that act on objects. (Bower, 1977; Baillargeon, Spelke, & Wasserman, 1985; Baillargeon, 1987; Spelke, Breinlinger, Macomber, & Jacobson, 1992; Santos & Hauser, 2002; Cacchione & Krist, 2004). However, clearly the majority of the data presented thus far in this thesis has not alluded to a particularly competent young child or monkey. The experiments presented in chapters 5, 6, 7 and 8 suggest that neither young children nor monkeys are very good at taking into account physical constraints on object movement and their attempts to find a hidden object reflect the use of simple heuristics like proximity and alignment. So what is it about the looking-time paradigm that seems to yield such success when so many search tasks yield failure?

This looking-searching dissociation first became apparent with the studies of Bower and colleages (1971; Bower, 1974; Bower, 1977) and Baillargeon and colleagues (Baillargeon et al., 1985; Baillargeon, 1987). Using the habituation paradigm Baillargeon et al. (1985) found evidence for an understanding of object permanence in 3.5-month-old infants. In this paradigm (see figure 10.1), infants are shown an event in which a screen rotates away from them several times until the child stops paying attention (until the length of time that they watch for reaches a minimum criterion). Then they are shown two different test events in which a box is placed in the pathway of the rotating screen. In one test event (the possible event), the screen rotates as far as it can until it hits the box (120°) and in the other event (the impossible event), the screen appears to rotate *through* the solid box (180°). To control for the possibility that infants might simply prefer to look at the full 180° rotation, they also showed infants the 120° rotation without the presence of a box. Three-and-a-half-month-old infants looked reliably longer at the impossible event than at the possible event and showed no preference for either the 180° or 120° rotation in the control conditions. Note here that the impossible event was perceptually more similar to the habituation event since it also had a rotation of 180° and it is well known that infants tend to prefer to look at novel over familiar stimuli (Cornell, 1979). The fact that infants do look longer at the perceptually more familiar yet physically impossible event suggests that they are representing the box and appreciating that the screen should not be able to pass through it.

There are a multitude of other studies alluding to the fact that infants between two-and-a-half months and seven-and-a-half months do represent fully occluded objects (Baillargeon, 2000) and this creates somewhat of a problem for Piaget's stage theory of object permanence development because he claims that infants do not have object permanence before about 8 months of age.

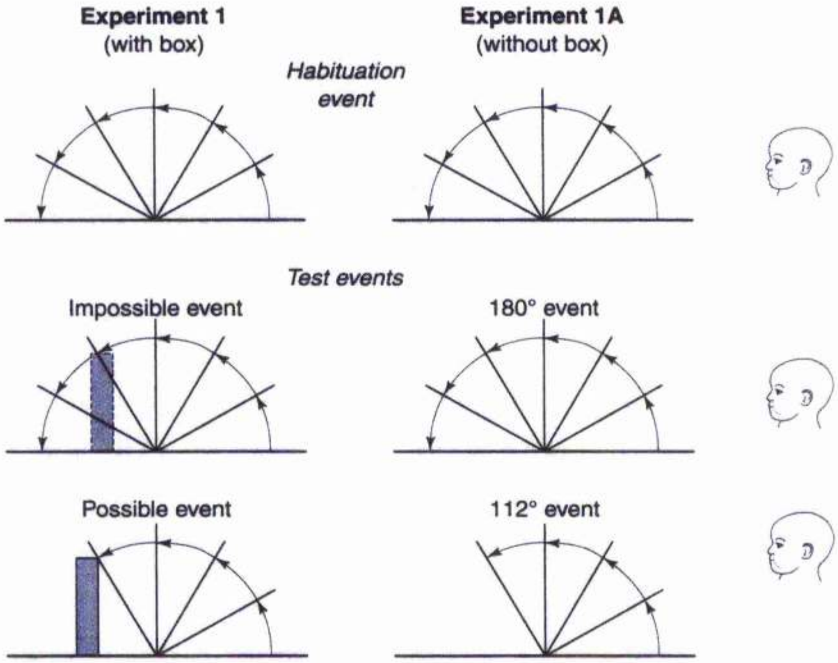


Figure 10.1 The habituation events used by Baillargeon et al. (1987)

10.2 Infant studies

However, object permanence is not the only realm in which young infants appear to show remarkable competence on looking tasks yet fail tasks that require a more explicit response. They appear able to appreciate how much support an object requires in order to remain supported (Baillargeon & Hanko-Summers, 1990; Baillargeon, 1992) and where this support needs to be in order for the object to remain stable (Dan et al., 2000, 2001). However, even children of four years seem to rely on a trial and error strategy in order to balance objects themselves (Karmiloff-Smith & Inhelder, 1975) and as Kohler has reported, "very young children…in attempting to pile one thing on another, try, by holding, and sometimes pressing, one against the other, to fix them in different and often curious positions" (Kohler, 1925; p.130). Most relevant to this thesis are the findings that children do not appear to show an understanding of solidity when presented with a number of invisible displacement tasks yet they do in looking tasks. In two previously described horizontal invisible displacement tasks (Berthier, DeBlois, Poirier, Novak, & Clifton, 2000; Hood, Carey, & Prasada, 2000), two-year-old children were unable to take into account the constraint of solidity when searching for a hidden object. However, in a looking version of the Berthier task, Hood, Cole-Davies & Dias (2003) found that two-year-old children looked longer at an outcome in which the ball was revealed to be in a location that was not adjacent to the solid wall.

In the field of social cognition too, there are dissociations between what young infants appear to understand and what older children appear not to understand. The ability to pass a false belief task – believed to demonstrate theory of mind – is thought to be present in children by about four years of age (Wimmer & Perner, 1983). In the false-belief task, children watch as one experimenter places an object in one of two boxes. The experimenter (E1) then leaves the room and another experimenter (E2) enters and moves the object to the other box and leaves. The child is then asked where they think E1 will look for the object when they return. If the child can attribute false-beliefs, they should be able to reason that E1 will look for the object in the location where they left it, because they were unaware that E2 moved it. Children under the age of four are unable to do this and usually respond that E1 will look for the object in the location where the object *actually* is. However, using a looking paradigm, Clements and Perner (1994) found that children of 2 years and 11 months tended to look in the direction of the empty box when E1 returned despite only 45% of these children giving this location when asked for an explicit response. More recently, Onishi & Baillargeon (2004) have shown that infants as young as 15.5-months-old appear to demonstrate an understanding of false-belief. In this experiment, infants watched as an experimenter hid a toy in one of two containers that were placed on a rotating table-top. When the experimenter left the room, the table-top was rotated so that the container in which the object was hidden was now on the opposite side. There were three conditions: the identical container condition where both containers were the same, a condition in which the empty container was transparent and one in which the empty container was a different colour from the one in which the experimenter had hidden the toy. When the experimenter returned to the room, she looked for the toy in the container in which she had hidden the toy, despite the fact that she did not know the containers had been moved. Infants looked significantly longer in the identical condition than in either of the other two conditions, suggesting that the experimenter's behavior in the identical condition was at odds with where they expected her to search for the toy. Other looking studies in the field of social cognition point to an even earlier understanding of theory-of-mind related capacities in infants as young as nine- and twelve-months (Gergely, Nadasdy, Csibra, & Biro, 1995; Gergely & Csibra, 1997; Kuhlmeier, Wynn, & Bloom, 2003).

10.3 NON-HUMAN STUDIES

Hauser and his colleagues have been instrumental in developing the looking time paradigm for use with non-human subjects and have used this paradigm to explore a broad range of topics in physical cognition (Hauser, MacNeilage, & Ware, 1996; Hauser, 1998, 2001a; Munakata, Santos, Spelke, Hauser, & O'Reilly, 2001). Through these studies, the same dissociation that we see in the developmental literature has emerged in the animal literature between the understanding that monkeys seem able to demonstrate on looking tasks and that which they cannot demonstrate on search tasks. Firstly, Santos & Hauser (2002) have shown that rhesus macaques look longer when presented with an outcome in which a food reward appeared to have fallen through a solid shelf than one in which it had not, suggesting that they perceived this outcome as strange. However, in the search version of this task (discussed earlier in chapter 6), monkeys appear to disregard the presence of the shelf and search beneath it for a fallen food reward (Hauser, 2001b). Again, in a looking task mirroring Baillargeon's support paradigm, Cacchione & Krist (2004) showed that chimpanzees appear able to recognize when an object is inadequately supported by looking longer at this display relative to one in which an object does have sufficient support. However, as discussed earlier, Kohler has shown that chimpanzees do not seem able to take these factors into account in their own actions (Kohler, 1925).

10.4 Why is there a looking-searching dissociation?

In attempting to address this paradox, many theories have been developed to account for this dissociation. The following section will examine each of these various accounts and look at the evidence provided to support them.

10.4.1 Perceptual accounts

A number of authors have taken issue with the cognitive interpretations from looking studies, particularly those of Baillargeon relating to the rotating screen paradigm (Rivera, Wakeley, & Langer, 1999; Bogartz, Shinskey, & Schilling, 2000; Cashon & Cohen, 2000). Among the most prominent adversaries to the studies proclaiming to show early understanding of object permanence are Haith (Haith, 1998, 1999) and Bogartz and colleagues (Bogartz, Shinskey, & Speaker, 1997; Bogartz et al., 2000).

These authors argue that the results from looking time experiments can be explained by more perceptual accounts in which differences in looking times towards impossible and possible displays can be accounted for by preferences for either familiarity or novelty. Employing a design they call 'event set x event set' on the Baillargeon rotating screen paradigm, Bogartz and colleagues have shown that depending on the event to which the infant was familiarized, one can predict observed looking times to both possible and impossible events (Bogartz et al., 2000). However, they argue that these looking times merely reflect individual infants' preferences for novelty or familiarity as a function of the extent to which they initially processed the familiarization/habituation display. However, it is problematic for these authors that although their model does not predict longer looking towards the impossible display when infants are familiarized to the 180° rotation, and they did not find longer looking towards the impossible display, Baillargeon (1987) did find longer looking and so their conclusions are based on a non-replication. As Baillargeon (2000) points out, in order to convincingly argue that looking-time experiments confound familiarity and novelty with possibility/impossibility, these authors would have to account for a huge body of literature that has emerged pointing to the fact that young infants do represent hidden objects, and show that each and every one of these results confounded these parameters.

10.4.2 Means-ends accounts

One explanation for the looking-searching dissociation has been that young children fail tasks requiring a manual response because they are limited in their problem-solving abilities. Specifically, they are unable to adequately plan means-end sequences of behaviour and coordinate actions with the information they have about the world (Willatts, 1989). Willatts (1989) found that when young infants were placed in a situation where they needed to remove obstacles in order to reach a goal object, they were not very good at this. In a Piagetian search task, according to Karmiloff-Smith, infants not only need to "make computations in the visual system", but they then need to "translate that information into a motor output system for manual search" (Karmiloff-Smith, 1992; p. 77). If infants' problem solving capacities are limited, they may succeed on a task requiring only a visual response but fail on a task requiring the additional coordination of a manual response as well.

However, the means-ends explanation is unlikely to account for the data for a number of reasons. Firstly, five-month-old infants appear to show an appreciation for object permanence a full three months before Piaget claimed, when the occluder is a dark room rather than a screen or cloth (Bower & Wishart, 1972; Hood & Willatts, 1986; Clifton, Rochat, Litovsky, & Perris, 1991; McCall & Clifton, 1999; Shinskey & Munakata, in press). Hood & Willatts (1986) presented infants with an object placed either to their left or right and then extinguished the lights in the room so that the infant could no longer see the object. Despite the object being no longer perceptible to the infant, they still reached out for the object with a good degree of accuracy. These results suggest that it is not the action of reaching that poses a problem for young infants in object permanence tasks. Similarly, Munakata (2002) has argued that deficits in means-ends behaviours cannot account for the looking-searching dissociation. Munakata et al. (1997) tested the means-end deficit account in 7-month-olds by training them to press a button to retrieve an object from behind an occluder. In this study, when infants pressed the button, a horizontal ledge would drop and if a toy were on the ledge, the toy would then slide down a ramp to within reach of the infant. In the test phase, either an opaque or a transparent screen was placed in front of the ledge. Infants showed no sensitivity to whether or not a toy was present behind an opaque screen, but when the screen was transparent they were able to push the button to retrieve the visible toy. Since the means-end behaviours were equivalent for both the visible and occluded condition, it is unlikely that failure on the occluded condition can be solely due to means-ends deficits. However, it is possible that infants simply failed to recognize the presence of the transparent screen and were behaving as if there was no screen present. If this were the case, then the means-end demands for the visible and occluded conditions might not be equal. To test this possibility, Shinskey & Munakata (2001) ran another version of this test in which infants had to actually pull down the screen in order to retrieve the toy so it was impossible for them to ignore the presence of the transparent screen. They found that infants were still able to pass this task showing that they were not ignoring the screen. It would seem that young infants really do show genuine means-end skills before they are able to search for an occluded object.

10.4.3 Two distinct pathways

One explanation for the looking-searching dissociation proposes that there are two distinct neural pathways subserving the visual control of actions and recognition of objects (Goodale & Milner, 1992; Bertenthal, 1996; Newman, Atkinson, & Braddick, 2001). According to Goodale & Milner, the dorsal stream of visual processing subserves the control of actions whereas the ventral stream concerns the perceptual recognition of objects, and these two streams are thought to be functionally dissociable such that someone can report being perfectly able to see objects but be unable to reach accurately or shape their hand in an appropriate way when they tried to reach for them. Not only is it proposed that these two visual processing streams are functionally dissociable but it is also proposed that they follow different developmental trajectories (Berthenthal, 1996). In order to account for the looking-searching dissociation then, it is argued that the ventral pathway, subserving the visual recognition of objects, has a more rapid developmental trajectory than the dorsal pathway that is involved in the control of action. Thus, infants are able to demonstrate an understanding when only a visual response is required (as in the looking-time paradigms) but not when a motor response is also required (as in the typical Piagetian search tasks). Newman (2001) presents evidence that when five-and-a-half-month-old infants are presented with two objects which differ in their size and hence their 'graspability', that they tend to reach for the object that they first fixate on, regardless of whether they will be able to grasp the object. Later, between eight and twelve months, infants are able to inhibit this reflexive response and reach, not to the more visually salient object, but to the object that they are likely to be able to grasp (i.e. the smaller object). The authors argue that these results might support the hypothesis the system subserving action develops later than that which subserves visual orienting.

However, whilst there is undoubtedly support for the idea that these two processing streams are functionally dissociable, both at the behavioural and neural level (Goodale & Milner, 1992), it seems unlikely that these separate pathways of knowledge can fully explain infant search failures. In addition to the looking searching dissociation, there is the intriguing dissociation regarding object permanence understanding even within the manual search domain. As described previously, five- to seven-month-old infants appear able to appreciate object permanence when the occluder is a darkened room, but not when the object is occluded by another object. If the pathway subserving control of action really was developmentally delayed, it is unclear why five-month-olds are able to competently reach for an object when it is in the dark but not when it is covered by a cloth or a screen. Any account of object permanence development and understanding needs to be able to account not only for the looking-searching dissociation but also for this dissociation within the manual search domain.

10.4.4 Graded Representations

The graded representations approach of Munakata and colleagues may go someway towards accounting for both of these dissociations. In this view, knowledge is not conceived of as an all-or-nothing domain. Rather, regarding object permanence in particular, this approach advocates the idea that infants may have some idea that the object is still present but that the knowledge they have is insufficient to support an action response. The ability to demonstrate knowledge about hidden objects may depend on the strength of the representation that the infant has and whilst a weak representation of the hidden object may be enough to drive a looking response, a strong representation may be needed for a manual response. The strength of the representation is defined at the neural level by the number of neurons that are firing and the rate at which the neurons associated with a representation fire. According to Mareschal et al. (1995), for the manual retrieval of both visible and hidden objects, infants need to coordinate the objects identity and position with motor action, but in order to retrieve a hidden object, its representation needs to be "strongly established" if the infant is to successfully coordinate the representation with motor action. Because manual search behaviour is so dependent on the strength of an object's representation in these graded representation accounts, these models predict that search behaviour will differ with the child's familiarity with the object that is hidden.

So, since an object that is more familiar to the infant (e.g. something they play with at home or something they have repeatedly seen) will have a stronger representation, infants should find it easier to retrieve a hidden familiar object than a hidden unfamiliar object. Findings by Keenan & Morris (2002) and Bigelow et al. (1995) both support this position. In Keenan & Morris' study, infants aged nine to twelve months were either tested on the standard A-not-B task with a novel toy, or with a toy they had played with for seven days prior to testing. Results showed that infants were significantly more likely to search correctly for the familiar toy than for the novel toy. Recently, Shinskey & Munakata (2004) have also shown that the well-documented novelty preference in infancy (Fantz, 1964; Cornell, 1979) reverses when infants are presented with hidden objects. In this study, when seven-month-old infants were presented with a visible novel toy versus a visible familiar toy, the majority of infants show a preference for reaching for the novel toy. However, when the lights are turned off such that the objects are no longer visible, the majority of infants show a reverse preference and reach more often when the object is a familiar object. These results support Munakata and colleagues' contention that only sufficiently strong representations will support retrieval of hidden objects. Moreover, the graded representations explanation can account for the dissociation searching for objects in the dark and searching for objects behind occluders. According to Munakata et al. (1997), when an object is occluded by the dark, there is no visual input to the infant at all, but when an object is occluded by a screen or a cloth, this visual input may suggest to the infant that no object is present. If the representation of the object is weak, as it may be in five-month-old infants, the visual input of the occluder may be enough to interfere with the representation that the child has of the object. Because there is no visual input when the object is hidden by the dark, this weak representation may be sustained and hence infants reach for the object (Munakata et al., 1997; Munakata, 2001; 2003).

