



University of
Massachusetts
Amherst

Visuospatial Reasoning in Toddlers: A Correlational Study of Door Task Performance

Item Type	Dissertation (Open Access)
Authors	Price, Iris Louella
DOI	10.7275/2ds2-j629
Download date	2026-05-20 17:04:09
Link to Item	https://hdl.handle.net/20.500.14394/39073

VISUOSPATIAL REASONING IN TODDLERS: A CORRELATIONAL STUDY OF
DOOR TASK PERFORMANCE

A Dissertation Presented

by

IRIS L. PRICE

Submitted to the Graduate School of the
University of Massachusetts Amherst in partial fulfillment
of the requirements for the degree of

DOCTOR OF PHILOSOPHY

May 2009

Neuroscience and Behavior Program

© Copyright by Iris L. Price 2009

All Rights Reserved

**VISUOSPATIAL REASONING IN TODDLERS: A CORRELATIONAL STUDY
OF DOOR TASK PERFORMANCE**

A Dissertation Presented

by

IRIS L. PRICE

Approved as to style and content by:

Neil E. Berthier, Chair

Matthew C. Davidson, Member

Rachel E. Keen, Member

Gordon A. Wyse, Outside Member

Jerrold S. Meyer, Director
Neuroscience and Behavior Program

DEDICATION

To my parents, Felton and Mildred Price; your many sacrifices made this possible.

ACKNOWLEDGMENTS

I am deeply grateful to my advisor, Neil Berthier, for all of his guidance and support throughout the course of this work. This has been a long and difficult process, but his patience, kindness, and understanding made it much easier to bear. I appreciate his willingness to believe in me when I didn't believe in myself. I am also thankful to my committee members, Matthew Davidson, Rachel Keen, and Gordon Wyse for their time and useful comments. I must also extend thanks to Sandy Petersen and the NorthEast Alliance for the Graduate Education and the Professoriate (NEAGEP) for their financial and emotional support.

Thanks to mom, dad, and my brother Jimmy for their love and encouragement every step of the way. Their pride in me pushed me forward. Thanks to my boyfriend, Robert Jenkins, for all of his love, patience, and support during this process. Also, thanks to my cousin, Patrick Robinson for being there for me, and my cousin/mentor Andrew Robinson, who has always shared his wisdom with me. I must also thank my Uncle George Baymon and my aunt, the late Mattie Baymon for their love and support.

I was also blessed to have the support of my friends: Shirissee Morgan, Shermeka Ellis, Janae Alleyne, and Rosemary Lockett. I am thankful for their understanding and willingness to provide me with a shoulder to cry on when needed. I must also thank my friend Destinee Chambers. Her presence as both friend and colleague made my experience at UMass a better one. I am so thankful for her friendship.

Finally, I must thank my pastor Bishop Bryant Robinson Jr., his wife Margaree Robinson, and the entire Macedonia Church of God in Christ family. Their prayers and words of wisdom and encouragement helped me to endure.

ABSTRACT

VISUOSPATIAL REASONING IN TODDLERS: A CORRELATIONAL STUDY OF DOOR TASK PERFORMANCE

MAY 2009

IRIS L. PRICE, B.A., MOUNT HOLYOKE COLLEGE

M.S., UNIVERSITY OF ARIZONA TUCSON

Ph.D., UNIVERSITY OF MASSACHUSETTS AMHERST

Directed by: Professor Neil E. Berthier

Previous research using violation-of-expectation paradigms suggests that very young infants have a good understanding of unobserved physical events. Yet toddlers appear to lack this knowledge when confronted with the door task, a visuospatial reasoning task which parallels ones used in the habituation/looking time studies. Many studies have been conducted in an effort to determine why toddlers perform poorly on the door task yet the answer remains unclear. The current study used a correlational approach to investigate door task performance from both psychological (executive function), and neuroscience (prefrontal cortex) perspectives.

Children between the ages of 2 ½ - 3 years were tested on the standard door task as well as four other tasks. Three of the tasks were believed to activate prefrontal cortex: the three boxes-stationary, a spatial working memory task; the three boxes-scrambled, a non-spatial working memory task; and the three pegs task, an inhibitory control task. The fourth task was a recognition memory task which had been previously linked to the medial temporal lobe.

Only a single task, the three pegs task, was found to correlate with door task performance ($r = .510$, $p < .01$). Even with age, sex, and performance on the other tasks controlled for, this correlation remained significant ($r = .459$, $p < .05$). Furthermore, in a logistic regression the three pegs task was found to be the only significant predictor of door task performance ($z = 2.87$, $p < .01$). An examination of the errors children made on the door task revealed that over half (58%) could be classified as inhibitory control errors (children returned to the previously rewarded location or repeatedly searched a favorite door). Taken together these data suggest a possible relationship between inhibitory control ability and successful completion of the door task.

TABLE OF CONTENTS

	Page
ACKNOWLEDGEMENTS.....	v
ABSTRACT.....	vi
LIST OF TABLES.....	x
LIST OF FIGURES.....	xi
CHAPTER	
I. INTRODUCTION.....	1
A. Development of Object Concept.....	1
B. Violation-of-Expectation Paradigms.....	5
C. Tasks Requiring Manual Manipulation.....	6
D. Toddler Performance on the Door Task: Psychological Perspectives.....	9
E. Prefrontal Cortex Development and Function.....	13
1. Synaptic Density.....	13
2. Number of Synapses per Neuron.....	14
3. Myelination.....	14
4. Dendritic Development.....	14
5. Prefrontal Cortex Function.....	15
6. Evidence for Prefrontal Cortex Processes.....	26
II. METHOD.....	32
A. Overview.....	32
B. Participants.....	34
C. Procedure.....	35
1. Door Task.....	35
2. Three Boxes-Stationary.....	36
3. Three Pegs.....	38
4. Three Boxes-Scrambled.....	41
5. Delayed Response Span Task (DRST).....	43
D. Data Scoring.....	46
III. RESULTS.....	48