10.4.5 Prediction versus Postdiction

Arguably the explanation that holds most appeal currently is the prediction-postdiction explanation favoured by Hood et al. (2003) This explanation proposes that there is a fundamental difference between what is required of a subject on a looking paradigm and what is required of them on a search paradigm. Specifically, when children or monkeys need to find an object on a search paradigm, in order to be successful they need to be able to *predict* exactly the location of that object. It is not enough for them to have a general inclination. By contrast, on a looking paradigm, subjects are shown the outcome and so do not have to make an explicit prediction. When an impossible outcome is revealed to a child, they are essentially asked to make a judgment regarding whether or not outcome is possible (Ahmed & Ruffman, 1998; Meltzoff & Moore, 1998; Keen, 2003). The subject may not even be sure exactly why the outcome is not possible. A simple increase in attention to an outcome because of an uncertainty may be all that longer looking towards impossible outcomes reflects.

This explanation is theoretically attractive because it may also account for some of the adult findings of dissociation in the realm of naïve physics. As described earlier, there are a number of studies that have shown that adults can accurately judge whether or not a particular object trajectory is correct, but they may *predict* quite a different, incorrect object trajectory (Shanon, 1976; McCloskey, Caramazza, & Green, 1980; McCloskey, Washburn, & Felch, 1983; Kaiser, Proffitt, & McCloskey, 1985). For example, in one of these studies, adults were shown a ball travelling through a c-shaped tube and asked to predict the trajectory that the object would take upon exit. Many of the adults reported that the ball would continue to follow a curved path on exiting the tube. However, when these same adults were shown video of either the correct straight trajectory or a contrived curvilinear trajectory, most adults reported that the straight trajectory looked more natural (Kaiser, Proffitt, & Anderson, 1985). These authors suggest that "people may possess a perceptual sensitivity to natural dynamics, enabling them to recognize when anomalous events violate dynamic laws, yet be unable to access this knowledge in an explicit manner in order to solve representational problems" (p.796).

This explanation is attractive, not least because it could potentially fit nicely with the graded representations account offered by Munakata and colleagues which, in itself, can account for a substantial proportion of the available data (see above). It is feasible that *predicting* outcomes of events requires stronger representations than simply *judging* outcomes. Furthermore, the proposal that young children are able to retrospectively, but not prospectively, judge events, even fits with findings from newborn infants. In one study looking at heart rate conditioning, Clifton (1974) found that infants were not able to anticipate delivery of glucose in response to a tone, but if these infants were not given glucose after the tone was played, their heart rate decreased.

However, whilst there has to date been no direct test of the prediction-postdiction hypothesis, there is reason to suspect that this again is not the whole story. Firstly, before this explanation was first proposed by Meltzoff & Moore (1998), there was evidence that young children were doing more than simply judging event outcomes in situations where their looking behaviour differed from more explicit behaviour. In the false-belief looking-paradigm devised by Clements & Perner

(1994), there is evidence that two-year-old children looked towards an empty location where they thought the actor thought the object should be – despite the fact that children cannot answer at this age that the actor will look in this empty location. This design employed a predictive looking measure, not the postdictive looking measure that most looking paradigms employ, and did find evidence for correct prediction. In addition, a study by Hofstadter & Reznick (1996) into the A-not-B error in young children, analyzed both reach responses and eye-gaze-prior-to-reaching and found that children looked towards the correct location more often than would be expected by chance, despite the fact that sometimes they did not reach towards the correct location.

A recent study by Mash et al (2003), although not directly testing the prediction-postdiction explanation, found that failing to predict the location of an object is unlikely to account for search failures in two-year-olds on their task. This study employed the Berthier et al. ramp apparatus, but the task was changed from an invisible displacement task to a visible displacement task. The solid wall was placed at a particular location along the ramp and the object was released from the top of the ramp. Only when the object had stopped by the wall was the opaque panel containing the four doors lowered into place. In this way, children saw exactly where the object was on the ramp and so they did not have to predict where the object would stop. However, despite this additional information, children were still inaccurate in their search performance, suggesting that something other than an inability to predict was contributing to poor performance.

The following chapter presents a study whose aim was to explicitly test the prediction-postdiction hypothesis. A looking paradigm was employed in which it was possible to assess the young child's prediction about where an object will be, rather than assessing retrospective judgment. If the prediction-postdiction hypothesis holds true, young children who fail a search task should also fail a predictive looking task, if it is their inability to predict the location of an object that leads them to fail the search task.

11

TESTING THE PREDICTION-POSTDICTION HYPOTHESIS

11.1 INTRODUCTION

The proposal that the looking-searching dissociation discussed in the previous chapter is explainable by the differences between the tasks in terms of whether or not they require a predictive response is an attractive proposal. Not only does it have the potential to account for the looking-searching dissociation in young children, but it may also be able to account for the dissociations in adult naïve physics discussed in the previous chapter.

Whilst there has been much speculation about the role of prediction in successful performance on search tasks to the extent that Hood has recently commented that "this prediction-postdiction account may provide a resolution to the discrepancies in findings between infant looking time studies and search studies" (Hood, Cole-Davis, & Dias, 2003 p.69), there has not been a direct test of this hypothesis. In fact, as noted in the previous chapter, several prior findings would suggest that the prediction-postdiction account may not fully explain the looking-searching dissociation since there is evidence that young children do look predictively to the correct location despite searching incorrectly (Diamond, 1991; Hofstadter & Reznick, 1996) and even when they are shown the ultimate location of an object that is then occluded from view such that no prediction is required, children still fail search tasks (Mash, Keen, & Berthier, 2003). The aim of the current study was to provide a direct test of the prediction-postdiction hypothesis by testing two-year-old children on a looking version of a task that we know they are unable to pass when presented as a manual search task. This task is Hood's tubes task, described extensively in Chapter 5, in which two-year-old children show a bias towards searching in the incorrect straight-down location. However, when this task is presented as an expectancy violation looking task, Hauser (cited in Hauser, 2003) reports that cotton-top tamarins do show evidence of knowing where the object really is. With this in mind, a new looking task was designed to test anticipatory or predictive looking in young children. In the current task, children are presented with a video of the tubes task and watch as an experimenter drops a ball into the tube. Children then hear an audio stimulus asking them where the ball is, and relative looking time to both locations is measured in response to this auditory stimulus.

11.2 Background and Aims

The results reported in the current chapter are from a broader study whose aim was twofold. Whilst the primary aim of the study was to investigate anticipatory or predictive looking (operationalised as 'direction of looking') in young children in order to directly test the prediction-postdiction account of the looking-searching dissociation, a secondary aim was to directly compare this kind of looking with the postdictive looking (operationalised as length of looking) evoked in an expectancy-violation paradigm. The stimuli designed to investigate anticipatory or predictive eye movements were presented first, followed by the stimuli designed to look at postdictive eye gaze. However, initial pilot testing of the latter stimuli presented in a standard expectancy-violation paradigm evoked ceiling effects such that children appeared to continue looking at the stimuli until they disappeared. It was decided to use a paired-comparison method to avoid such ceiling effects (see Friedman, 2002 for similar findings and methodology)[1]. Unfortunately, the use of a paired-comparison method appeared not to evoke differential looking towards either the possible or impossible outcomes. It is possible that this lack of looking preference towards the impossible outcome reflects a true lack of understanding that this outcome is indeed not possible. However, because one of the events which failed to elicit longer looking towards the impossible outcome was an event that children had competently passed during a manual search test (as described in Chapter 9), it seems more likely that this lack of looking preference was an artefact of the methodology employed. As a result, and because the expectancy-violation stimuli were always presented after the primary stimuli and so could not have influenced anticipatory looking obtained from these primary stimuli, it was decided to focus on these results and not to report the results from the second half of the study.

The initial aim was to include all the events presented to children in Chapters 5, 6, 7 and 9 to be subjected to a looking time analysis (see figure 11.1). However, only three of these events had search locations spatially distinct enough to allow for accurate coding of looking *direction*, and so only three events were planned for inclusion in a predictive looking analysis. For example, in the first event (figure 11.1: T1), the two search locations are on the left and the right so that it is clear to the experimenter which location the child is looking at. However, in the fourth event (figure 11.1: C1), the search options are close together and it would not be possible to discern where the child is looking. These non-discernable stimuli were planned for inclusion only in the expectancy violation analysis.

[1] While standard expectancy violation tasks present the subject with the possible and impossible event one after the other and measure relative looking at each stimulus, a paired comparison method presents the possible and impossible event simultaneously and measures relative looking to each event.

11.2.1 Subjects

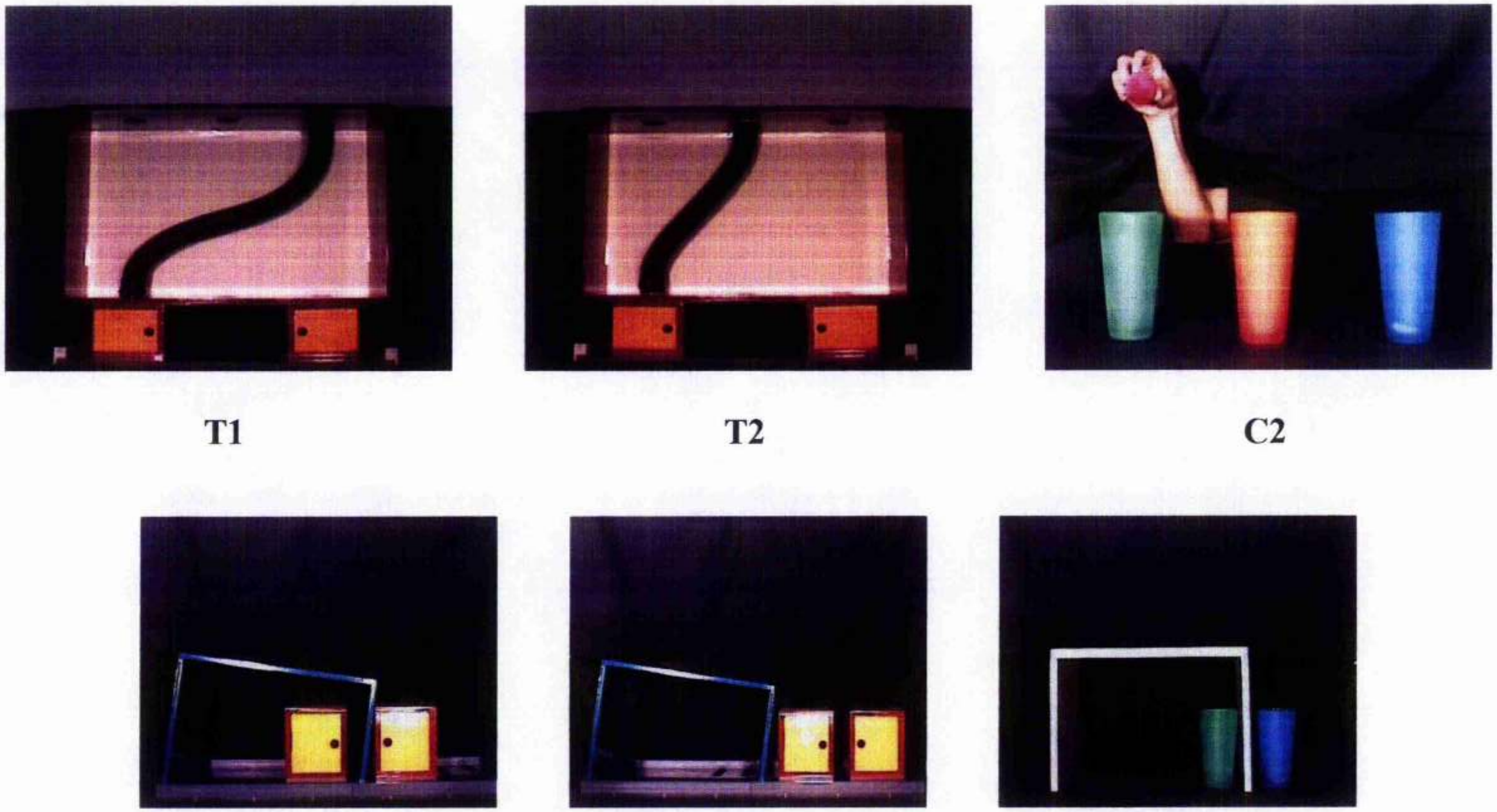
20 24-month-olds and 16 36-month-olds participated in the current study. 14 boys and 6 girls comprised the 24-month-old group (mean age: 25.0 months, s.d. 1.5 months) and 8 boys and 8 girls comprised the 36-month-old group (mean age: 37.5 months, s.d. 1.8 months). These same children simultaneously participated in a number of the search tasks described in previous chapters. Tables 4.2 and 4.3 in chapter 4 identify which children participated in this study and which other studies they also participated in. The original aim was to test all those children who had participated in the search tasks described in Chapters 5 through 9 on the looking versions of these same tests. However, a number of children were unwilling to sit and look at stimuli if they had already played with the real stimuli in the search task. Because of this, the number of 3-year-olds tested in the current study is less than the number who participated in the search tasks. In addition, because there were a total of 6 different events designed for presentation in the looking task and the order of presentation was randomly assigned for each child, a number of children did not complete all 6 trials, and so, depending on the event, a different number of children were included in the analysis.

11.2.2 Visual stimuli

Each child was presented with a set of 6 events (pictured in figure 11.1) and each event comprised three pieces of video, presented one after the other. The first and second videos (hereafter called 'action 1' and 'action 2' trials) showed an event in which a ball disappeared. Actions 1 and 2 were identical except that 'action 2' events were shorter and were designed to serve as a reminder to the child of what they saw in 'action 1' events. These reminder 'Action 2' events were included to maximise the chances that the child would attend to the critical event (children in looking paradigms often look away from the screen for short periods and as the critical moment is only a short part of the trial, if the child misses this part then they would have to be excluded. By having 2 action events, the chances of the child attending to the critical aspect are increased). The third piece of video was the outcome video in which children were simultaneously presented with 2 videos in which the ball was revealed in both the possible location and the impossible location. Figure 11.2 shows an example of a sequence of events in pictures, including the outcome trials, not included in the analysis for this chapter.

Video sequences were created using a canon MV500 digital video camcorder and then edited in adobe premiere to create a number of AVI video files. The three events of interest for the current chapter are standard tubes (henceforth T1), prepotent removed tubes (henceforth T2) and inverted cups (henceforth C2) and the stimuli for these will be described separately.

In both the T1 and T2 events, children saw an 'action 1' trial in which two search locations were initially shown as empty, two hands reach around from behind to close the doors and then one hand appears from above and drops a ball into the tube (see figure 11.3). In the 'action 2' trial, the same video is presented, except that the initial portion of the video is cut so that the video starts with the hand appearing at the top to drop the ball into the tube. For the C2 event, the 'action 1' trial initially showed three upright cups and then a hand appeared from behind and, one-by-one, turned each cup towards the child to show that it was empty and then replaced it in the upright position. Then another hand appeared from behind and dropped a ball into one cup and then overturned this cup onto the third cup in the row. The overturned cup was then returned to its original position (see figure 11.4). In the 'action 2' trial,



T1 T2 C2

RB1 RB2 C1

Figure 11.1 The six different events shown to children corresponding to the search tasks presented in chapters 5, 6, 7 and 9. Only events T1, T2 and C2 are analysed for the purposes of the current chapter, because it is only in these events that search locations are spatially distinct enough to allow for looking direction as well as looking time (as opposed to only looking time which is measured in expectancy violation studies) to be discerned.

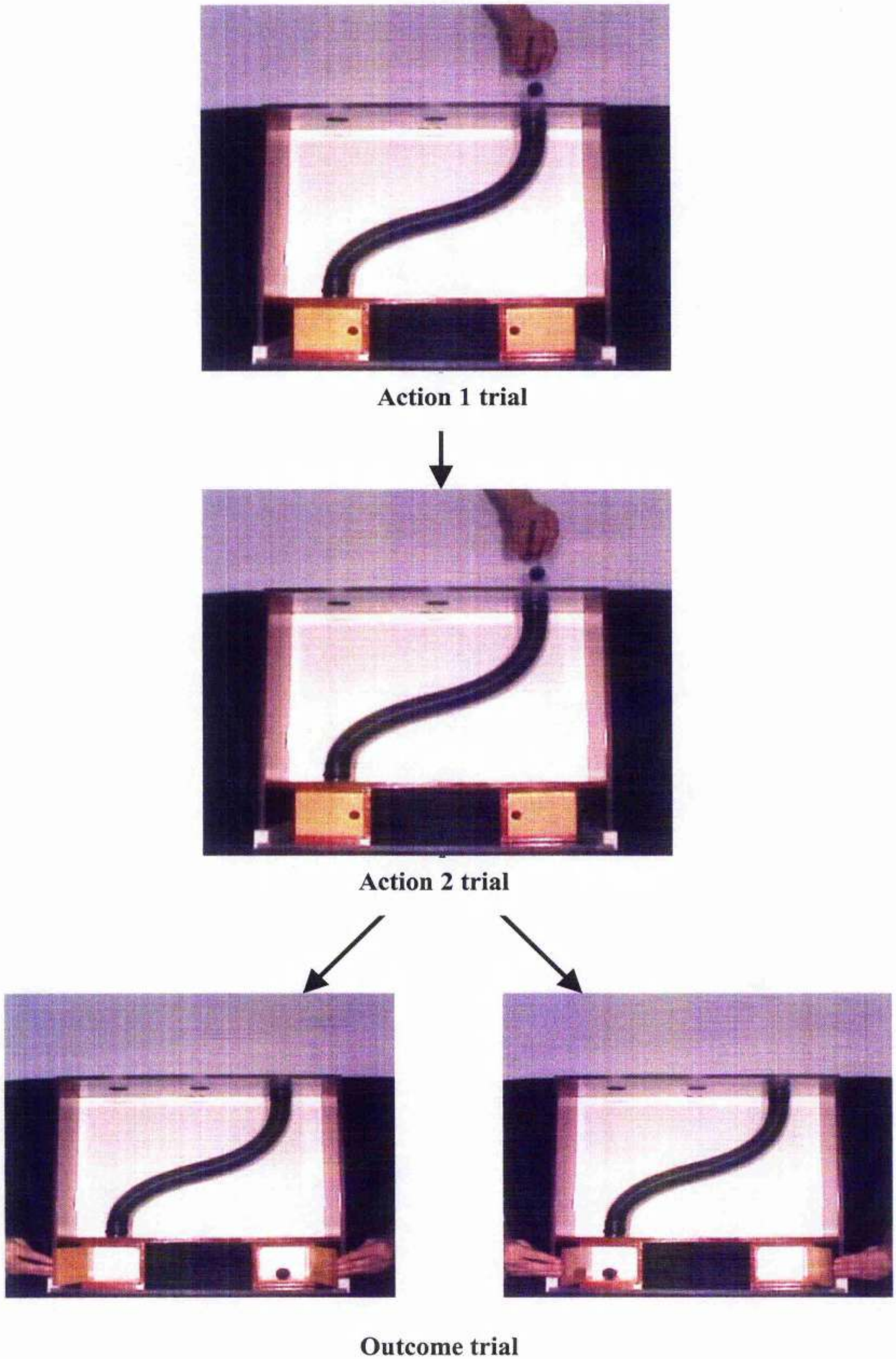


Figure 11.2 General sequence of trials shown to children 1) 'Action 1' trial; 2) 'Action 2' trial and 3) 'Outcome' trial (left: impossible, right: possible).

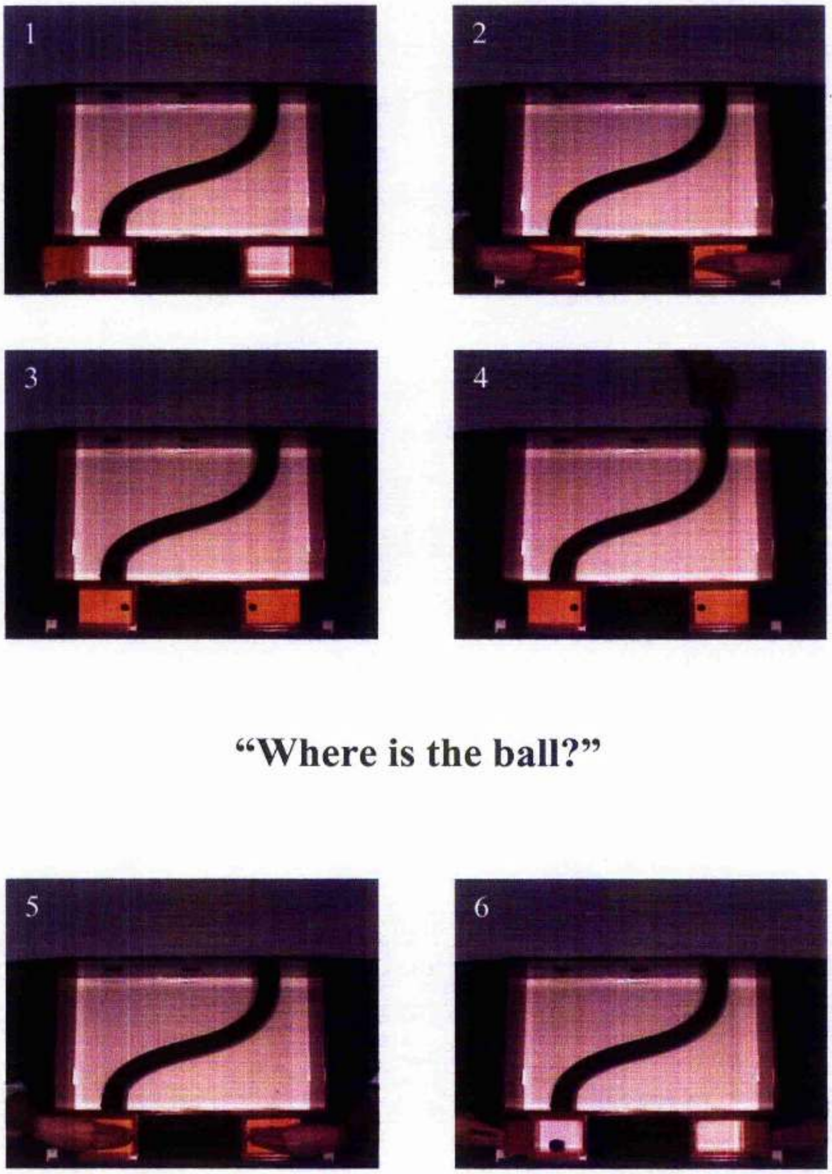


Figure 11.3 Frames taken from the T1 video sequence demonstrating the point at which the child hears the auditory stimulus "Where is the ball?" The sequence is identical for the T2 event, except that the tube is attached from the top middle to the bottom left box.

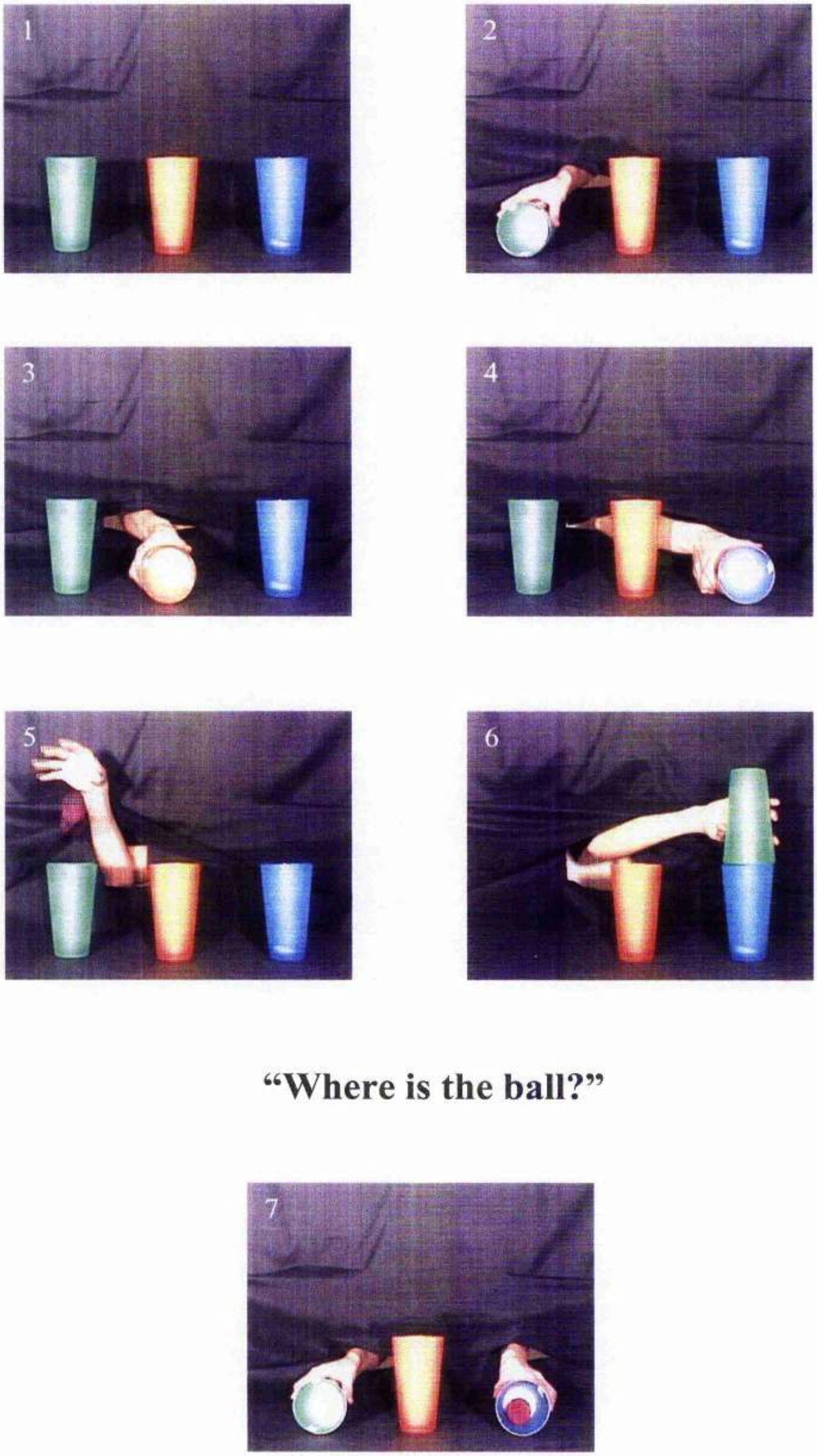


Figure 11.4 Frames taken from the C2 video sequence demonstrating the point at which the child hears the auditory stimulus "Where is the ball?"

the trial started with the hand appearing from behind and dropping the ball into the first cup.

Each video presented to the child measured 360 x 288 pixels and was presented on a flat projection screen (via an NEC Multisync MT 1030+ projector) measuring 1.45 metres in length and 65 cm in height. The length of each video/trial is detailed in table 11.1.

11.2.3 Auditory stimuli

A sound file was created using Avisoft-SASLab Pro to accompany each of the action trials. Auditory stimuli of the type "Where is the ball?" were recorded by a female speaker using infant-directed speech. The same auditory stimulus was used for each action trial. In addition, for the T1 and the T2 events, the sound that the ball made upon impact was included in the sound file at the appropriate point to alert the child to the fact that the ball had fallen down the tube. The ball impact sound was taken from the digital video, but when played in the stimuli file, this sound was non-directional such that the child could not use the noise as a cue to discern the location of the ball.

The length of the auditory stimulus was 560 milliseconds and the point of onset of the auditory stimulus is detailed in table 11.1. In the case of the two tubes events (T1 and T2), the onset of the auditory stimulus occurred roughly 2000 milliseconds after the child had heard the sound of the ball impacting the box. The sound files that accompanied each action trial were created in Adobe Premiere.

Event	Length of trial		Point of onset of auditory stimulus	
	Action 1	Action 2	Action 1	Action 2
T1	21020	10008	15044	04068
T2	18050	10011	14060	04076
C2	32072	16019	31068	11008

Table 11.1 Table showing length (in milliseconds) of both 'action 1' and 'action 2' trials for each of the three different events (T1, T2 and C2) and the point of onset (in milliseconds) of the auditory stimulus "Where is the ball" for both the 'action 1' and 'action 2' trials, again for each of the three different events.

11.2.4 Design

In as far as was possible, each child who participated in the search studies reported in Chapters 5, 6, 7 and 9 also simultaneously participated in the looking study described here. The order in which children participated in the search and looking studies was randomised such that half the children took part in the looking study before participating in the search task and half participated in the search tasks before being run on the looking trials. The order of presentation of each of the six original events was pseudo-randomised and only three of the looking events were presented per session. The pseudo-randomisation entailed presenting children with three different events in a random order. The three events witnessed were also randomly chosen except that similar events were separated by session. There were a total of six different events (see figure 11.1) but some events were more similar than others. For example, two events contained tubes, two events contained cups and two events contained the ramp and the rolling ball. Because of this similarity, these pairs of events were always separated by session such that if a child viewed the standard tube event (T1) on the first session, they would see the prepotent removed tube event (T2) on the second session. As described in Chapter 4, because of the limited attention span of young children, most were tested over the course of two sessions. As with the search tasks, the looking events were also divided over these two sessions because each event was quite lengthy. As a result some children received the trials of interest to this chapter on their first visit to the lab and others received these trials on their second visit.

11.2.5 Procedure

The children were sitting centred on their parent's lap at a distance of about 90 cm from the projection screen. For a diagram of the looking booth, see figure 11.5. A loudspeaker was situated centrally above the projection screen so that the sound of the ball impacting the box in the two tubes events was non-directional and could not be used as a cue to the location of the ball. As the children entered the testing booth and were seated on their parent's lap, they were presented with some distracter stimuli aimed at making them comfortable in the testing booth. These distracter stimuli took the form of a screensaver whereby an animated small yellow face or an angel was seen passing across the screen. Once the child was seated on the parent's lap, the parent was instructed to put on headphones and to close their eyes so that they could not influence the looking direction of their child. The headphones worn by the parents played instructions reminding them to keep their eyes closed and their child centred. The children's eye movements were recorded using two light-sensitive video cameras mounted above the projection screen. One camera pointed from the left of the projection screen and one camera pointed from the right.

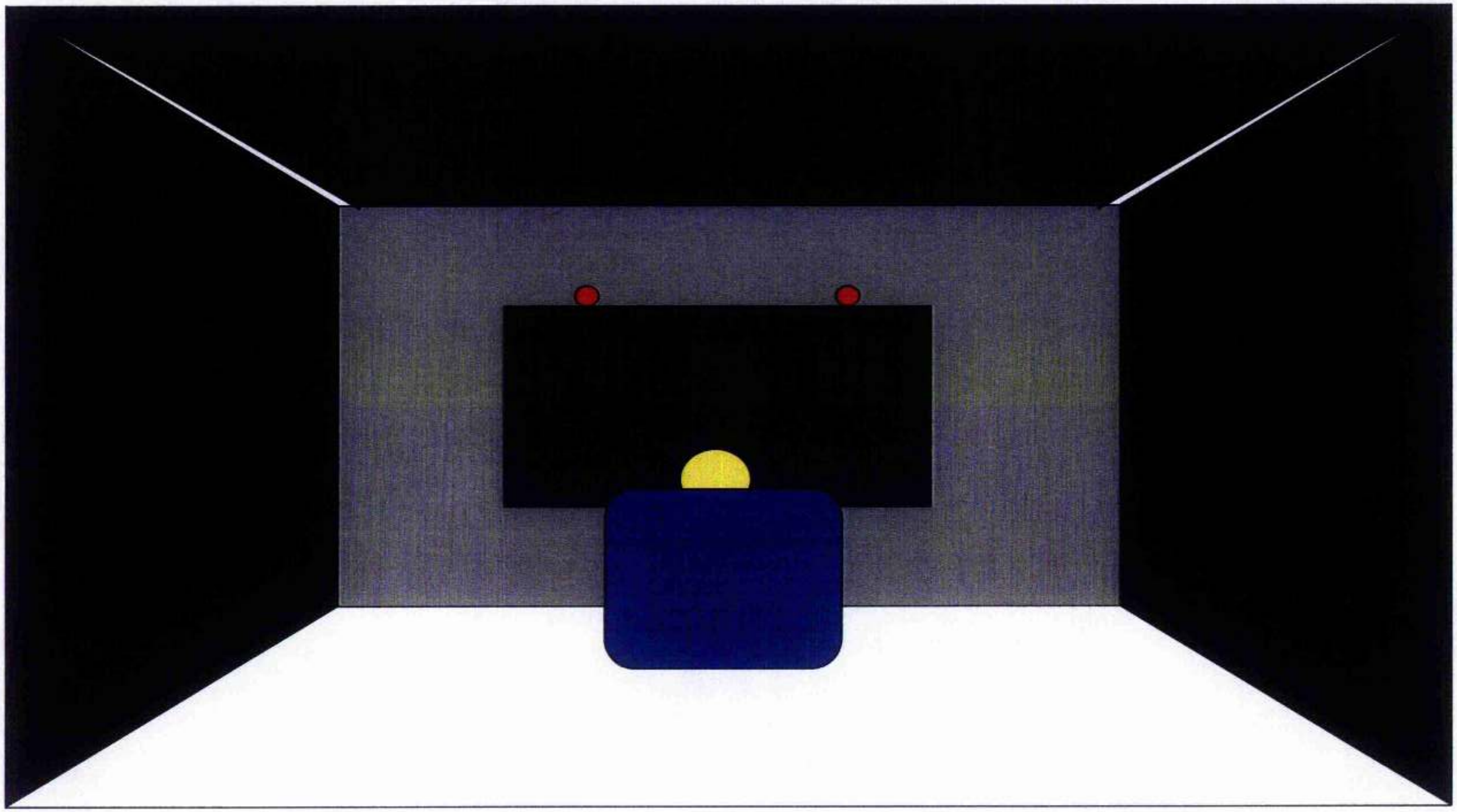


Figure 11.5 Diagram of looking paradigm for use with children

During the experiment, the testing booth was in near darkness. The first trial was launched when the child was centred and appeared comfortable. The stimuli were encoded into a trial file that specified the location that the image should appear on the screen, the length of the file and the order of presentation of each stimulus. This trial file was then run from a PC in an adjacent room. If at any point the child appeared restless or turned away from the screen, the experimenter played a chime over the speaker or flashed a red blob up on the projection screen to get the child's attention, but this was only done in between trials.