A. Description of the Data	48
B. Correlations	50
C. Logistic Regression	54
D. Inhibitory Control Errors	56
IV. DISCUSSION	58
APPENDICES.....	76
A. RECRUITMENT LETTER.....	78
B. INFORMED CONSENT	80
C. INDIVIDUAL TASK SCORES	82
D. TASK SCRIPTS	84
E. COPYRIGHT PERMISSIONS.....	95
REFERENCES	99

LIST OF TABLES

Table	Page
1: Summary of Task Attributes.....	32
2: Order of Presentation of Comparison Tasks.....	34
3: Position of Boxes during the Three Boxes-Scrambled Task.....	43
4: Means and Standard Deviations	48
5: Correlations.....	51
6: Partial Correlations	52
7: Partial Correlations with Door Task	53
8: Regression using Generalized Linear Mixed Model	55
9: Partial Correlations of Inhibitory Errors and Pegs Scores.....	57
10: Individual Task Scores.....	82

LIST OF FIGURES

Figure	Page
1: Door Apparatus from Berthier et al. (2000)	7
2: Door Apparatus from Shutts, Keen, & Spelke (2006).....	9
3: Apparatus used in Mash, Keen, & Berthier (2003)	10
4: Hiding Boxes used for Three Boxes-Stationary Task	37
5: Work Bench and Pegs used for Three Pegs Task	39
6: Hiding Boxes used during the Three Boxes-Scrambled Task	42
7: Sample Pictures used for Delayed Recognition Span Test.....	45
8: Strip Chart Showing Individual Task Scores.....	49
9: Partial Regression Plot.....	54

CHAPTER I

INTRODUCTION

A. Development of Object Concept

Piaget used six stages to describe the development of object concept in infants. Object concept refers to the basic beliefs that individuals have concerning objects as individual entities as well as in relation to themselves. For example, part of object concept is the understanding that objects exist whether they remain in sight or not. While this may seem like commonsense, Piaget argued that these types of concepts are not innate in infants, but rather are acquired through experience. Each of the stages of development occurs in succession, that is, infants do not skip over stages. The time frame for each stage, however, is flexible. Infants don't always begin and end stages at the same age.

The first and second stages occur roughly between zero and four months-of-age. During these stages infants have the ability to track moving objects with their eyes. Infants will track an object until it is out of view and then lose interest in it or continue to look at the place where it was last seen for a short time. The infant shows no sign of visual or manual search for the object. Therefore, Piaget concludes that the infant shows no knowledge of the object's continued existence in the absence of visual contact. In other words: out of sight, out of mind.

The third stage occurs roughly between 4- and 8- months-of-age. During this stage infants not only track moving objects, but they also begin to anticipate future movements using information about the current direction of movement. Infants also

begin to reach for familiar objects that are only partially visible. In the case that the object is completely invisible, infants in this stage of development will not reach for it. Although the infants have the physical ability to reach, the object seems to be out of existence for them when it is hidden from view. This even seems to be the case if the infant is grasping an object and both the object and the infant's hand are suddenly out of sight. Piaget believed that during this stage infants do not have an understanding of the object being a separate entity outside of the infant's visual contact with it.

It is not until stage four (between 8- and 12- months-of-age) that the infant is able to search for and retrieve hidden objects according to Piaget. Infants at this stage are successful even in the absence of visible clues to the object's existence. In spite of the improvement, there are yet limitations to the infant's abilities during search. Infants of this stage often make what is known as the A-not-B error. When searching for a hidden object in one of two locations, the infant will continually choose the location where the object was first successfully found. If the object is not located at this position, the infant will not choose the alternative location, but rather will abandon the search. Piaget believed that this was because infants in this stage do not have a clear understanding of hidden objects. The infant may have formed a behavioral rule that says, for example, "searching in position A will cause something interesting to happen". The infant does not separate the object from his actions toward it. Therefore, the infant continually searches in position A and does not move to position B when the object is moved.

During stage five (between 12- and 18- months-of-age) the infant has overcome the A-not-B error. When confronted with an A not B situation, the infant will not continually search at the location where success was previously found, but instead will

search at the alternative location. Piaget believed that the infant at this stage can separate the object from his actions towards it. Although the infant has improved with this ability, there is a limitation in this stage as well. The infant is unable to find invisibly displaced objects. That is, the infant uses information about where the object went out of view in order to locate the object and can only locate the object if it remains where the infant saw it go out of view (visible displacement). If the object is moved after it is out of view (invisible displacement) the infant will be unable to find it during search. Infants in this stage cannot make inferences about where the object might be using the visual evidence available. They will only search where the object was visibly displaced.

This problem is overcome during the final stage of development (between 18- and 24- months-of-age). During stage six the child is able to find invisibly displaced objects. During this stage object concept is fully developed. The child has the understanding that objects continue to exist regardless of changes in contact with the object. In the above stages of object concept, Piaget claims that infants do not have the understanding that objects exist even when not in view (object permanence) until approximately 8- months-of-age.

More recently, a number of studies have challenged Piaget's ideas concerning object permanence and the understanding of unobserved physical events (Baillargeon, Spelke, & Wasserman, 1985; Spelke et al., 1992; Wang, Baillargeon, & Brueckner, 2004). Using violation-of-expectation paradigms, these studies use a measure of looking time to suggest that infants as young as 5-months-of-age have object permanence and an understanding of unobserved physical events.

Nevertheless previous research in our lab (Berthier et al., 2000) has shown that children as old as 2 ½ -years-of-age are unable to succeed on a visuospatial reasoning task that parallels tasks used in violation-of-expectation paradigms. This task, known as the door task, requires that toddlers use their knowledge of the physical properties of objects in order to successfully complete a manual search. Although young infants appear to have the knowledge necessary for successful completion of the door task, toddlers are unable to search successfully.

With such differences in the literature it is necessary to attempt to resolve them. Understanding the normal course of human development in terms of cognitive abilities is important for the detection of developmental abnormalities. Furthermore, understanding the relationship between brain development and cognitive abilities may allow for the creation of cognitive tasks for detecting abnormal brain development.

Three-year-old children successfully solve the door task. Therefore, there is a transition period between 2 ½- and 3-years-of-age where children develop the ability to solve the task. One hypothesis presented by Berthier et al. (2000) to explain toddler's abilities during this transition period is based on the prefrontal cortex (PFC). The PFC continues to develop over the first few years of life (Huttenlocher & Dabholkar, 1997) and has been implicated to play a role in visuospatial reasoning and tasks that require working memory (Luciana & Nelson, 1998; Quintana & Fuster, 1999). It is also possible that there are components of the door task that require certain cognitive skills that do not develop until 3-years-of-age.

The purpose of this study is to investigate the relationship between door task ability and prefrontal cortex-dependent abilities during the transition period (between 2

½- and 3-years of age). In addition, this study investigates the relationship between door task performance and the development of other cognitive skills that may be relevant to solving the door task.

Generally, two different approaches have been taken by researchers in studying what infants know about objects and their properties. One approach involves the use of violation-of-expectation paradigms and the other approach involves tasks that require actual manual manipulations on the part of the infant/toddler. These different approaches have led to different results and conclusions. The following sections will discuss these approaches in more detail.

B. Violation-of Expectation Paradigms

These studies typically conclude that young infants have object permanence and knowledge about solidity of objects (Baillargeon, Spelke, & Wasserman, 1985; Spelke et al., 1992; and Wang, Baillargeon, & Brueckner, 2004). For example, in a study by Baillargeon, Spelke & Wasserman (1985) five-month-old infants were habituated to a screen which moved back and forth in an arc. After infants were habituated a box was placed behind the screen and infants were shown both “possible” and “impossible” events. During “possible” events the movement of the screen would be stopped by the presence of the box. However, during “impossible” events the screen would not be stopped by the presence of the box and would appear to move through the box. The measure of interest was looking time. Infants looked longer at the “impossible” event.

The authors argued that the longer looking time during “impossible” events was due to the fact that 5-month-olds have object permanence. They understood that the box existed even when it was out of view because they expected the screen to stop moving

when it made contact with the box. Furthermore, this study suggested that infants at a very young age understood something about solidity. They understood that two solid objects should not be able to pass through one another. Thus, in the absence of manual manipulation, very young infants appear to have an understanding of objects and their properties.

C. Tasks Requiring Manual Manipulation

Although the violation-of-expectation time studies suggest that young infants have a good understanding of unobserved physical events, infants and even toddlers appear unable to use this knowledge when confronted with tasks that require manual manipulation. This finding is consistent across many studies which involve infants and toddlers reaching for and retrieving objects that have moved out of view (Hood, 1995; Hood, Santos & Fieselman, 2000; Berthier et al., 2001). The current study builds off of a study that was previously carried out in our lab (Berthier et al., 2000), the door study.

In the door study toddlers between 2- and 3-years-of-age were presented with a ramp on which a barrier was placed. The barrier could be positioned at one of four different positions along the ramp. An opaque, wooden screen containing four doors was placed in front of the ramp. The screen hid the bottom half of the barrier while the top half was visible above the screen (see Figure 1).

During test trials a ball was rolled down the ramp and stopped by the barrier. Children were then asked to open one of the doors and find the ball. Although the barrier was clearly visible over the top of the screen, it did not help children younger than 3-years-of-age on this task. Toddlers did not seem to take into account the location of the barrier. The apparatus was also modified so that rather than using the opaque, wooden,

screen, a clear Plexiglas was used (Butler et al., 2002). This gave toddlers an intermittent view of the ball's movement. Two and a half-year-olds were able to use the visual information in order to perform slightly better on the task, while 2-year-olds were not. They visually tracked the ball correctly to the place of disappearance, but still did not choose the proper door. Children were only helped if they kept their gaze fixed on the place of disappearance. The children still had a hard time with the task overall.



Figure 1 – Door Apparatus from Berthier et al. (2000). The ball rolled behind the doors and out of view of the child. The child then opened the 3rd door to correctly locate the ball which was stopped by the barrier.

One study using the door apparatus did find some success with 2- and 2 ½-year-olds (Kloos & Keen, 2005). The authors sought to eliminate different components of the original task in an effort to understand the difficulty toddlers have in solving the problem. A doll named “Lorie” was used throughout this study instead of just the ball used in Berthier et al. (2000). On some trials the children had to find Lorie by opening one of the four doors after she’d been held above one of the doors and lowered straight down behind the screen. This search task was made easier because “Lorie” was behind the door where the children saw her disappear. In the original door study (Berthier et al. 2000), the ball

rolled past other doors before coming to rest behind the door next to the barrier. Rather than rolling a ball that would stop at a barrier, “Lorie” was lowered onto the ramp behind the screen by hand. The children turned out to be very good at this task.

The second set of trials in this study was of interest because children had to “use their knowledge of object solidity to reason about a barrier” (Kloos & Keen, 2005). The children were asked to predict where Lorie should stand in order to catch the ball. This required an understanding of where the ball would stop. The child would place Lorie on the ramp which already contained a barrier that would be used in the trial. There was no screen so that the child had a view of all elements of the task. After the child placed Lorie on the ramp, the ball was rolled. If Lorie was in the correct position she would catch the ball. If she was too far ahead of the barrier she would be knocked down and if she was behind the barrier she would end up with nothing. In this way, the children could see the results of their decisions. Children did not do exceptionally well on this task but were correct on about half of the trials. Both 2- and 2 ½- year-olds had some success at predicting where the ball would stop if the screen did not hide the critical task elements (approximately half of each age group was above chance). A correct prediction required that the child reasoned about future events using knowledge about solidity.

Another study also found some success on the door task (Shutts, Keen & Spelke, 2006). Toddlers were asked to find a car that rolled out of view and behind one of two doors. The car was stopped by a barrier as in previous door studies. This study differed from previous door studies in that a toy car was rolled down the ramp instead of a ball. In addition, a pompom on an antenna was attached to the toy car. The height of the pompom varied (see Figures 2A, B).