11.2.6 Data analysis

All looking during all trials was recorded to standard VHS tapes. In order to analyse left/right looking in response to the auditory stimulus "where is the ball?", the relevant trials (i.e. T1, T2 and C2 'action 1' and 'action 2' trials) were digitized in Adobe Premiere to create AVI files for each child for each of these different trials.

Stimuli	Action 1	Action 2	Outcome
Tubes 1	✓	✓	-
Tubes 2	✓	✓	-
Cups 1	-	-	-
Cups 2	✓	✓	-
Rolling Ball 1	-	-	-
Rolling Ball 2	-	-	-

Table 11.2 Table showing data that was used in the current analysis. '✓' denotes data used and '–' denotes data discarded.

A visual basic program was written to analyse the AVI files. The program allowed analysis of every two frames and gave an output in Excel of which direction the coder deemed the child to be looking on each of these frames and the corresponding point in the trial in milliseconds. Each trial was coded twice by the experimenter and a quarter of these trials were also coded by a second coder (interrater reliability: $r = 0.89$). Although the entirety of each trial was coded, only a small section (2 seconds) of each trial following the auditory stimulus "where is the ball" was used for subsequent analysis. However, it was felt important to code the entire trial and then to isolate the portion that would be subjected to analysis so that the experimenter/coder was blind to the important section of the trial and could not know at which point the child should be looking to the left or right.

After the entire trial had been coded, a two-second period following the end of the auditory stimulus was isolated for analysis. In addition, because "responses to the spoken word require the mobilization of an eye movement" (Swingley & Aslin, 2000 p.155), and are not instantaneous, the beginning of the isolated two-second period commenced 400 milliseconds after the end of the auditory stimulus. There is considerable variation in estimates of the minimum time required to make a saccade following an auditory stimulus, and this probably varies depending on age and species. However, based on theirs and others research, Swingley & Aslin propose that 400 milliseconds is probably a good estimate. The two-second period for analysis was also chosen based on the findings of Swingley & Aslin. They report that the "few eye movements occurring after this time are usually spontaneous re-fixations unrelated to the spoken stimulus" (p.155).

To be included in the analysis, it was required that 90% of the frames be coded the same on the two scorings carried out by the main coder. Considering that there were 25 frames coded for a two-second period (1 frame is equal to 40 milliseconds but since every two frames were coded, two seconds is 25 coded frames), this amounts to 23 out of the 25 frames needing to be identically coded. If there was not 90% agreement in the two codings, two more codings were taken until there was 90% agreement.

11.2.7 Results

The final number of subjects who completed each of the three trials of interest (T1, T2 and C2) varied because of a number of factors. Firstly, a number of children simply did not complete all the trials of interest and because of the random order in which the different events were presented for each child, the trials that were not completed differed depending on the individual child. Secondly, although the light sensitive camera employed during this study was usually sufficient to allow the experimenter to accurately score where the child was looking, there were some trials where this was deemed impossible. For example, some children sat with their heads in such a position that it was impossible to view the eye movements. These trials were discarded from analysis. Thirdly, a number of trials had to be discarded because of experimental error. Trials ended when a light on the computer screen indicated that the previous trial had finished, but on a few occasions the experimenter started the new trial before the previous trial had ended, and so these trials were also excluded from analysis. At the conclusion of the study, only 6 out of 20 two-year-olds and only 4 out of 16 three-year-olds had complete data sets with results for each of the two action trials ('action 1' and 'action 2') on each of the three different events of interest to this chapter (T1, T2 and C2). Because of this large variation in the number and type of trials that each child completed, it was not possible to carry out a repeated measures omnibus tests as such analyses do not allow for missing data[2]. I opted to run a number of independent t-tests analysing performance on the separate events in order to investigate whether looking at the correct location in any of these events is greater than would be expected by chance, while simultaneously looking at differences between age groups. It is unlikely that performance on any of the 'action 2' trials could have been affected by the experience of viewing an 'action 1' trial beforehand because neither of the action trials showed any outcome so viewing the trial is unlikely to have affected children's expectations. Furthermore, although there were two events that involved tubes, and children did see an outcome after the second action trial for a tube event before they would have viewed the second tube event, these two different tube events (T1 and T2) were always presented to children on different sessions. Because of this, it would seem justified to analyse behaviour on these two events as independent data. Finally, because there were no apparent learning effects over trials on the manual search tasks, it seems unlikely that performance on one trial in the looking study would influence performance on subsequent trials, except that some children may have become less attentive as trials went on. As a result, it seems reasonable to treat the different events as independent and subject them to independent analyses. As events were presented in a random order, even if children did become inattentive and therefore not complete all events in each session, the random order of presentation should ensure that no particular event is privileged in terms of receiving more attention from the child than another.

[2] There are a number of solutions to this problem, none of which are definitive or necessarily correct. Firstly, one could discard any subjects who have missing data for any of the trials. However, clearly this is undesirable, especially since such a small number of subjects in each of the age groups have a complete set of data. At least two alternatives remain. One possibility is to estimate the missing data points by substituting the missing point with the grand mean – that is, the mean of all subjects over all trials over all three events. However, this method entails the problem of artificially inflating the mean especially since it was assumed *a priori* that children would do well on the C2 event since the results from the manual search study revealed that children were able to pass this task when presented as a manual search task. The third possibility is to carry out a number of independent tests and this was the approach was chosen.

Therefore, it was decided to carry out separate analyses for each of the three different event types: T1, T2 and C2.

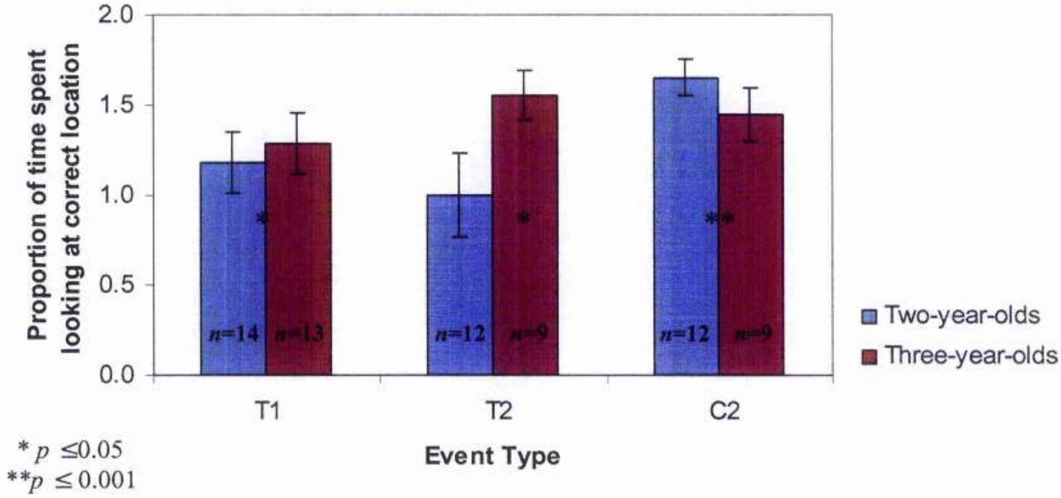


Figure 11.6 Graph displaying the mean proportion (± *SE*) of the two-second time period children spent looking towards the correct location for each 'action 1' event type. An * denotes performance that differs significantly from chance and asterisks that lie in the middle of two bars indicate a significant effect from data that has been pooled across age groups.

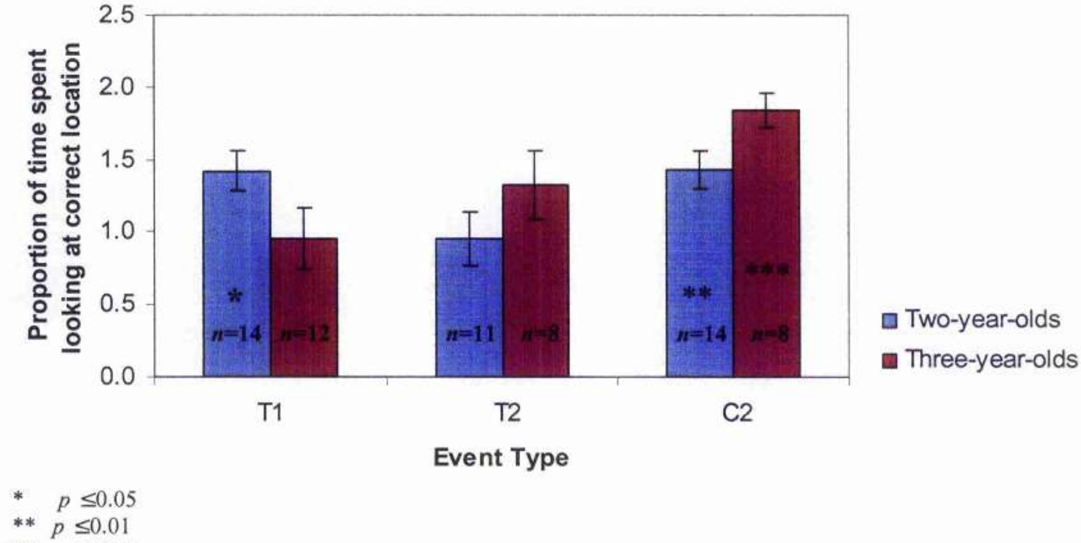


Figure 11.7 Graph displaying the mean proportion (± *SE*) of the two-second time period children spent looking towards the correct location for each 'action 2' event type. An * denotes performance that differs significantly from chance.

11.2.7.1 Analysis for T1

For the T1 event (standard tubes), 19 24-month-olds were tested and 14 of these subjects successfully completed the two action trials. For the 36-month-olds, 14 were originally run on the T1 event and 13 of these subjects completed the 'action 1' trial and 12 completed the 'action 2' trial.

'Action 1' trial: An independent samples t-test revealed no significant differences in the proportion of time spent looking towards the correct location according to age [$t(25) = 0.43$, *ns*]. Due to the lack of difference between age groups, the data was pooled for the remaining analysis. A one-sample t-test was then carried out to investigate whether the mean proportion of looking time towards the correct location is greater than would be expected by chance. As the period chosen for assessment of looking time was two seconds, looking for one second at the correct location would be expected by chance. However, the one-sample t-test indicated that children were looking significantly more at the correct location (the left box) than would be expected by chance [$t(26) = 2.02$, $p \leq 0.05$].

'Action 2' trial: An independent samples t-test revealed an effect of age that approached significance [$t(24) = 1.90$, $p = 0.07$] indicating that 24-month-olds were looking longer at the correct location than were 36-month-olds on the 'action 2' trial. Considering this trend, it seemed sensible to analyse the looking behaviour of these two age groups individually rather than pooling the data and assuming no difference. When independent sample t-tests were carried out, they revealed that 24-month-olds were looking significantly longer at the correct location on 'action 2' trials than would be expected by chance [$t(13) = 2.90$, $p \leq 0.05$], but that 36-month-olds were not [$t(11) = 0.24$, *ns*]. It is notable that in the case of the 24-month-olds, the two children who displayed the opposite looking preference on the 'action 1' trial (i.e. they looked longer at the incorrect location following the auditory stimulus) also showed this reverse looking pattern on the 'action 2' trial. 11 out of the 14 two-year-olds who completed both 'action 1' and 'action 2' trials displayed the same pattern of looking on both trials. The results for the three-year-olds are more puzzling. On the one hand, these children performed above chance on 'action 1' trials, preferring to look at the correct location when asked where the ball was. However, their performance on 'action 2' trials – exactly the same stimulus – indicates chance performance. It seems unlikely that the results from the second action trial for three-year-olds reflect a genuine misunderstanding of the task since three-year-olds generally perform well on the manual search version of the tubes task and displayed above chance predictive abilities on the 'action 1' trial. One alternative explanation is simply that three-year-olds lost interest in the second action trial and stopped paying attention to the important parts of the event. Although it is not possible to tell whether they were truly engaged in this second action trial, it is notable that at least three of the three-year-olds showed some looking away from the screen during (turning around to look at their parent) during the second action trial which they did not do on the first action trial. This distraction on the part of the three-year-olds may have resulted in their either no longer being motivated to respond correctly, or not paying attention to the vital elements of the task which would subsequently allow them to respond correctly to the auditory stimulus.

11.2.7.2 Analysis for T2 event

For the T2 event (tubes task with prepotent response removed), 17 24-month-olds were tested. 12 of these subjects completed the action 1 event with codeable data. For the 'action 2' trial, 11 subjects completed the trial with codeable data. For the 36-

month-olds, 14 subjects were tested on the T2 event. Only 9 of these subjects completed the 'action 1' event with scoreable data. For the 'action 2' event, 8 subjects completed the trial with scoreable data.

'Action 1' trial: An independent samples t-test revealed an effect of age on looking time that approached significance for the 'action 1' trial. That is, three-year-olds looked longer towards the correct location than two-year-olds although this effect did not reach significance [$t\ (19) = 1.87$, $p = 0.8$]. Because of this near-significant effect of age, it was decided to carry out two separate one-sample t-tests to assess whether the looking of either the two- or three-year-olds towards the correct location differed from chance. A one-sample t-test showed that the looking behaviour of two-year-olds did not differ from chance [$t\ (11) = 0.00$, $p = 1.00$]. However, a one-sample t-test on the three-year-old data revealed that these subjects did look significantly longer at the correct location than would be expected by chance [$t\ (8) = 4.03$, $p \leq 0.05$].

'Action 2' trial: An independent samples t-test revealed no significant differences in looking times between 24-month-olds and 36-month-olds [$t\ (17) = 1.21$, *ns*]. As a result, the data from both groups was pooled for a one-sample t-test to assess whether looking times towards the correct location were greater than would be expected by chance. This analysis revealed that children did not look towards the correct location more than would be expected by chance [$t\ (18) = 0.71$, *ns*].

11.2.7.3 Analysis for C2 event

For the C2 event (inverted cups), 16 24-month-olds were tested and 12 of these subjects completed the 'action 1' trial with codeable data. On the 'action 2' trial, 14 subjects completed the trial with scoreable data. For the 36-month-olds, 13 subjects were run on the C2 event. For the 'action 1' trial, 9 subjects completed the trial with useable data and for the 'action 2' trial, 8 subjects completed with useable data.

'Action 1' trial: An independent samples t-test comparing the performance of two-year-olds and three-year-olds on the 'action 1' trial of the C2 event revealed no difference in looking times towards the correct location between the two age groups [$t(19) = 0.59$, $p = ns$]. Due to the fact that there were no differences between two- and three-year-olds, the data was pooled for the rest of the analysis. A one-sample t-test was then carried out to investigate whether looking time towards the correct location was greater than would be expected by chance. The one-sample t-test revealed that looking time towards the correct (right hand side) location was greater than would be expected by chance [$t(20) = 6.37$, $p \leq 0.001$].

'Action 2' trial: The independent samples t-test comparing the looking of two-year-olds and three-year-olds revealed that three-year-olds were looking significantly longer towards the correct cup than two-year-olds [$t(20) = 2.10$, $p \leq 0.05$. Despite this difference in looking times between the age groups, one-sample t-tests revealed that both groups looked significantly longer at the correct cup than would be expected by chance [two-year-olds: $t(13) = 3.25$, $p \leq 0.01$ and three-year-olds: $t(7) = 7.23$, $p \leq 0.0001$].

RESULTS SUMMARY

Overall then, the results from the basic looking analysis suggest that, with the exception of the three-year-olds on the T1 'action 2' event, both two-year-olds and three-year-olds look towards the correct location when asked where the ball is on the T1 and C2 event. However, with regard to the T2 event, only three-year-olds exhibited longer looking towards the correct location with two-year-olds performing at chance. Again, as with the T1 event, the three-year-old children only exhibited above chance looking on the first action trial, with their looking behaviour dropping to chance level on the second action trial.