Children performed best when the pompom was closer to the body of the car (Figure 2B). One way of explaining these results is that when the pompom was positioned closer to the body of the car the children encoded the pompom and car as a single object. Therefore, when the pompom was visible they were able to open the correct door and find the car.

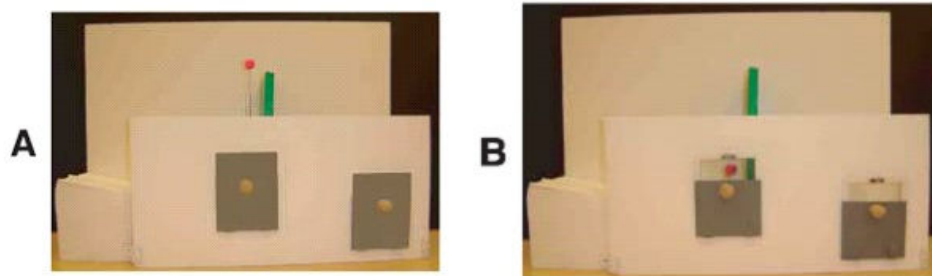


Figure 2 – Door Apparatus from Shutts, Keen, & Spelke (2006). The pompom was attached to the car by antennae and was positioned either close to the height of the barrier (A) or closer to the body of the car (B).

A number of studies have used modifications to the door task apparatus and procedure in an effort to determine why toddlers have such difficulty with the task (Mash, Keen, & Berthier, 2003; Kloos & Keen, 2005; Mash et al., 2006; and Shutts, Keen, & Spelke 2006; Keen, et al., 2008). There are still no clear answers. However, these studies have led to a number of hypotheses from both psychological and neuroscience perspectives. These hypotheses will be discussed in the following sections.

D. Toddler Performance on the Door Task: Psychological Perspectives

It is possible that there are task features that present a problem for toddlers because they involve skills that younger toddlers have not yet acquired. For example, in a study by Mash, Keen & Berthier (2003), 2-year-old toddlers watched as a ball was

rolled down the ramp and came to rest next to the barrier. After the ball had come to rest the occluding panel with four doors was added and the toddlers had to again choose the appropriate door in order to locate the ball (Figure 3).

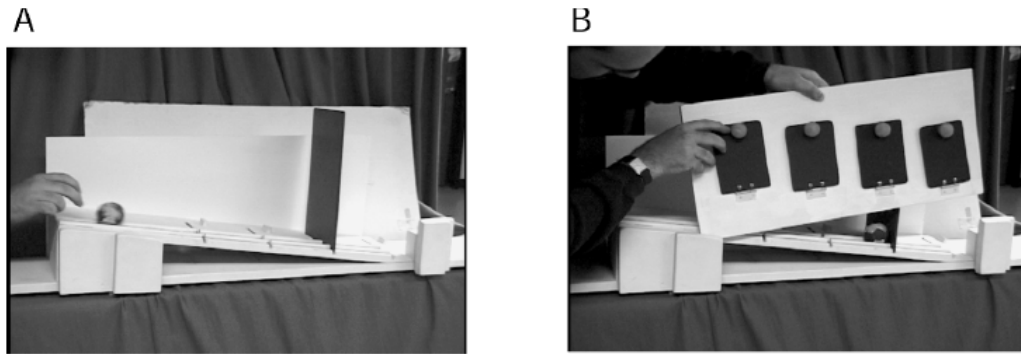


Figure 3 – Apparatus used in Mash, Keen, & Berthier (2003). Two-year-old children watched as the ball was rolled across the ramp and stopped at the barrier (A). The occluding panel with doors was then added and children were asked to select the appropriate door in order to find the ball (B).

Although children performed better on this task than on the initial task given by Berthier et al. (2000), they still performed poorly. They were only systematically accurate if they kept their eyes fixed on where the ball had been before the occluding panel with the doors was added. If children looked away they were unable to locate the ball. If children did look away they would need to find the ball based only on using the wall as a cue for location; using spatial location information. It is possible that this skill hasn't developed in children who are unable to solve the door task.

As mentioned above, Shutts, Keen, & Spelke (2006) found that toddlers performed better on their task when the pompom was located close to the body of the car used in the task (see Figure 2). It is possible that these toddlers were able to solve that task because when the pompom was lower they saw it as an extension of the car itself.

On the other hand, when the pompom was further removed from the car, they may have seen it as separate from the car and therefore not taken the pompom into consideration while attempting to solve the task. Although visual information is available to them, children who fail on the door task may not have learned how it is to be used in order to solve the task.

Alternatively, it is possible that failure on the door task is a result of working memory failure. Working memory involves both storage of information as well as manipulation of that information to bring about a response. In order to be successful on the door task toddlers must, (1) hold in mind that the barrier is continuous; it is actually in contact with the ramp, (2) know the location of the ball, and (3) open the door corresponding to the correct location. Toddlers who are able to successfully solve the task may be doing so through the use of working memory. There is information to be held in mind as well as manipulated in order to successfully complete the door task.

The previously mentioned study by Kloos & Keen (2005) suggests that toddlers may have knowledge they are unable to use when attempting to solve the door task. When all the elements of the problem are visible, toddlers are better able to predict where the ball should stop. When toddlers do not have to hold in mind the elements of the problem, they are better able to solve it. Recently another set of studies has provided support for this notion (Hood et al., submitted). In this study toddlers were presented with the standard door task, but were not required to carry out a manual search. Instead they were asked to respond verbally to questions posed by the experimenter.

A toy fish, “Nemo”, was placed into a cylindrical tube and rolled down a ramp behind four doors as in the previously described studies. Rather being asked to find

Nemo, the experimenter pointed to one of two locations and asked the question “Is Nemo here?”. The experimenter always pointed to the locations on either side of the wall. One would be the “correct” location while the other would be incorrect”. This was done to determine if the children understood the role of the wall in the task. The authors found that children who were able to successfully complete the verbal task were yet unable to successfully complete the standard door task which requires a manual search. In this case it appears that children fail the door task not because they don’t know where the object is located, but rather because there is a failure during search. This leads to the question of why there is a search failure.

Hood et al. (submitted) suggested that the search failure is related to inhibitory control after examining the types of errors often made by children who failed on the door task. Children often returned to the door where “Nemo” was previously found, or they repeatedly chose a door they seemed to prefer. This led to the idea that although children may know where the hidden object is located they are unable to inhibit the inappropriate response. One of the studies conducted by Hood et al. (submitted) specifically examined inhibitory control and the door task.

In the inhibition study children were biased to choose one particular door by having the wall in the same position for several trials. On test trials the position of the wall would be switched so that children would have to overcome experimentally induced perseveration in order to correctly locate the hidden object (Nemo). Although children had successfully found Nemo at one location they would have to inhibit that response and find him at a new location. As expected, children who successfully passed the standard

door task also performed well on the inhibition task indicating that they were good at inhibiting the inappropriate response of selecting the previously biased door.

It is possible that inhibitory control and/or working memory may be important for solving the door task. These two abilities are related and have been previously shown to be linked to the PFC. The next section will explore what we know about PFC and why it may be important for success on the door task.

E. Prefrontal Cortex Development and Function

The cortex goes through several stages during the course of development. These stages include the migration of postmitotic neurons to the cortical plate, axon and dendrite growth, myelination of axons, formation of synaptic contacts (synaptogenesis), and finally synaptic reorganization. During synaptic reorganization there is a pruning or loss of connections which is also known as synaptic elimination. The prefrontal cortex is known to have the most prolonged period of postnatal development of any region of the human brain (Johnson, 2005). Much of the research on PFC development focuses on synaptogenesis and synaptic reorganization.

1. Synaptic Density

Measures of synaptic density in the middle frontal gyrus (MFG), a gyrus in the prefrontal cortex, revealed that synaptic density in the human brain does not remain constant over the course of development (Huttenlocher & Dabholkar, 1997). There is an increase in synaptic density from birth through the first year of life. After year 1 synaptic density reaches its plateau and remains there until approximately 7 years of age. It is during this time period that synaptic density is at its peak and is actually significantly

above adult levels. After year 7 there is a decrease in synaptic density with adults having only about 60% of the synaptic density of the early childhood peak.

2. Number of Synapses per Neuron

The number of synapses per neuron has also been found to change over the course of development based on measurements taken from layer III of the MFG (Huttenlocher & Dabholkar, 1997). There are an average of 100,000 synapses per neuron at 1 year of age. This level is maintained between the ages of 1 and 7. However, the average number of synapses per neuron decreases to approximately 80,000 in the young adult indicating that a significant number of connections are lost over the course of development. There are also other changes taking place in the brain during development such as myelination and dendritic development. These changes will be discussed below.

3. Myelination

Myelin is a fatty sheath that surrounds axons resulting in improved conduction. The myelination process begins near term with the central region of the brain and spreads posteriorly (Huttenlocher and Dabholkar, 1997). The prefrontal region of the brain is the last to begin the myelination process during the second half of the first year of life. Myelination of this region appears to be complete at the end of the first year.

4. Dendritic Development

Dendritic development refers to the branching or arborization of the dendrites. Like myelination dendritic branching occurs later in the prefrontal cortex than in the other areas of the brain (Huttenlocher and Dabholkar, 1997). At birth there are very few dendritic branches. This is expected since there is very limited substrate for synapse formation. However, dendritic development advances rapidly between 1 and 3 months of

age in all cortical areas and dendrites continue to elongate even after 2 years of age is reached. In the PFC maturational changes such as dendritic growth are seen until puberty.

The developmental changes in the brain described above may be reflected in the cognitive abilities that children acquire as they grow older. It is possible that performance on the door task is related to PFC development. The PFC continues to develop over the first few years of life and it remains unclear how these changes relate to function. In addition, the PFC has been linked to a number of cognitive abilities that may be important for success on the door task such as working memory and inhibitory control. These roles for the PFC will be discussed in the following sections.

5. Prefrontal Cortex Function

Presently there is not a universally accepted theory for PFC function, however, there are particular forms of cognitive processing that have been consistently linked with the prefrontal cortex. These forms of cognitive processing include: the maintenance and manipulation of information online during brief temporal delays (working memory), the ability to inhibit responses that may be appropriate in one context but not another (inhibitory control), planning, as well as selective attention and response selection (Johnson, 2005). What is known about prefrontal cortex function has been derived from both clinical and experimental observations of the effects of injury to this region of the brain. More recently neuroimaging studies have also contributed to ideas about prefrontal cortex function as well.

In spite of what is known about the prefrontal cortex there is still much to be learned. A number of theories have been put forth in an effort to explain how the prefrontal cortex works. Wood and Grafman (2003) developed criteria to be used when examining the validity of prefrontal cortex theories. Several theories are presented in detail below.

a. Adaptive Coding Model

In this model proposed by Duncan (2001), working memory, attention, and cognitive control are subserved by the same underlying process. This is due to the adaptability of PFC neurons. PFC neurons are believed to code information in a task-relevant manner which provides a temporary, task-dependent, and context-dependent operating space. If the task or the context changes, these neurons will code different information that is relevant for that particular task or context. In this way PFC neurons may provide a mechanism for selective attention. That is, although a given PFC neuron can code for different information in different task contexts, in any particular context there is a selective removal of inputs that might drive the cell, but are currently unnecessary.

For example, a neuron may be able to code for both object and location features of a task. However, during an object task there will be emphasis on object features rather than location features which will be driven by the PFC. Therefore according to this model, PFC neurons provide a mechanism for selective attention. This selective attention mechanism can regulate posterior cortical brain regions involved in lower level processes, reflexes, or schemas that do not require executive function or working

memory. The PFC can regulate these brain regions by focusing processing in these regions on task-relevant information. As a situation becomes more familiar less involvement of the PFC would be expected. In terms of activation in the PFC, this model proposes that PFC neurons should be involved in almost all tasks and have weak functional specialization between PFC regions.