11.2.8 ORDER ANALYSIS

Since most children who participated in the looking experiment described in the current chapter simultaneously participated in the manual search tasks described in Chapters 5 through 9, an analysis of the order in which they participated in the looking and search tasks was carried out to assess whether or not those children who participated in the search tasks first were more successful on the looking task than those who participated in the opposite order. Separate ANOVAs were carried out for each event and for each action trial, but these analyses revealed no effect of order of presentation, and no interaction between order and age, for any of the events or action trials.

11.3 DISCUSSION

The results presented in the current chapter provide suggestive evidence for an ability in two-year-old human children to be able to visually predict the correct location of an object when it has disappeared from view. To reiterate the main findings of this chapter:

- Both two- and three-year-olds look longer at the correct location when a ball is dropped down an s-shaped tube in the T1 event and they hear the auditory stimulus "where is the ball?"

- Only three-year-olds look longer at the correct location when a ball is dropped down an s-shaped tube in the T2 event.

• Both two- and three-year-olds look longer at the correct location in the C2 event when an object is dropped into a cup and that cup is overturned on top of another cup and the object invisibly displaced into the second cup.

• The order in which the children participated in the search and looking versions of the tasks does not affect performance on the looking tasks.

Why did two-year-old children look longer at the correct location on the T1 event but not on the T2 event? Certainly the lack of positive looking on the T2 event weakens the conclusion that two-year-old children are able to predict the correct location of an invisibly displaced object. Moreover, there is no immediately obvious explanation for this discrepancy as the two events are practically identical in their demands.

However, consider the following possibility. If we accept the interpretations of looking behaviour on expectancy-violation studies, infants as young as three months interpret events in accord with the principle of solidity (Spelke, Breinlinger, Macomber, & Jacobson, 1992; Baillargeon, 2004) and they appear to know that one object cannot pass through another object. If we suppose that children evoke this principle when interpreting physical events, it is possible to imagine that when viewing the tube event, children initially extrapolate a straight-down linear trajectory from the portion of object movement that they witness, but when asked, "where is the ball?", they reason that the tube would prevent this straight-down movement. Having reasoned that a straight-down trajectory would not have been possible, children are left with only one other possibility on the T1 looking event: the correct location. Hence, children look towards the correct location as the only other feasible location but they need not understand the exact function of the tube in order to deduce that this is the correct location. They only need to reason about where the ball *cannot* be.

However, in the T2 event (where the straight-down box is removed), having reasoned again that the ball could not have travelled straight-down, children are then left with two options of places to search. If they do not understand the function of the tube, they may believe that either location is a feasible location for the ball to be in and hence children look randomly at both boxes. A separate question is why children may be able to use their knowledge of solidity to interpret the looking event but not the manual search task? This question will be discussed further in the general discussion (Chapter 12).

The current experiment does not support the 'prediction-postdiction' hypothesis, according to which children are unable to predict the location of an object. On the contrary, when presented with a video of the standard tubes task, two-year-old children appear able to correctly predict where the ball must be. However, this reasoning need not be based on an understanding of the function of the tube but may be based on a perhaps simpler interpretation of the event in accord with the principle of solidity that will dictate where the ball cannot be and by chance lead the child to the correct location. The apparent dissociation between the inability of two-year-olds to find the ball on the manual version of the tubes task (Chapter 5) and their apparent ability to correctly predict the location of the ball on the looking paradigm may not reflect a true difference in knowledge exhibited on each task. Rather, it is possible that the looking paradigm may yield correct responses without reflecting real knowledge.

12

General discussion

The aim of the experiments presented in this thesis was to explore claims that failures on some invisible displacement tasks may reflect limitations in a subject's executive functioning (i.e. memory and inhibition capacities) rather than an inability to represent the displacements of absent objects. A further aim was to identify factors that may influence search behaviour and contribute to successes and failures on such tasks. The results show that a variety of biases exist and emerge in behaviour, depending upon a particular situation. These biases are sometimes shared by humans and monkeys but are sometimes not. However, contrary to the contentions of some authors, such biases do not necessarily mask existing and correct knowledge representations, but, on the contrary, the elicitation of biases may prevent the formation of correct representations.

12.1 Summary of findings

The proposal that subjects may have 'hidden' the relevant knowledge that a particular task encompasses, motivated the studies presented in Chapters five, six and seven. In Chapter 5, Hood's prediction that "participants should be capable of performing the correct response (on the tubes task) when the prepotent response is removed" (Hood, 1995 p. 595) was tested by presenting a version of the tubes task in which there was no option of making the prepotent response. The task was presented to both two-year-old human children and monkeys; two groups of subjects that have demonstrated a pervasive gravity bias on the standard version of the tubes task (Hood, 1995; Hood, Hauser, Anderson, & Santos, 1999). If subjects really do have knowledge about tubes and an understanding of the invisible displacement that they are presented with, then removing the option of prepotent responding should facilitate the demonstration of this knowledge. This was not the case. Both monkeys and children exhibited random responding.

Moreover, the results of the experiments reported in Chapter 5 demonstrate that, contrary to Hood's claims, the 'gravity' error is not restricted to cases of falling objects and is also seen in a task in which an object travels up a tube. The contention of both Hood and Hauser that children and monkeys would be able to pass this task were they able to inhibit a prepotent gravity response (Hood, 1995; Hauser, 2003), does not hold up under the weight of evidence presented in this Chapter. The existence of a bias is likely to reflect a more general alignment bias rather than anything specifically related to gravity.

The results from the experiments presented in Chapter 6 add strength to the conclusions from Chapter 5. Hauser (2001b) proposed that an additional example of the 'gravity' bias is also evident on the shelf task. In this task, rhesus macaques search beneath a solid shelf for an object that is dropped from above. According to Hauser, this error reflects another dimension of the gravity bias: subjects who are ordinarily able to take into account the constraint of solidity on object motion behave as if they cannot, because of a pervasive gravity bias. The results of Chapters 6 and 7 call this conclusion into question by providing evidence that a) searching in the beneath-shelf location occurs irrespective of whether or not any objects are seen falling, or whether there is any difference between the two search locations in terms of their gravitational plausibility, and b) that the results obtained by Hauser, which ostensibly demonstrate an understanding of solidity, are more likely to reflect a bias towards searching in a location closest to where the reward was last seen. The behaviour witnessed on Hauser's task then is unlikely to be the consequence of failing to inhibit a prepotent response *resulting* from a naïve theory of gravity.

In discounting this bias as being specifically related to gravity, the results from these Chapters have also highlighted a number of other biases that influence search behaviour. In Chapter 5, an alignment bias rather than a gravity bias was proposed to account for the behaviour witnessed in both children and monkeys. In Chapter 6, a rather different bias emerged for monkeys – a bias towards searching for food in a sheltered location. This bias does not appear to emerge in human children; instead, children present a bias that is better explained by handedness. In Chapters 7 and 8, a proximity bias is identified which leads both monkeys and young children to search for a hidden object in the location closest to where this object disappeared. The results from Chapter 8 highlight how situation-specific biases can be, and how seemingly mundane changes in tasks (such as whether or not the apparatus is within or out-of-reach of the subject) can elicit entirely different patterns of search.

In addition to identifying a number of biases that influence search behaviour, the experiments presented in these Chapters also point to a glaring inability on the part of these two groups of subjects to take into account how the physical constraint of solidity impacts on object trajectories. Despite the fact that there is evidence that in other situations, both children and monkeys do appear to reason in accord with the physical constraint of solidity (Santos & Hauser, 2002; Baillargeon, 2004), this ability is not demonstrated in the current tasks. In all of the tasks presented in Chapters 5, 6, 7 and 8, both monkeys and young children appear ignorant to the constraint of solidity and systematically ignore the constraints on object pathways imposed by the presence of tubes and solid shelves.

Although the results from these earlier Chapters point towards subjects that do not understand how physical features influence the trajectories of objects, the results from Chapters 9 and 11 suggest that in some situations, our infant and monkey subjects may not be as ignorant as these results suggest. In Chapter 9 we see some possible evidence that rhesus monkeys may be able to solve an invisible displacement task involving gravity, suggesting that, in principle, they may be capable of representing the movement of an invisible object. Likewise, the failure of two-year-old children to pass a double invisible displacement, but their ability to pass the single invisible displacement task described in Chapter 9, strongly suggests that it is not a general ability to represent hidden object movement that determines success and failure on invisible displacement tasks, but rather features more specific to individual tasks. If both monkeys and children are able to solve some invisible displacement tasks, then it is necessary to accept that the ability exists. The task then becomes one of identifying the factors that contribute to instances of success and failure.

Much research over the past few decades has highlighted the dissociation that exists between the understanding that subjects (both human and nonhuman) can demonstrate on looking tasks and that which they can demonstrate on manual search tasks. The results from Chapter 11, indicating that two-year-old children can predict the location of a ball when only a looking response is required, contrast with the inability of these same children to find a ball when a manual response is required (Chapter 5). These results contribute another example of a looking-searching dissociation in development, but go beyond this by addressing one specific hypothesis that has been proposed to account for the dissociation; the prediction-postdiction hypothesis. It appears that, contrary to the contentions of some authors (Meltzoff & Moore, 1998; Hood, Cole-Davis, & Dias, 2003; Keen, 2003), children do not fail manual search tasks because they are unable to predict the location of an object. In the task presented in Chapter 11, children were able to visually predict the location of a ball that had disappeared by exhibiting longer looking to the correct location in response to the question, "where is the ball?" Most looking studies that have found positive results (i.e. subjects react with increased attention to physically impossible outcomes), rather than measuring looking in advance, have measured looking retrospectively to outcomes. In this way, the task presented in Chapter 11 emulates its searching counterpart (of Chapter 5) more closely, as both require the ability to predict an object's location in order to be successful. The results of Chapter 11 strongly suggest that an inability to predict an object's location does not account for the looking-searching dissociation. However, the suggestion was also made that correct prediction on this task need not reflect complete understanding of the task either, and could be achieved by a process of elimination.

12.2 INTERPRETING THE RESULTS

The overall results presented in this thesis cannot be explained in any simple way. That neither monkeys nor children show evidence of correct understanding of the tubes task even once the prepotent response is removed, contradicts the contentions of both Hood and Hauser that a dominant prepotent response masks correct existing knowledge (Hood, 1995; Hauser, 2003). The observed response – searching at the straight-down location – is not concealing an accurate representation of the task when it is presented in the search domain. Likewise, the proposed 'other dimension' of the 'gravity' bias – leading monkeys to search for a fallen object beneath a solid shelf – does not mask an existing correct representation of the task. Monkeys also do not take into account the constraint of solidity when this and similar tasks are presented horizontally. Gravity is not the culprit. But, if subjects do not have the requisite physical knowledge that would enable them to pass the task were it not for an interfering prepotent response, why do children appear to show an understanding of the tubes task when it is presented in the looking domain?

The results from Chapters 8 (within reach vs. out of reach task) and 9 (inverted cups task) highlight the importance of considering ostensibly mundane aspects of tasks in the quest to understand why children and nonhuman species fail invisible displacement tasks; Chapter 8 because it shows how a seemingly small variation in the presentation of a task can have a large effect on search behaviour and Chapter 9 because it shows that, in principle, children and monkeys can fail one invisible displacement task yet pass another. If both tasks require mental representational abilities, mental representation of invisible trajectories is unlikely to be the principal factor that determines success on these tasks.

In an attempt to address these issues, I adopt the framework proposed by Munakata and colleagues who have stressed the need to consider that knowledge can be present to varying degrees, or in Munakata's terms, knowledge representations can be 'graded in nature' (Munakata, McClelland, Johnson, & Siegler, 1997). The degree or strength of a subject's representation may determine what the subject can do with that representation. Munakata proposes that, while a weak representation may be sufficient on some tasks, a stronger representation may be needed to pass another type of task (Munakata, 2000). At the neural level, according to Munakata, "representations can be graded in terms of the number of relevant neurons firing, their firing rates and the coherence of the firing patterns" (Munakata, 2001 p. 309). In addition to this distinction between varying strengths of knowledge representations, I propose that there are also occasions where no degree of correct representation of a task is formed. The different behavioural biases that have been identified in this thesis may be thought of as belonging to two different groups. Firstly there are biases that may *create* misrepresentations of tasks such that no correct representation of the task exists. Secondly there are biases in behaviour that emerge in situations where the subject has not formed the correct representation or has only a weak (correct) representation of the task.

12.3 UNDERSTANDING INVISIBLE DISPLACEMENT PERFORMANCE

Although it is not possible to draw conclusions on the origins of such biases from the current work, in thinking about why they emerge in some situations and not others, we can identify directions for future research. Four different biases have been identified from the studies presented in this thesis: an alignment bias and a proximity bias were identified in Chapters 5 and 7 and found to be present both in monkeys and young children, whilst a bias to search beneath a solid shelf and a handedness bias were identified in Chapter 6 but found to each be present only in monkeys (beneath-shelf bias) or young children (handedness bias). I propose that two of these biases (the alignment and proximity biases) are biases that prevent the subject from forming even a weak representation of the task, whilst the other two biases (the beneath-shelf bias and the handedness bias) emerge in situations where the subject either has no representation (because of an inability to consider the relevant physical constraints) or a weak representation of the task.

The position advocated in this thesis, to be described in greater depth in the next section, makes the following points:

- Young children and monkeys do not take into account task-relevant details in advance of an object's disappearance
- Their attention focuses on the most salient feature of a task (e.g. the falling object) and weak inhibitory skills mean that attention is not easily disengaged from the most salient feature
- Focusing on the most salient feature leads to an initial expectation that is in accord with this most salient feature
- Weak inhibitory skills prevent subjects from suppressing a reach response to the location where their attention is initially focused (because of their initial interpretation of the task in accord with the most salient feature).
- The inability to suppress a reach response prevents the subjects from further reasoning about the location of the object.
- In cases where a representation is weak, numerous external factors may, in effect, destroy the representation, and lead to the emergence of pre-existing biases.

12.3.1 BIASES THAT LEAD TO INCORRECT REPRESENTATIONS

Although I have concluded that inhibition at the response level cannot account for the bias displayed on the tubes task, and is unlikely to account for other biases, the position advocated here is that inhibition at the representational level may play a role in these failures. By 'inhibition at the representational level', I adopt Harnishfeger's definition that it is inhibition that "involves the control of cognitive contents or processes" (Harnishfeger, 1995 p.184) and Zelazo et al.'s definition that this type of inhibition means that subjects have "difficulty inhibiting an incorrect representation and establishing a correct one" (Zelazo, Reznick, & Spinazzola, 1998 p.203). Although inhibition at the response level is thought to mask existing knowledge (Diamond, 1991; Hood, 1995; Zelazo, Reznick, & Pinon, 1995) an inhibitory failure at the representational level does not mask existing knowledge since the correct representation is never formed. As the prefrontal cortex matures, the resulting enhancement in inhibitory capacity may increasingly allow subjects to inhibit incorrect representations and establish correct ones. Inhibition may enable subjects to establish correct representations by allowing them to simultaneously consider all the task relevant features that determine the location of an object. A lack of inhibitory control at this level may lead subjects to focus exclusively on the most salient feature of a task and neglect other relevant variables. (One point that should be made here however, is that if the subject does not have the understanding or appreciation of the physical principles that a particular task entails, even in the absence of the stimuli that elicits the bias, a correct representation will not be formed).

12.3.1.1 FAILING TO ATTEND TO TASK-RELEVANT DETAILS AND FOCUSING ON THE MOST SALIENT VARIABLE

One reason why a correct representation of an object's location may never emerge in the first place may be because young children and monkeys find it difficult to take in and process multiple sources of information simultaneously. One of the prerequisites for solving invisible displacement tasks like those that have been designed by Hood (1995) and Berthier et al. (2000) is that subjects need to be able to integrate knowledge they may have about natural object trajectories with what knowledge they have about object interactions. It is possible that monkeys and young children are able to demonstrate a sensitivity to such factors independently, but are not able to take them both into account simultaneously. When a child sees a falling object, they need to not only know that falling objects will keep moving down in the absence of support, but that when this falling object encounters another solid object (like a tube), this will affect the pathway that the falling object will take. Likewise, in the case of the Berthier et al. task (2000), it is necessary to know that when the rolling object disappears from view, it will continue to roll straight down, but that the presence of a solid wall will determine how far this object will roll. If subjects focus exclusively on only one of these factors, their response to the disappearance of the object will be incorrect.

However, such integration may be difficult for a two-year-old child or other subjects who have limited inhibitory capacities. Flavell (1977) has argued that young children are prone to 'centration' - the tendency to focus attention exclusively on one variable at the expense of attending to other, equally relevant variables. The point of attention may be the most salient or interesting element of the visual display and this may lead the child to neglect other task-relevant features (Flavell, 1977, p.81). As children get older, they become better able to 'decentrate' and pay attention to, and consider, other variables that may be relevant to the task in hand. Flavell does not speculate on how this comes about, but it is feasible that as inhibitory capacities mature, subjects become better able to disengage from the most salient feature, or the feature that most interests them, to enable them to attend to other factors. In a recent study in which children's eye movements were recorded while they participated in a version of the Berthier et al. rolling ball task, it was found that two-year-olds rarely looked at the solid wall at all, focussing predominantly on the disappearance and emergence of the ball, whereas three-year-olds did look at the solid wall (Haddad, Kloos, & Keen, 2004). Two-year-olds subsequently fail to find the ball whereas three-year-olds perform well. The looking behaviour of children on this task conforms to the contention that children who fail a search task may be focussing exclusively on one relevant aspect of a task, at the expense of other relevant aspects.