This model fits well with what is known about sustained firing of PFC neurons and the idea that the PFC plays a role in selecting and integrating sensory information. However, it is unclear if this model fits with neurophysiological and evolutionary ideas [see Wood & Grafman, 2003] of action representation and memory integration within the PFC. Furthermore, there are a number of studies that have shown consistent differences in PFC localization depending on function as well as response selectivity to particular task (Wood & Grafman, 2003).

b. Attentional Control Model

In this model (Norman & Shallice, 1986; Shallice & Burgess, 1993) there are two mechanisms which control behavior. One mechanism is the contention scheduler which is responsible for automatic processing. A particular input yields a particular output without much conscious awareness of the individual. The contention scheduler is believed to result in the automatic priming of stored knowledge. The second mechanism for controlling behavior is the supervisory attention system (SAS). The SAS is believed to reflect conscious awareness on the part of the individual rather than simple responses to stimuli that are seen with the contention scheduler. The SAS does have the ability to

override the contention scheduler if necessary. The SAS is localized to the PFC, however the localization of the contention scheduler has not been specified.

There is mixed support for the attentional control model. It would be expected that damage to the SAS would result in distractibility and impaired behavioral control due to the fact that the contention scheduler would dominate. In addition, you would expect routine behavior, for which a behavioral template (schema) is already available, to be unaffected by damage to the SAS since the SAS is believed to be biased towards novel situations. It turns out that the data only partially fit these expectations. Damage to the PFC does result in distractibility and impaired behavioral control (Fuster, 1997). However, routine behavior has also been shown to be affected by damage to the PFC (Allain et al., 1999; Sirigu et al., 1996). Neuroimaging data has shown that the PFC is involved in event knowledge. Furthermore, novel tasks have been shown to activate anterior PFC while over-learned tasks have been shown to activate the medial and slightly posterior PFC regions (Koechlin et al., 2000). All of these data are inconsistent with the predictions of the model (Wood & Grafman, 2003).

c. Connectionist Model

This is one of many connectionist models of cerebral cortex function where the PFC is responsible for the acquisition and expression of complex behaviors (Burnod, 1991; Gulgon et al., 1994). According to this model there are four levels of the cortical system (cell, module, tissue, and global) each of which have different functions. The cellular level processes information and modifies neuronal behavior. The modular level allows for computation and learning within a cortical column. The tissue level is

responsible for the activation of different inputs in parallel and the integration of successive learning experiences. Finally the global level integrates functions from different cortical regions in order to produce behavior.

According to the connectionist model proposed by Burnod and colleagues (1991), the PFC carries out the following processes: integration of sensory inputs and motor information, storage of information about past events, and modulation of behavior based on previous experiences and current motivation. The PFC is also considered to be important for structured learning and temporal processing. All of these ideas are consistent with what is known about the structure, connectivity, and neurophysiology of the PFC. However, the model does not provide information on the nature of each of the levels of the cortical system. Since the model is so broad it is difficult to make predictions that enable specific hypotheses to be tested (Wood & Grafman, 2003).

d. Guided Activation Theory

This theory developed by Miller & Cohen (2001), like the adaptive coding model, proposes that the PFC can regulate representations that are stored in the posterior cortical regions. The PFC is thought to temporarily store representations of task specific rules, attentional templates, and goals. With this stored information the PFC biases the representations in the posterior cortical regions which is particularly important during the learning of new rules and behaviors. As pathways are repeatedly activated the connections between them become stronger and therefore do not rely as much on the PFC. In other words, more frequently used sets of rules or behaviors are less likely to need the guidance of the PFC. In terms of localization, Miller and Cohen put forth the idea that the PFC would not necessarily represent different classes of information in a

modular or localized form. Rather, the PFC is thought to show localization based on the strengths of competing responses.

One of the weaknesses of this theory according to Wood and Grafman (2003) is that it is not explicit about how representations are transferred from the PFC to posterior regions. One of the positive attributes of this theory is that Miller and Cohen can make predictions based on the theory. Since the PFC is acting as a guide to posterior regions it is expected that it will be activated mostly in newly learned behaviors. As mentioned above this is not the case which is one of the weaknesses of the theory. On the other hand there is support for the theory in terms of the PFC being activated in conjunction with posterior regions of the brain. In addition, it would be expected that as processing demands increase the activation in PFC would increase as well. This does turn out to be the case in studies of cognitive control (MacDonald et al., 2000).

e. Temporal Organization Model

This model proposed by Fuster (1997) asserts that the PFC is a permanent memory store and is the site of processes such as working memory, attention, monitoring, and planning. Memories that are stored in the PFC are thought to become more complex or abstract as the region becomes more anterior. The PFC is believed to use mechanisms for monitoring, memory, and attentional selections in order to prioritize behavioral goals and to ensure that behavioral sequences are performed in the proper order. Temporal integration of information is believed to be mediated by PFC neuronal activity as well as through interactions between the PFC and posterior brain regions. According to Fuster, automatic actions are stored in the basal ganglia and premotor cortex while the PFC represents behaviors that are not habitual or well-learned.

According to Wood and Grafman (2003), this model is mainly consistent with what is known about the structure, connectivity, and neurophysiology of the PFC. However, there are some data that do not support this theory. For example, it would be expected that with automatic actions being stored in the basal ganglia and premotor cortex, the PFC would be reserved for actions or behaviors that are not habitual or well learned. As mentioned several times above, this is not the case. The PFC has been implicated in both novel and well-learned tasks. There is some mixed support for the idea, however, because both the premotor cortex and the basal ganglia are known to be important in movement preparation (Wood & Grafman, 2003). Fuster also puts forth the idea that inhibitory control is performed by orbitomedial PFC neurons, but other studies have shown a role for the dorsolateral PFC in inhibition also (MacDonald et al., 2000).

f. Working Memory Model * Since working memory is one of the major focuses of this study, this model will be discussed in detail below.