12.3.1.2 FOCUSING ON THE MOST SALIENT FEATURE LEADS TO AN INITIAL EXPECTATION IN ACCORD WITH THIS FEATURE

By neglecting other task-relevant features, and concentrating solely on the most salient feature, it follows that children and monkeys may initially interpret an object's motion in accord with this most salient feature. For example, if a subject is focusing solely on the linear trajectory of an object, they may initially interpret the remaining invisible trajectory of the object as continuing this linear pathway. Having done this, and initially focused on the location that accords with this initial interpretation, young children and monkeys may find it difficult to disengage from this initial 'choice' and to suppress a reach response to this location. Goldman-Rakic notes a similar response in monkeys when she writes that monkeys with prefrontal deficits have a tendency to "respond to the first food well that catches (their) eye" (Goldman-Rakic, 1987 p.604). Although suppressing a reach response in both two-year-olds and monkeys *is* possible on other tasks, these may be tasks in which subjects already have some degree of representation of the object's true location. For example, both two-year-olds and monkeys can suppress a prepotent response to location 'A' on the A-not-B task, but their representation of the location at 'B' may be strong enough to allow them to suppress the urge to reach to 'A'. In an invisible displacement task where the subject's representation of the object's location may be absent or very weak, it may be less easy for them to suppress reaching to the location that they initially focus on.

In order to account for the divergent reaching-looking findings from Chapter 5 and 11, it is proposed that initially, children and monkeys do interpret the movement of the ball in accord with a pre-existing alignment bias. The reason why they have this initial interpretation is because it is the dynamic feature of the task (the moving object) that captures their attention. However, in a looking task, like the one described in Chapter 11, children may have the opportunity to reason that the solid nature of the tube prevents the object from travelling in, or continuing on, its linear pathway. As a result, they are able to discount this location as a possible search option. In the standard tubes looking condition, this leaves them with just one other option – the correct option, whereas in the prepotent removed condition, having discounted the aligned location, they then have two alternative locations. The kind of cognitive back-peddling that would be required for them to then work out, with knowledge of how tubes function, which of these two locations is the right one, may be too difficult for young children (especially if they have little experience with tubes and how they function) and so they look randomly between the two locations. On the standard tubes trial, as there is only one option after discounting the aligned location, correct looking is seen.

On the search version of the tubes task however, children of this age may never get the opportunity to reason about where the ball must be. Having initially interpreted the event in terms of a linear pathway and having set eyes on the aligned location, they may find it difficult to inhibit a subsequent reach to this location. The difference between looking and reaching is that in the reaching task, children find it difficult to inhibit reaching to the location that first catches their eye, so not allowing them the option of further reasoning about where the object could be. In the looking task, the removal of the option of any reach response might allow the child the option of reasoning about whether this aligned location is likely or not. So, despite having the ability to recognize the way in which solidity constrains object motion, it is only in the looking task that they have the opportunity to indulge this capacity.

The same phenomenon may also account for the search errors seen on the different ramp tasks described in Chapters 7 and 8. Subjects initially focus solely on the dynamic event (the object movement), and do not take into account other elements of the task that will affect the final location of the object. In the task described in Chapter 7, in which subjects watch as a ball rolls down a ramp, and have the option of searching either underneath the ramp (the nearer, yet incorrect location) or at the end of the ramp (the further, but correct location), both monkeys and children search predominantly underneath the ramp. If subjects focus exclusively on the rolling object, at the expense of other task relevant features like the solid ramp, their initial representation of the task may be in accord with a pre-existing proximity bias. Such a bias may have a long evolutionary history. For example, if a predator disappears behind a large rock, it would be beneficial to the prey to pay attention to this part of the environment rather than any other part. Again, when the subject's initial representation is in accord with a pre-existing bias, a reach response to this attended location quickly follows.

Neither of these biases masks a correct representation of the task. Such biases stem from the subject's over-attending to the most salient variable (the dynamic one) and initially forming a representation of the task in accord with this variable. As inhibitory capacities mature, children become better able to focus on other relevant features and consider the interaction between the different variables. Monkeys, on the other hand, may never develop sophisticated enough inhibitory skills and remain unable to overcome 'centration' even as adults.

12.3.2 ABSENT REPRESENTATIONS

In the section above, I proposed that where there are dynamic events like falling or rolling objects, the salience of such events leads those with weak inhibitory control to focus exclusively on this variable and form a representation of the task accordingly. However, on some tasks, this may not lead to a representation of the task that specifies one search location as more likely to contain the vanished object than another. In such situations, I propose that behavioural biases like the handedness bias seen in children, and the beneath-shelf preference seen in monkeys, will emerge.

Even if children and monkeys evoked an alignment or proximity bias upon witnessing the falling object in Chapter 6, the spatial closeness of the two search locations in these tasks does not dictate one search location to be more likely to contain the reward than another. As a result, the child may have no representation (correct or incorrect) of the object's location and in such cases pre-existing behavioural biases like handedness (children) and sheltered-foraging (monkeys) may surface. However, in the task described in Chapter 6, when spatial cues are provided which give one search location special status, the beneath-shelf bias does not surface, as the monkey has been able to form an alternative representation.

12.3.3 WEAK REPRESENTATIONS

The discussion so far has focused on situations where, because of representational biases, subjects may have no accurate representation of a task. Furthermore, I have proposed that initial interpretations of tasks in accord with the most salient feature, and the subsequent reaching behaviour that follows, may not allow subjects the option of reasoning about where the object really could be.

However, there are some tasks where a young child or a monkey may be able to form some degree of representation about an object's location, but this representation may still be relatively weak. When representations are weak, biases like handedness may surface again to influence search behaviour. The experiment described in Chapter 6 suggests a difference in search behaviour between two-year-olds and three-year-olds such that three-year-olds perform better on the ramp task than two-year-olds. However, while two-year-olds appear to show no understanding of the task, the behaviour of three-year-olds suggests that they may know something more about the task. However, handedness still appears to exert an effect on search behaviour even at this age. It is possible that, by three years, children are able to attend more to task-relevant features (other than the most salient dynamic event) and may form a correct, albeit weak, representation of the object's location. However, the weakness of the representation may mean that biases like handedness still exert an influence on behaviour. Perhaps it is only when the child is able to form a sufficiently strong representation of the object's location that biases like handedness no longer exert an influence on search.

So far, I have argued that the salience of moving objects captures attention to such an extent that subjects with weak inhibitory control may not be able to disengage attention from this single variable. If excessive attention is given to the dynamic aspect of a task and this leads subjects to a representation of the task in accord with the one feature they are focussing on, one prediction would be that if the dynamic event was somehow made less salient, subjects may be able to focus on other relevant features that may help them to solve the task. Perhaps this is what we see in the study described in Chapter 9. In this task, because there is no salient object trajectory, subjects may be more easily able to attend to other relevant features, such as the overturning of the cup, and the effect that this has on an object inside. This may also help to explain why two-year-old children can do well on a standard Piagetian invisible displacement but fail the kind of invisible displacements involving object trajectories that are described in this thesis.

However, although rhesus monkeys show some ability to solve the invisible displacement in Chapter 9, this result is inconsistent with many results that have shown monkeys to be incapable of solving invisible displacements when the appropriate controls have been employed. In attempting to explain this discrepancy, it may be helpful to consider the results from Chapter 8, which suggested that seemingly mundane task differences might, in reality, have profound effects on a subject's ability to solve a task. One possible explanation for the differences seen in the two conditions described in Chapter 8 is that the post-disappearance movement of the apparatus leads to a disruption in the monkey's (incorrect) representation of the task. So, even if monkeys have evoked an initial (incorrect) representation of the task in accord with a proximity bias, the movement of the apparatus may disrupt or destroy this representation. It seems possible that the post-disappearance movement of apparatus in most invisible displacement tasks carried out with animals (Vaughter, Smotherman, & Ordy, 1972; Mathieu, Bouchard, Granger, & Herscovitch, 1976; Natale, Antinucci, Spinozzi, & Poti, 1986; Schino, Spinozzi, & Berlinguer, 1990; De Blois & Novak, 1994; Dumas & Brunet, 1994; De Blois, Novak, & Bond, 1998; Mendes & Huber, 2004) may have the effect of disrupting the monkey's representation and the weaker the representation is, the more likely that mundane features of a task (like apparatus or subject movement) will disrupt this representation. Either the movement of the apparatus or the delay imposed by this kind of design may affect a fragile or weak representation of the location of the object and result in failure. One of the few tests of invisible displacement understanding in which the animals have shown competence in invisible displacements did not involve any movement of the apparatus because the apparatus was kept within reach of the subject (Neiworth et al., 2003).

In cases where a representation is weak, factors such as the movement of the apparatus may have a devastating effect on an already fragile representation. As Berthier and colleagues have previously noted, even on a visible displacement version of their task, if a two-year-old child's gaze is disrupted from the location of disappearance prior to search, they tend to search randomly (Mash, Keen, & Berthier, 2003). This indicates the fragility of the child's representation of the object's location.

12.3.4 FUTURE DIRECTIONS

In an attempt to reconcile some of the apparently discrepant findings, I have proposed some possible explanations based on representational inhibition and weak representations. From these speculations, a number of predictions can be made.

Firstly, in relation to the possibility that it is the saliency of dynamic events that prevents subjects with weak inhibitory control from considering other relevant task features, by removing or reducing the dynamism of the event, the performance of these subjects should change. For example, on the tubes task, if the experimenter placed an object into the tube rather than dropping it, would this reduce the salience of this aspect of the event and allow subjects to attend to other features as well?

Secondly, with respect to the claim made at the end of Chapter 11, that the apparent ability of two-year-olds to visually predict the location of the ball at the end of the tube need not necessarily reflect true understanding of how tubes function, providing three search locations instead of two could test this claim. If the findings reflect elimination of the straight-down location, rather than real understanding about how tubes function, perhaps children would not look towards the correct location if there were two other boxes.

Thirdly, the direction that I find most exciting is the possibility to explore to what extent invisible displacement failures in monkeys could be attributable to mundane task features that have not, to date, been considered. If monkeys might be able to solve invisible displacements, but the representations that they form are weak enough to be disrupted by apparatus movement, it is possible to design tasks that do not involve post-disappearance movement of apparatus. Perhaps the only reason great apes have displayed such competence on invisible displacement tasks is because of their hypothesised superior executive functioning abilities. Call's finding that apes in his task fell victim to sequential searching (choosing the next container in line even though this container was not visited by the experimenter) has been interpreted as an inhibitory failure (Call, 2001) and it is possible that the urge to search at the next sequential location could be better overcome if the ape had a stronger representation of the food's location. One way to examine the idea that strength of representation may affect the likelihood of these types of biases emerging is to compare visible and invisible displacement tasks that entail similar memory demands. For example, even on a double visible displacement, the subject only need remember the final location of the object in order to solve the task and so the memory demands are less for a visible displacement than an invisible displacement. If two rewards were hidden visibly in different locations, such that there was still a middle container that was empty, the memory demands on the subject might approach those of an invisible displacement, as now the subject has to also remember two locations, not just the final location visited. If, having retrieved one food reward, the subject was able to bypass the middle container, perhaps this would indicate that inhibitory problems surface mainly in situations where representations might be relatively weaker.

12.4 CONCLUDING REMARKS

The experiments in this thesis have revealed a number of biases that emerge in the search behaviour of both young human children and adult macaque monkeys. These biases do not mask existing correct representations of the tasks, but rather emerge instead of correct representations. Pre-existing biases may be most likely to emerge in behaviour when an individual's representation of a task is non-existent or relatively weak. The position advocated in this thesis is that although subjects may have difficulty inhibiting an incorrect representation of a task in both looking and reaching modalities, the task of establishing a correct representation may be especially difficult on a search task. This is because, having initially evoked an incorrect representation, young children may find it difficult to suppress a reach response to that location. When no reach response is possible, the task of establishing a correct representation may be easier.

It seems likely that the role of executive function in invisible displacement failures has been underestimated and while some authors have raised contentions that some search behaviours seen on these tasks do reflect executive limitations (Gagnon & Dore, 1992; Call, 2001), the full extent to which executive limitations may impinge on successful solving of an invisible displacement task may, in reality, be much greater. The fact that most invisible displacement tasks that monkeys have failed to solve representationally have been presented out of reach and involved post-disappearance movement of apparatus is concerning in light of findings in this thesis that such seemingly insignificant task differences can evoke such different search patterns.

These findings raise serious questions about the usefulness of tasks that we use to assess a species capacity for object permanence abilities. The kind of tasks that Piaget conceived for measuring the developing cognitive skills of young children were readily adopted for use with non-human species precisely because they appeared so readily transferable to the study of non-human cognition (Pepperberg, 2002). As Macphail (1987) once said "comparative analyses are doomed to failure in the absence of comparative methods that could be used across species". However, with increasing interest in the role of executive functions in task failures, the time has come to consider whether object permanence tasks really do measure what we think they do. Seemingly mundane factors like whether or not there is movement of apparatus after an invisible displacement task or the time difference between hiding and searching that is necessarily imposed depending on whether an invisible displacement is single or double, may make all the difference between success and failure. Given the differences in prefrontal structure between species and the consequent differences in inhibitory capacities, any element of a task that requires more attention than another, or greater memory skills than another, is likely to yield species differences in task performance because some species simply have better executive skills than others.

****

One of the most difficult challenges facing comparative psychologists is to convince the scientific community that animals can solve the challenges that face them in ways that approximate human problem solving. The many reports of monkeys' failure to solve invisible displacements in ways that would suggest representational thought, solving them instead by more simple strategies, appears an ideal example of the how the same end may be achieved via different means. Although this body of research has led to a consensus that monkeys are not capable of solving such problems in the same way that young human children eventually become able to, more recent research has suggested that executive functioning limitations, rather than representational limitations, may be responsible for this difference. The results presented in this thesis, whilst acknowledging that certain elements of some invisible displacement tasks may make them more difficult for subjects with inferior executive functioning skills to solve, do not support the contention that monkeys and young children have representations that they are unable to demonstrate. If the biases identified do determine the subject's representation of a task, then it follows that, if young children and non-human species are less able to prevent these biases from influencing their representations, then the representations that emerge will be very different.

REFERENCES

Ahmed, A., & Ruffman, T. (1998). Why do infants make A not B errors in a search task, yet show memory for the location of hidden objects in a nonsearch task? *Developmental Psychology, 34*(3), 441-453.

Annett, M. (1985). *Left, right, hand and brain: The right shift theory.* Hillsdale, NJ: Erlbaum.

Baillargeon, R. (1987). Object permanence in 3.5- and 4.5-month-old infants. *Developmental Psychology, 23*, 655-664.

Baillargeon, R. (2000). Reply to Bogartz, Shinskey, and Schilling; Schilling; and Cashon and Cohen. *Infancy, 1*(4), 447-462.

Baillargeon, R. (2004). Infants' reasoning about hidden objects: evidence for event-general and event-specific expectations. *Developmental Science, 7*(4), 391-424.

Baillargeon, R., & Hanko-Summers, S. (1990). Is the top object adequately supported by the bottom object? Young infant's understanding of support relations. *Cognitive Development, 5*, 29-53.

Baillargeon, R., Kotovsky, L., & Needham, A. (1995). The acquisition of physical knowledge in infancy. In D. Sperber, Premack, D., & Premack, A. (Eds) (Ed.), *Causal Cognition: A multidisciplinary Debate.* Oxford: OUP.

Baillargeon, R., Needham, A., & DeVos, J. (1992). The development of young infants' intuitions about support. *Early Development and Parenting, 1*, 69-78.

Baillargeon, R., Spelke, E. S., & Wasserman, S. (1985). Object permanence in five-month-old infants. *Cognition, 20*, 191-208.

Bates, E. (1976). *Language, Thought and Culture: Advances in the Study of Cognition*. New York: Academic Press.

Benson, J. B., DeBlois, S., Bottani, M. A., & Hansen, S. T. (2000). *Spatial location estimation from 18 to 36 months.* Paper presented at the International Conference on Infant Studies, Brighton, England.

Berger, S. (in press). Demands on Finite Cognitive Capacity Cause Infants' Perseverative Errors. *Infancy*.

Bertenthal, B. I. (1996). Origins and early development of perception, action, and representation. *Annual Review of Psychology, 47*, 431-459.

Berthier, N., Bertenthal, B., Seaks, J., Sylvia, M., Johnson, R., & Clifton, R. (2001). Using object knowledge in visual tracking and reaching. *Infancy, 2*(2), 257-284.

Berthier, N., DeBlois, S., Poirier, C. R., Novak, M. A., & Clifton, R. K. (2000). Where's the ball? Two- and three-year-olds reason about unseen events. *Developmental Psychology, 36*, 394-401.

Bever, T. G., Mehler, J., & Epstein, J. (1968). What children do in spite of what they know. *Science, 162*(3856), 921-924.

Bigelow, A. E., MacDonald, D., & MacDonald, L. (1995). The Development of Infants' search for their mothers, unfamiliar people and objects. *Merrill Palmer Quarterly Journal of Developmental Psychology, 41*(2), 191-208.

Bogartz, R. S., Shinskey, J. L., & Schilling, T. H. (2000). Eight-Month-Old Infants' Perception of Possible and Impossible Events. *Infancy, 1*(4), 403-428.

Bogartz, R. S., Shinskey, J. L., & Speaker, C. J. (1997). Interpreting infant looking: the event set x event set design. *Developmental Psychology, 33*(3), 408-422.

Bower, T. G. (1974a). *Development in Infancy*. New York: Freeman.

Bower, T. G. (1974b). Development of infant behaviour. *Br Med Bull, 30*(2), 175-178.

Bower, T. G. R. (1977). *The Perceptual World of the Child*. London: Fontana.

Bower, T. G. R., Broughton, J. M., & Moore, M. K. (1971). Development of the object concept as manifested in the tracking behavior of infants between 7 and 20 weeks of age. *Journal of Experimental Child Psychology, 11*, 182-193.

Bower, T. G. R., & Wishart, J. G. (1972). The effects of motor skill on object permanence. *Cognition, 1*(2), 28-35.

Boysen, S. T. (1996). 'More is less': the distribution of rule-governed resource distribution in chimpanzees. In A. E. Russon, Bard, K.A., & Parker, S.T. (Ed.), *Reaching into Thought: the Minds of the Great Apes.* (pp. 177-189). Cambridge, MA: Cambridge University Press.

Bremner, J. G. (1978). Spatial errors made by infants: Inadequate spatial cues or evidence of egocentrism? *British Journal of Psychology, 69*, 77-84.

Butler, S. C., Berthier, N., & Clifton, R. K. (2002). Two-Year-Olds' Search Strategies and Visual Tracking in a Hidden Displacement Task. *Developmental Psychology, 38*(4), 581-590.

Butterworth, G., & Hopkins, B. N. (1993). Origins of handedness in human infancy. *Developmental Medicine and Child Neurology, 35*, 177-184.

Byrne, G. D., & Suomi, S. J. (1991). Effects of woodchips and buried food on behavior patterns and psychological well-being of captive rhesus monkeys. *American Journal of Primatology, 23*, 141-151.

Cacchione, T., & Krist, H. (2004). Recognizing Impossible Object Relations: Intuitions About Support in Chimpanzees (Pan troglodytes). *Journal of Comparative Psychology, 118*(2), 140-148.

Call, J. (2001). Object Permanence in Orangutans (Pongo pygmaeus), Chimpanzees (Pan trogodytes) and Children (Homo sapiens). *Journal of Comparative Psychology, 115*, 159-171.

Call, J., & Tomasello, M. (in press). Reasoning and thinking in nonhuman primates. In K. H. R. Morrison (Ed.), *The Cambridge Handbook of Thinking and Reasoning*. Cambridge: Cambridge University Press.

Carlson, D. F., & Harris, L. J. (1985). Development of infant's hand preference for visually directed reaching: Preliminary report of a longitudinal study. *Infant Mental Health Journal, 6*, 158-172.

Carlson, S. M., Moses, L. J., & Hix, H. R. (1998). The role of inhibitory processes in young children's difficulties with deception and false belief. *Child Development, 69*, 672-692.

Cashon, C. H., & Cohen, L. B. (2000). Eight-month-old infants' perception of possible and impossible events. *Infancy, 1*(4), 429-446.

Clements, W. A., & Perner, J. (1994). Implicit understanding of belief. *Cognitive Development, 9*, 377-397.

Clifton, R. K. (1974). Heart rate conditioning in the newborn infant. *Journal of Experimental Child Psychology, 18*, 9-21.

Clifton, R. K., Rochat, P., Litovsky, R., & Perris, E. (1991). Object Representation Guides Infants' Reaching in the Dark. *Journal of Experimental Psychology: Human Perception and Performance, 17*(2), 323-329.

Cornell, E. H. (1979). Infants' recognition memory, forgetting and savings. *Journal of Experimental Child Psychology, 28*, 359-374.

Cummings, E. M., & Bjork, E. L. (1981). The search behavior of 12-14 month old infants on a five-choice invisible displacement hiding task. *Infant Behaviour and Development, 4*, 47-60.

Dan, Naoko, Omori, Takahide, Tomiyasu, & Yoshikazu. (2000). Development of infants' intuitions about support relations: sensitivity to stability. *Developmental Science, 3*(2), 171-180.

Dan, Naoko, Omori, Takahide, Tomiyasu, & Yoshikazu. (2001). Determinants of infants' understanding of supporting relations: Amount of contact versus position of the center of gravity. *Psychological Reports Special Issue, Vol 88*(1), 175-181.

Dan, N., & Omori, T. (2002). *Self-sitters know that objects should fall straight down.* Paper presented at the International Conference on Infant Studies, Toronto, Ontario, April 18 - 21.

Dan, N., Omori, T., & Tomiyasu, Y. (2000). *Dominance of gravity rules in falling events during infancy.* Paper presented at the International Conference on Infant Studies, Brighton, UK, July 2000.

De Blois, S.T., Novak, M.A., & Bond, M. (1999). Can memory requirements account for species' differences in invisible displacement tasks? *Journal of Experimental Psychology: Animal Behavior Processes, 25*(2), 168-176.

De Blois, S. T., & Novak, M. A. (1994). Object Permanence in Rhesus Monkeys (Macaca mulatta). *Journal of Comparative Psychology, 108*(4), 318-327.

De Blois, S. T., Novak, M. A., & Bond, M. (1998). Object Permanence in Orangutans (Pongo pygmaeus) and Squirrel Monkeys (Saimiri sciureus). *Journal of Comparative Psychology, 112*(2), 137-152.

DeLoache, J. S. (1987). Rapid change in the symbolic functioning of very young children. *Science, 238*, 1556-1557.

Diamond, A. (1981). Retrieval of an object from an open box: The development of visual-tactile control of reaching in the first year of life. *Society for Research in Child Development Abstracts, 3*, 78.

Diamond, A. (1990). Developmental time course in human infants and infant monkeys, and the neural bases of, inhibitory control in reaching. *Annals of the New York Academy of Sciences, 608*, 637-676.

Diamond, A. (1991). Neuropsychological insights into the meaning of object concept development. In S. G. Carey, R. (Ed.), *The epigenesis of mind* (pp. 67-110). Hillsdale, N.J.: Lawrence Erlbaum Associates.

Diamond, A., & Gilbert, J. (1989). Development as progressive inhibitory control of action: retrieval of a contiguous object. *Cognitive Development, 4*(3), 223-249.

Diamond, A., & Goldman-Rakic, P. S. (1989). Comparison of human infants and rhesus monkeys on Piaget's AB task: evidence for dependence on dorsolateral prefrontal cortex. *Experimental Brain Research, 74*(1), 24-40.

Dore, F. Y., & Dumas, C. (1987). Psychology of Animal Cognition - Piagetian Studies. *Psychological Bulletin, 102*(2), 219-233.

Dore, F. Y., & Goulet, S. (1998). The Comparative Analysis of Object Knowledge. In J. Langer, & Killen, M. (Ed.), *Piaget, Evolution and Development*. Mahwah, New Jersey: Lawrence Erlbaum Associates, Inc.

Dumas, C. (1992). Object permanence in cats (Felis catus): An ecological approach to the study of invisible displacement. *Journal of Comparative Psychology, 106*, 404-410.

Dumas, C., & Brunet, C. (1994). Permanence de l'object chez le singe capuchin (Cebus capella): etude des deplacement invisibles. *Canadian Journal of Experimental Psychology, 48*(3), 341-357.

Fa, J. E., & Lindburg, D. G. (1996). *Evolution and Ecology of Macaque Societies*. Cambridge: Cambridge University Press.

Fantz, R. L. (1964). Visual experience in infants: decreased attention to familiar patterns relative to novel ones. *Science, 146*, 668-670.

Farroni, T., Johnson, M. H., Brockbank, M., & Simion, F. (2000). Infants' use of gaze direction to cue attention: The importance of perceived motion. *Visual Cognition, 7*(6), 705-718.

Farroni, T., Massaccesi, S., Pividori, D., & Johnson, M. H. (2004). Gaze Following in Newborns. *Infancy, 5*(1), 39-60.

Filion, C. M., Washburn, D. A., & Gulledge, J. P. (1996). Can monkeys (Macaca mulatta) represent invisible displacement? *Journal of Comparative Psychology, 110*(4), 386-395.

Flavell, J. H. (1977). *Cognitive development*: Englewood Cliffs. NJ: Prentice-Hall.

Flombaum, J. I., & Santos, L. R. (2004). *What Rhesus Monkeys Understand About the Knowledge of Others.* Paper presented at the International Conference on Infant Studies, Chicago, Illinois, May 5-8th.

Friedman, W. (2002). Arrows of Time in Infancy: The Representation of Temporal-Causal Invariances. *Cognitive Psychology, 44*(3), 252-296.

Fuster, J. M. (1980). *The Prefrontal Cortex: Anatomy, physiology, and neuropsychology of the frontal lobe.* New York: Raven Press.

Gagnon, S., & Dore, F. Y. (1992). Search behaviour of various breeds of adult dogs (Canis familiaris): object permanence and olfactory cues. *Journal of Comparative Psychology, 106*, 58-68.

Gergely, G., & Csibra, G. (1997). Teleological reasoning in infancy: The infant's naive theory of rational action. A reply to Premack & Premack. *Cognition, 63*, 227-233.

Gergely, G., Nadasdy, Z., Csibra, G., & Biro, S. (1995). Taking the intentional stance at 12 months of age. *Cognition, 56*, 165-193.

Goldman-Rakic, P. S. (1987). Development of cortical cicuitry and cognitive function. *Child Development, 58*, 601-622.

Gomez, J. C. (2004). *Apes, monkeys, children and the developing mind.* Harvard University Press.

Goodale, M. A., & Milner, A. D. (1992). Separate visual pathways for perception and action. *Trends in Neuroscience, 15*, 20-25.

Gopnik, A., Meltzoff, A. N., & Kuhl, P. K. (2001). *The scientist in the crib: What early learning tells us about the mind.* New York: Perennial: HarperCollins.

Goulet, S., Dore, F. Y., & Rousseau, R. (1994). Object permanence and working memory in cats (Felis Catus). *Journal of Experimental Psychology: Animal Behavior Processes, 20*, 347-365.

Graybiel, A. M. (1998). The Basal Ganglia and Chunking of Action Repertoires. *Neurobiology of learning and memory, 70*, 119-136.

Griffith, E. M., Pennington, B., Wehner, E., & Rogers, S. (1999). Executive functions in young children with autism. *Child Development, 70*(4), 817-832.

Haddad, J. M., Kloos, H., & Keen, R. (2004). *Cognitive Strategies in a Dynamic Search Task: The Effects of Congruent and Conflicting Cues*. Paper presented at the International Conference on Infant Studies, Chicago, Illinois, May 5-8th.

Haith, M. M. (1998). Who put the cog in infant cognition? *Infant Behaviour and Development, 21*(2), 167-179.

Haith, M. M. (1999). Some thoughts about claims for innate knowledge and infant physical reasoning. *Cognitive Science*, 153-156.

Harnishfeger, K. K. (1995). The development of cognitive inhibition: Theories, definitions, and research evidence. In F.F. Dempster & C.J. Brainerd (Ed.), *New Perspectives on interference and inhibition in cognition* (pp. 175-204). San Diego, C.A.: Academic Press.

Harris, P. L. (1985). The development of search. In P. Salapatek & L.B. Cohen (Ed.), *Handbook of Infant Perception*. New York: Academic Press.

Hauser, M. D. (1998). A nonhuman primate's expectations about object motion and destination: The importance of self-propelled movement and animacy. *Developmental Science, 1*(1), 31-37.

Hauser, M. D. (1999). Perseveration, inhibition, and the prefrontal cortex: A new look. *Current opinions in neurobiology, 9*, 214-222.

Hauser, M. D. (2000). *Wild Minds*. London: Allen Lane The Penguin Press.

Hauser, M. D. (2001a). Can rhesus monkeys spontaneously subtract? *Cognition, 79*, 239-262.

Hauser, M. D. (2001b). Searching for food in the wild: A nonhuman primate's expectations about invisible displacement. *Developmental Science, 4*(1), 84-93.

Hauser, M. D. (2002). *Evolutionary constraints on object knowledge.* Paper presented at the International Conference on Infant Studies, Toronto, Ontario, April 18 – 21st.

Hauser, M. D. (2003). Knowing about knowing: Dissociations between Perception and Action Systems over Evolution and during Development. *Annals of the New York Academy of Sciences, 1001*, 79-103.

Hauser, M. D., Kralik, J. D., & Botto-Mahan, C. (1999). Problem solving and functional design features: Experiments with cotton-top tamarins. *Animal Behaviour, 57*, 565-582.

Hauser, M. D., Kralik, J. D., Williams, T., & Moskovitz, D. (2001). What Guides a Search for Food That Has Disappeared? Experiments on Cotton-Top Tamarins (Saguinus oedipus). *Journal of Comparative Psychology, 115*, 140-151.

Hauser, M. D., MacNeilage, P., & Ware, M. (1996). Numerical representations in primates. *Proceedings of the National Academy of Sciences of the United States of Amercia, 93*(4), 1514-1517.

Hofstadter, M., & Reznick, J. S. (1996). Response modality affects human infant delayed-response performance. *Child Development, 67*, 646-658.

Hood, B.M., Carey, S., & Prasada, S. (2000). Predicting the outcomes of physical events: two-year-olds fail to reveal knowledge of solidity and support. *Child Development, 71*(6), 1540-1554.

Hood, B.M., Cole-Davis, V., & Dias, M. (2003). Looking and Search Measures of Object Knowledge in Preschool Children. *Developmental Psychology, 39*(1), 61-70.

Hood, B.M., Hauser, M., Anderson, L., & Santos, L. (1999). Gravity biases in a nonhuman primate? *Developmental Science, 2*, 35-41.

Hood, B.M., & Willatts, P. (1986). Reaching in the dark to an object's remembered position: evidence for object permanence in 5-month-old infants. *British Journal of Developmental Psychology, 4*, 57-65.

Hood, B. M. (1995). Gravity rules for 2-4 year-olds? *Cognitive Development, 10*, 577-598.

Hood, B. M. (1998). Gravity does rule for falling events. *Developmental Science, 1*(1), 59-63.

Hood, B. M., Santos, L., & Fieselman, S. (2000). Two-year olds' naive predictions for horizontal trajectories. *Developmental Science, 3*(3), 328-332.

Jacques, S., Zelazo, P. D., Kirkham, N. Z., & Semcesen, T. K. (1999). Rule Selection Versus Rule Execution in Preschoolers: An Error-Detection Approach. *Developmental Psychology, 35*(3), 770-780.

James, W. (1890). *Principles of Psychology*. New York: Henry Holt.

Kaiser, M. K., Proffitt, D. R., & Anderson, K. (1985). Judgments of natural and anomalous trajectories in the presence and absence of motion. *Journal of Experimental Psychology: Learning, Memory and Cognition, 11*, 795-803.

Kaiser, M. K., Proffitt, D. R., & McCloskey, M. (1985). The development of beliefs about falling objects. *Perception and Psychophysics, 38*, 533-539.

Karin-D'Arcy, M. R., & Povinelli, D. J. (2002). Do Chimpanzees Know What Each Other See? *International Journal of Comparative Psychology, 15*, 21-54.

Karmiloff-Smith, A. (1991). Beyond Modularity: Innate Constraints and Developmental Change. In S. Carey, & Gelman, R. (Ed.), *The Epigenesis of Mind*. Hillsdale, N.J.: Lawrence Erlbaum Associates.

Karmiloff-Smith, A., & Inhelder, B. (1975). If you want to get ahead, get a theory. *Cognition, 3*, 195-211.

Keen, R. (2003). Representation of Objects and Events: Why Do Infants Look So Smart and Toddlers Look So Dumb? *Current Directions in Psychological Science*, 79-83.

Keenan, T., & Morris, T. L. (2002). *The Effect of Object Familiarity on Infants' Search Performance in A-not-B Task.* Paper presented at the International Conference on Infant Studies, Toronto, Ontario, April 5-8th.

Kim, I. K., & Spelke, E. S. (1992). Infants' Sensitivity to Effects of Gravity on Visible Object Motion. *Journal of Experimental Psychology: Human Perception and Performance, 18*(2), 385-393.

Kim, I. K., & Spelke, E. S. (1999). Perception and understanding of effects of gravity and inertia on object motion. *Developmental Science, Vol 2*(3), 339-362.

King, J. E. (1995). Laterality in Hand Preferences and Reaching Accuracy of Cotton-Top Tamarins (*Saguinus oedipus*). *Journal of Comparative Psychology, 109*(1), 34-41.