The working memory model proposed by Baddeley and Hitch (1974) initially had three major components: a central executive and two slave systems (the phonological loop and the visuo-spatial sketchpad). The central executive was considered the control system. It was responsible for the manipulation of information as well as for controlling the two slave systems; the phonological loop and the visuospatial sketchpad. The phonological loop was thought to store and maintain phonological (language) information while the visuospatial sketchpad was responsible for storage and maintenance of visual and spatial information (visual semantics). Both the phonological loop and visuospatial sketchpad were believed to interact with the central executive; however, they were not

believed to interact with each other. Therefore phonological and visual/spatial information were believed to be handled independently in working memory. Each of these working memory components will be detailed further below.

i. The Central Executive

The central executive is the most important, but least understood component of the working memory model due to a lack of empirical research (Repovs & Baddeley, 2006). It is the component of the model that is believed to be supervisory over the phonological loop and the visuospatial sketchpad. In terms of cognitive abilities, it is believed that the central executive is involved in attentional control, the focusing of attention, and the division of attention between tasks. In addition, the central executive is believed to play a role in task switching.

ii. The Phonological Loop

The phonological loop actually consists of two components (Repovs & Baddeley, 2006). The first component is the phonological store which is responsible for holding information in phonological or acoustic form. This information fades after a few seconds and therefore a second component is needed in order to maintain the information. The second component of the phonological loop is the articulatory rehearsal process which is analogous to subvocal speech. The articulatory rehearsal process allows individuals to refresh the memory trace by retrieving and rearticulating the information from the phonological store.

One example of this process is trying to remember a phone number. If an individual hears a phone number aloud the phone number will automatically enter the phonological store. If there is no articulatory rehearsal process the phone number will

quickly fade from memory. However, during the articulatory rehearsal process the memory trace in the phonological store is rehearsed and refreshed. The individual is then able to hold the phone number in memory until s/he is able to write it down. The capacity of the phonological store is therefore limited by the number of items that can be articulated in the time before the memory trace has faded away.

Researchers that are testing the Baddeley and Hitch model of working memory often wish to separate out the components using experiments that are targeted to specific parts of the model. One of the problems faced when attempting to collect data about the visuospatial sketchpad for example, is the fact that subjects may automatically code visual information that is to be remembered into a phonological form such that the phonological loop is activated. One way that researchers have found to get around this problem is using articulatory suppression (Repovs & Baddeley, 2006). Subjects are presented with a visual stimulus that they are to remember, but they are instructed to repeatedly articulate an unrelated word. This disrupts phonological loop function by disabling the articulatory rehearsal process.

iii. Visuospatial Sketchpad

Most of the research that has been done on Baddeley and Hitch's working memory model has been done with the phonological loop and therefore a lot of questions remain about the visuospatial sketchpad. There is some evidence to suggest, however, that there are visual and spatial subcomponents of the visuospatial sketchpad. For example, one study was able to show that spatial interference disrupts performance on a spatial working memory task while it does not disrupt performance on a visual working

memory task (Della Sala et al., 1999). Subjects were given the Corsi block tapping test which is a test of spatial working memory.

During this test subjects watched as an experimenter tapped sequences of blocks. The subject was then asked to tap out the same sequence the experimenter had demonstrated. During trials where there was to be spatial interference, subjects were shown the tapping sequence and then instructed to haptically follow an arrangement of pegs on a board for 10 seconds. The board was out of view and therefore the subjects were only able to navigate haptically. Subject performance on the Corsi blocks task decreased when spatial interference occurred.

As a visual working memory task subjects were given the Visual Patterns test. Subjects were presented with a grid containing a pattern of filled and unfilled cells. After a brief exposure to the pattern subjects were asked to reproduce the pattern on an empty grid. Performance on the Visual Patterns test was unaffected by the spatial interference task. However, it was affected when subjects were given a visual interference task. The visual interference task required that subjects viewed a series of irrelevant abstract pictures for 10 seconds after brief exposure to the test pattern. The visual interference task had no affect on the spatial working memory task (Corsi blocks test).

These data suggest that there are separate visual and spatial subcomponents of visuospatial working memory. The visual subcomponent seems to be more concerned with the retention of distinct basic features such as color, shape, and orientation. Therefore the visual subcomponent is thought to be more closely related to perception and imagery. The spatial subcomponent, on the other hand, seems to be more closely related to attention and action although the exact relationship has not yet been established

(Repovs & Baddeley, 2006). Based on these types of data, Baddeley and Hitch's three-component model of working memory has persisted in the working memory literature.

iv. The Episodic Buffer

More recently, however, a new component has been added to the model (Baddeley, 2000). This component is called the episodic buffer. The point of this component is to link information across domains so that you can have integrated units of visual, spatial, and verbal information as episodes (Repovs & Baddeley, 2006). One of the things that the three-component model lacked was an explanation for how information leaves this short term memory and ends up in long term memory. The episodic buffer is thought to be a limited capacity storage system for integrated information. It is the link between the phonological loop and visuospatial sketchpad and is believed to be the place where information from the phonological loop and visuospatial sketchpad is combined.

The episodic buffer is believed to have a direct relationship with the central executive, but an indirect relationship with the phonological loop and visuospatial sketchpad. According to the model, information is processed in the visuospatial sketchpad and the phonological loop which results in visual semantics and language. Visual semantics and language are then combined to produce episodic long-term memory. This integration is performed by the episodic buffer which is under the control of the central executive. The working memory model including the episodic buffer is now called the multi-component model of working memory.

Animal research has shown that frontal areas of the brain do have the ability to retain and hold visuospatial information (Funahashi et al., 1989; Fuster, 1997). Lesion

and imaging studies have also been performed in the context of the Baddeley working memory model. Initially these studies found that separable regions of the PFC subserved the visuospatial sketchpad and the phonological loop, however these ideas are now being questioned. A number of studies have more recently suggested that there are many functional areas (Postle, 2006) so more distributed processing models have been suggested.