Kohler, W. (1925). *The mentality of apes*. Harmondsworth, Middlesex: Penguin Books.

Kuhlmeier, V., Wynn, K., & Bloom, P. (2003). Attribution of dispositional states by 12-month-olds. *Psychological Science, in press*.

Kummer, H. (1995). Causal knowledge in animals. In D. Sperber, Premack, D., & Premack, A. (Ed.), *Causal cognition: a multidisciplinary approach* (pp. 26-39). Oxford: Clarendon Press.

Leslie, A. M. (1994). ToMM, ToBY, and Agency: Core architecture and domain specificity. In L. A. Hirschfeld, & Gelman, S.A. (Ed.), *Mapping the mind: Domain specificity in cognition and culture* (pp. 119-148). New York: Cambridge University Press.

Leslie, A. M., & Keeble, S. (1987). Do six-month-old infants perceive causality? *Cognition, 25*(3), 265-288.

Limongelli, L., Boysen, S. T., & Visalberghi, E. (1995). Comprehension of cause-effect relations in a tool-using task by chimpanzees (Pan troglodytes). *Journal of Comparative Psychology, 109*(1), 18-26.

Macphail, E. (1987). The comparative psychology of intelligence. *Behavioral and Brain Sciences, 10*(645-695).

Marcovitch, S., Zelazo, P. D., & Schmuckler, M. A. (2002). The effect of the number of A trials on performance on the A-not-B task. *Infancy, 3*(4), 519-529.

Mareschal, D., Plunkett, K., & Harris, P. (1995). *Developing object permanence: A connectionist model.* Paper presented at the Proceedings of the Seventeenth Annual Conference of the Cognitive Science Society.

Mash, C., Keen, R., & Berthier, N. E. (2003). Visual Access and Attention in Two-Year-Old's Event Reasoning and Object Search. *Infancy, 4*(3), 371-388.

Mathieu, M., & Bergero, G. (1981). Piagetian assessment of cognitive development in chimpanzee (*Pan troglodytes*). In A.B. Chiarelli & R.S. Corruccini (Ed.), *Primate behaviour and sociobiology* (pp. 142-147). Berlin: Springer-Verlag.

Mathieu, M., Bouchard, M., Granger, L., & Herscovitch, J. (1976). Piagetian Object-Permanence in cebus capucinus, lagothrica flavicauda and pan troglodytes. *Animal Behaviour, 24*, 585-588.

Matsuzawa, T. (2001). *Primate Origins of Human Cognition and Behavior*: Springer.

McCall, D. D., & Clifton, R. K. (1999). Infants' means-end search for hidden objects in the absence of visual feedback. *Infant Behaviour and Development, 22*, 179-195.

McCloskey, M., Caramazza, A., & Green, B. (1980). Curvilinear motion in the absence of external forces: naive beliefs about the motion of objects. *Science, 210*, 1139-1141.

McCloskey, M., Washburn, A., & Felch, L. (1983). Intuitive physics: The straight-down belief and its origin. *Journal of Experimental Psychology: Learning, Memory and Cognition, 9*, 636-649.

Mehler, J., & Bever, T. (1967). Cognitive capacity of very young children. *Science, 158*(3797), 141-142.

Meltzoff, A. (2000). *Keynote address: Infants' Understanding of People and Things.* Paper presented at the International Conference on Infant Studies, Brighton, UK, July 2000.

Meltzoff, A., & Moore, M. K. (1998). Object Representation, Identity, and the Paradox of Early Permanence: Steps Toward a New Framework. *Infant Behaviour and Development, 21*(2), 201-235.

Mendes, N., & Huber, L. (2004). Object Permanence in Common Marmosets (*Callithrix jacchus*). *Journal of Comparative Psychology, 118*(1), 103-112.

Milner, B. (1963). Effects of different brain lesions on card sorting. *Archives of Neurology, 9*, 90-100.

Munakata, Y. (2000). Challenges to the Violation-of-Expectation Paradigm: Throwing the Conceptual Baby Out With the Perceptual Processing Bathwater. *Infancy, 1*(4), 471-477.

Munakata, Y. (2001). Graded representations in behavioral dissociations. *Trends in Cognitive Sciences, 5*(7), 309-315.

Munakata, Y. (2002). *Two approaches to understanding knowledge dissociations: Ancillary deficits and graded representations.* Paper presented at the International Conference on Infant Studies, Toronto, Ontario.

Munakata, Y., McClelland, J. L., Johnson, M. H., & Siegler, R. S. (1997). Rethinking infant knowledge: toward an adaptive process account of successes and failures in object permanence tasks. *Psychological Review, 104*(4), 686-713.

Munakata, Y., Santos, L. R., Spelke, E. S., Hauser, M. D., & O'Reilly, R. C. (2001). Visual representation in the wild: how rhesus monkeys parse objects. *Journal of Cognitive Neuroscience, 13*(1), 44-58.

Natale, F., Antinucci, F., Spinozzi, G., & Poti, P. (1986). Stage 6 object concept in nonhuman primate cognition: A comparison between gorilla (Gorilla gorilla gorilla) and Japanese macaque (Macaca fuscata). *Journal of Comparative Psychology, 100*, 335-339.

Needham, A., & Baillargeon, R. (1998). Effects of prior experience on 4.5-month-old infants' object segregation. *Infant Behaviour and Development, 21*, 1-24.

Neiworth, J. J., Steinmark, E., Basile, B. M., Wonders, R., Steely, F., & DeHart, C. (2003). A test of object permanence in a new-world monkey species, cotton top tamarins (*Saguinus oedipus*). *Animal Cognition, published online: February 21, 2003.*

Newman, C., Atkinson, J., & Braddick, O. (2001). The development of reaching and looking preferences in infants to objects of different sizes. *Developmental Psychology, 37*(4), 561-572.

Onishi, K. H., & Baillargeon, R. (2004). *False-Belief Understanding with Invisible Displacement in 15.5-Month-old Infants.* Paper presented at the International Conference on Infant Studies, Chicago, Illinois.

Osthaus, B., Slater, A. M., & Lea, S. E. G. (2003). Can dogs defy gravity? A comparison with the human infant and a non-human primate. *Developmental Science, 6*(5), 489-497.

O'Sullivan, L. P., Mitchell, L. L., & Daehler, M. W. (2001). Representation and perseveration: Influences on young children's representational insight. *Journal of Cognition and Development, 2*(4), 339-365.

Parker, S. T., & Gibson, K. R. (1979). A developmental model for the evolution of language and intelligence in early hominids. *Behavioural and Brain Sciences, 2*, 367-408.

Pepperberg, I. M. (2002). The value of the Piagetian framework for comparative cognitive studies. *Animal Cognition, 5*, 177-182.

Pepperberg, I. M., & Funk, M. S. (1990). Object permanence in four species of psittacine birds: An African Grey parrot (*Psittacus erithacus*), and Illiger mini macaw (*Ara maracana*), a parakeet (*Melopsittacus undulatus*), and a cockatiel (*Nymphicus hollandicus*). *Animal Learning and Behavior, 18*(1), 97-108.

Pepperberg, I. M., & Kozak, F. A. (1986). Object permanence in the African Grey parrot (*Psittacus erithacus*). *Animal Learning and Behavior, 14*(322-330).

Peskin, J. (1992). Ruse and representation: On children's ability to conceal information. *Developmental Psychology, 28*, 84-89.

Piaget, J. (1952). *The origins of intelligence in children*. NY: Norton.

Piaget, J. (1955). *The Child's Construction of Reality* (M. Cook, Trans.). London: Routledge & Kegan Paul Ltd.

Piaget, J. (1960). *The Psychology of Intelligence*. NJ: Littlefield, Adams, Peterson.

Povinelli, D. J. (2000). *Folk Physics for Apes*: OUP.

Povinelli, D. J. (2002). *Theory of Mind is not an inevitable byproduct of social evolution.* Paper presented at the Rational Animals Workshop, Oxford, UK, October, 2002.

Povinelli, D. J., Reaux, J. E., Theall, L. A., & Giambrone, S. (2000). The Support Problem: Physical Connection Revisited. In D. J. Povinelli (Ed.), *Folk Physics for Apes* (pp. 254-270). Oxford: OUP.

Ramsay, D. S. (1980). Onset of unimanual handedness in infants. *Infant Behaviour and Development, 2*, 69-76.

Redshaw, M. (1978). Cognitive development in human and gorilla infants. *Journal of Human Evolution, 7*, 133-143.

Rivera, S., Wakeley, A., & Langer, J. (1999). The Drawbridge Phenomenon: Representational Reasoning or Perceptual Preference? *Developmental Psychology, 35*(2), 427-435.

Rochat, P. (1992). Self-sitting and reaching in 5- to 8-month-old infants: the impact of posture and its development on early eye-hand coordination. *Journal of Motor Behaviour, 24*, 210-220.

Rumbaugh, D. (1997). Competence, cortex, and primate models: A comparative primate perspective. In G. R. L. N. Krasnegor, & P.S. Goldman-Rakic (Ed.), *Development of the prefrontal cortex* (pp. 117-140). Baltimore: P.H. Brookes.

Russell, J., Mauthner, N., Sharpe, S., & Tidswell, T. (1991). The "windows task" as a measure of strategic deception in preschoolers and autistic subjects. *British Journal of Developmental Psychology, 9*, 331–349.

Santos, L. R. (2004). 'Core Knowledges': a dissociation between spatiotemporal knowledge and contact-mechanics in a non-human primate? *Developmental Science, 7*(2), 167-174.

Santos, L. R., Ericson, B., & Hauser, M. D. (1999). Constraints on problem solving and inhibition: Object retrieval in cotton-top tamarins. *Journal of Comparative Psychology, 113*, 186-193.

Santos, L. R., Flombaum, J. I., & Hauser, M. D. (2002). *What Does A Non-Human Primate Understand About Self-Propelled Motion.* Paper presented at the ICIS, Toronto, Ontario, April 18-21st.

Santos, L. R., & Hauser, M. D. (2002). *Monkey see versus monkey do: Dissociations between looking and acting in a non-human primate.* Paper presented at the International Conference on Infant Studies, Toronto, Ontario, April 18-21st.

Santos, L. R., & Hauser, M. D. (2002). A Non-Human Primate's Understanding of Solidity: Dissociations Between Seeing and Acting. *Developmental Science, 5*(2), F1-F7.

Schino, G., Spinozzi, G., & Berlinguer, L. (1990). Object concept and mental representation in Cebus apella (capuchin) and Macaca fascicularis (longtail macque). *Primates, 31*, 537-544.

Schott, J. M., & Rossor, M. N. (2003). The grasp and other primitive reflexes. *Journal of Neurology and Psychiatry, 74*, 558-560.

Semendeferi, K., Lu, A., Schenker, N., & Damasio, H. (2002). Humans and great apes share a large frontal cortex. *Nature Neuroscience, 5*, 272-276.

Shanon, B. (1976). Aristotelianism, Newtonianism and the physics of the layman. *Perception, 5*, 241-243.

Shepard, R. N. (1984). Ecological constraints on internal representations: Resonant kinematic of perceiving, imagining, thinking, and dreaming. *Psychological Review, 91*, 417-447.

Shettleworth, S. (1998). *Cognition, evolution and behavior*. New York: Oxford University Press.

Shinskey, J. L., & Munakata, Y. (2001). Detecting transparent barriers: Clear evidence against the means-end deficit account of search failures. *Infancy, 2*, 395-404.

Shinskey, J. L., & Munakata, Y. (2004). *7-month-olds' Novelty Preference Reverses with Hidden Objects.* Paper presented at the International Conference on Infant Studies, Chicago, Illinois, May 5-8th.

Shinskey, J. L., & Munakata, Y. (in press). Are Infants in the Dark About Hidden Objects? *Developmental Science*.

Smith, B., & Casati, R. (1994). Naive Physics: An Essay in Ontology. *Philosophical Psychology, 7*(2), 225-244.

Spelke, E. (1994). Initial knowledge: six suggestions. *Cognition, 50*(1-3), 431-445.

Spelke, E. (2002). *Symposium: Interpreting dissociations between infant looking and reaching: A comparative approach.* Discussant at the International Conference on Infant Studies, Toronto, Ontario, April 18 - 21.

Spelke, E., Breinlinger, K., Macomber, J., & Jacobson, K. (1992). Origins of knowledge. *Psychological Review, 99*, 605-632.

Spelke, E., & von Hofsten, C. (2001). Predictive Reaching for Occluded Objects by 6-Month-Old Infants. *Journal of Cognition and Development, 2*, 261-281.

Spelke, E. S., Katz, G., Purcell, S. E., Ehrlich, S. M., & Breinlinger, K. (1994). Early knowledge of object motion: continuity and inertia. *Cognition, 51*, 131-176.

Spence, K. W. (1937). Experimental studies of learning and the mental processes in infra-human primates. *Psychological Bulletin, 34*, 806-850.

Suddendorf, T. (2003). Early Representational Insight: Twenty-Four-Month-Olds Can Use a Photo to Find an Object in the World. *Child Development, 74*(3), 896-904.

Swingley, D., & Aslin, R. N. (2000). Spoken word recognition and lexical representation in very young children. *Cognition, 76*(2), 147-166.

Tebbich, S., & Bshary, R. (2004). Cognitive abilities related to tool use in the woodpecker finch, Cactospiza pallida. *Animal Behaviour, 67*, 689-697.

Thelen, E., Schoner, G., Scheier, C., & Smith, L. B. (2001). The dynamics of embodiment: A field theory of infant perseverative reaching. *Behavioral and Brain Sciences, 24*(1), 1-86.

Tomasello, M., & Call, J. (1997). *Primate Cognition*: OUP.

Uzgiris, I. C., & Hunt, J. (1975). *Assessment in infancy: ordinal scales of psychological development.* Champaign-Urbana, Ill.: University of Illinois Press.

Vaughter, R. M., Smotherman, W., & Ordy, J. M. (1972). Development of object permanence in the infant squirrel monkey. *Developmental Psychology, 7*, 34-38.

Visalberghi, E., Fragaszy, D. M., & Savage-Rumbaugh, S. (1995). Performance in tool-using task by common chimpanzees (Pan troglodytes), bonobos (Pan paniscus), an orangutan (Pongo pygmaeus), and capuchin monkeys (Cebus apella). *Journal of Comparative Psychology, 109*, 52-60.

Visalberghi, E., & Limongelli, L. (1994). Lack of comprehension of cause-effect relations in tool-using capuchin monkeys (Cebus apella). *Journal of Comparative Psychology, 108*(1), 15-22.

Visalberghi, E., & Tomasello, M. (1998). Primate causal understanding in the physical and psychological domains. *Behavioral Processes, 42*, 189-203.

von Hofsten, C., Vishton, P., Spelke, E. S., Feng, Q., & Rosander, K. (1998). Predictive action in infancy: tracking and reaching for moving objects. *Cognition, 67*(3), 255-285.

von Hofsten, C., Vishton, P., Spelke, E. S., Rosander, K., & Feng, Q. (1998). Principles of predictive action in infancy. *Cognition, 76*, 255-285.

Warren, J. M. (1953). Handedness in the Rhesus Monkey. *Science, 118*, 622-623.

Watson, J. S., Gergely, G., Csanyi, V., Topal, J., Gacsi, M., & Sarkozi, Z. (2001). Distinguishing logic from association in the solution of an invisible displacement task by children and dogs: using negation of disjunction. *Journal of Comparative Psychology, 115*(3), 219-226.

Welsh, M., & Pennington, B. F. (1988). Assessing frontal lobe functioning in children: Views from developmental psychology. *Developmental Neuropsychology, 4*(3), 199-230.

Willats, P. (1999). Development of means-end behavior in young infants: Pulling a support to retrieve a distant object. *Developmental Psychology, 3*(3), 651-667.

Willatts, P. (1984). The stage-IV infant's solution of problems requiring the use of supports. *Infant Behaviour and Development, 7*, 125-134.

Willatts, P. (1989). Development of problem-solving. In A. Slater, & Bremner, J.G. (Ed.), *Infant Development*: Erlbaum.

Wimmer, H., & Perner, J. (1983). Beliefs about beliefs: Representation and constraining function of wrong beliefs in young children's understanding of deception. *Cognition, 13*, 103-128.

Wise, K. L., Wise, L. A., & Zimmerman, R. R. (1974). Piagetian object permanence in the infant rhesus monkey. *Developmental Psychology, 10*, 429-437.

Woodward, A. L. (2003). Infants' developing understanding of the link between looker and object. *Developmental Science, 6*(3), 297-311.

Zelazo, P. D., Frye, D., & Rapus, T. (1996). An age-related dissociation between knowing rules and using them. *Cognitive Development, 11*, 37-63.

Zelazo, P. D., Reznick, J. S., & Pinon, D. E. (1995). Response Control and the Execution of Verbal Rules. *Developmental Psychology, 31*(3), 508-517.

Zelazo, P. D., Reznick, J. S., & Spinazzola, J. (1998). Represenational Flexibility and Response Control in a Multistep Multilocation Search Task. *Developmental Psychology, 34*(2), 203-214.