Many of the theories above suggest that the PFC is involved in the regulation/control of processing in more posterior brain regions involved in sensory, perceptual, motor, and cognitive functions. According to these theories, information stored in the PFC for a short period of time is used for directing posterior brain regions resulting in appropriate responses. The goal of this proposal is not to test these theories of PFC function and working memory, but rather to use them to provide a context for thinking about PFC development as it relates to the door task. As previously mentioned, the PFC continues to develop over the first few years of life (Huttenlocher & Dabholkar, 1997). For the purpose of this study it is important to focus on what is developing in the prefrontal areas. Based on the theories above, working memory, selective attention, response inhibition, as well as reasoning processes may be influenced by PFC development. Successful completion of the door task may rely heavily on one or more of these processes subserved by the PFC.

6. Evidence for Prefrontal Cortex Processes

Lesion studies in monkeys provided some early clues about the types of functions carried out by the prefrontal cortex. Diamond and Goldman-Rakic (1989) tested brain

lesioned rhesus monkeys on a version of Piaget's A not B task. In this task subjects watch as an object is hidden at location A and are then required to retrieve the object after a brief delay. Subjects will successfully retrieve the object at location A for several trials before watching the experimenter switch the location of the hidden object to location B. Piaget (1954) found that human infants younger than 7 months of age are unable to successfully retrieve the object after it has been moved to location B. Instead, they make perseverative errors and choose the location where the object was successfully located previously (location A). Like human infants, rhesus monkey infants are also unable to successfully complete this task while adult monkeys can. When Diamond and Goldman-Rakic (1989) tested adult rhesus monkeys who had lesions to the dorsolateral PFC they found that they were severely impaired on the A not B task. This led to the conclusion that the PFC is involved in delayed response tasks that require spatial information to be maintained over a temporal delay (spatial working memory).

It is possible that the emergence of working memory abilities is linked to the maturation of the PFC. As mentioned above the PFC is the most slowly developing region of the brain. If maturation of the PFC is linked to the development of working memory it would be expected that young infants would not perform well on working memory tasks while adults should perform well. This has been found to be the case with both rhesus monkeys and humans. In addition, rhesus monkeys with damage to the PFC perform similarly to infant monkeys on working memory tasks (Diamond & Goldman-Rakic, 1986, 1989) suggesting that it is the maturation of the PFC that has contributed to working memory abilities.

These same studies (Diamond & Goldman-Rakic, 1986, 1989) have also been used to argue for the involvement of the PFC in inhibitory control. In order to successfully complete the A-not-B task, subjects must not only remember the location of the hidden object, but they must also inhibit an incorrect search to the previously rewarded location. Since adult rhesus monkeys with PFC damage tend to choose the previously rewarded location on the A-not-B task it has been argued that the PFC also plays a role in inhibitory control.

A study by Durston et al. (2002) used fMRI to compare children (mean age = 8.7 years) and adults (mean age = 28 years) on a response inhibition task. In this study the go/no-go task was used. In go/no-go task subjects are presented with a sequence of visual stimuli. On go trials subjects must respond by pushing a button when they view the stimuli on the screen. However, upon viewing a specific predetermined stimulus subjects are asked to inhibit their response/withhold the button push (no-go trial). Normally several go trials precede a no-go trial. The task can be made easier or more difficult depending upon the number of go trials that precede the no-go trial. Durston et al. (2002) tested children and adults with 1, 3, or 5 go trials preceding the no-go trials. Overall they found that adults were both faster and more accurate than the children. However, the number of errors for both children and adults increased as the number of preceding go trials increased.

In terms of the PFC, activation of the PFC was associated with successful inhibition on no-go trials in both children and adults. However, the researchers found that PFC activation was always stronger in children. There was an increase in PFC activation in adults as the number of go trials preceding the no-go trials increased. For

children, on the other hand, the PFC was maximally activated regardless of whether there were 1, 3, or 5 go trials preceding the no-go trial. The authors argue that the stronger activation in children is the result of an immature inhibitory control system. Adults, having more mature systems, only need to increase activation of the PFC when there is an increased need for inhibition (as task difficulty is increased). These data suggest that the PFC is involved in inhibitory control and that the role of the PFC in inhibitory control is fine-tuned as development proceeds.

Besides working memory and inhibitory control, the PFC has also been shown to play a role in object permanence. Baird et al. (2002) used near-infrared spectroscopy (NIRS) and tested 5- through 12-month-old infants on a simple object permanence task. NIRS is a non-invasive method of examining changes in neurophysiological activity; particularly changes in oxy- and deoxy-hemoglobin in specific brain areas. These changes reflect changes in brain activity. Baird et al. (2002) used NIRS on infants beginning at 5-months-of-age and then every four weeks up until 12-months-of-age. Infants sat on their parent's lap at a table and were given a small toy to play with. The experimenter then took the toy and hid it under a cloth in front of the infant. Infants were then allowed to search for the toy. The goal was to see the types of changes in brain activity that would occur as the infants developed object permanence. During each visit infants were given four trials. If an infant could successfully locate the toy on all four trials s/he was considered to have achieved object permanence.

NIRS data collected from the frontal cortex were compared pre- and post-emergence of object permanence. The authors found that post-emergence of object permanence there was an increase in hemoglobin concentration in the frontal cortex. In

other words, infants who have achieved object permanence show increased activity in the frontal cortex. These data support the idea that the PFC is involved in object permanence. The relationship between object permanence and the PFC can be thought of in terms of working memory. Object permanence requires the short-term storage of information involved in working memory. The maturation of the PFC and working memory abilities may be at least partially responsible for changes in object permanence abilities as infants develop.

Each of the cognitive processes described above (working memory, inhibitory control, and object permanence) have been linked to the PFC. It is known that the PFC continues to develop over the first few years of life (Huttenlocher & Dabholkar, 1997). The studies described above suggest that an immature or damaged PFC may contribute to poor performance on working memory, inhibitory control, and object permanence type tasks. In addition, Diamond et al. (1997) found this to be the case for children diagnosed with phenylketonuria (PKU).

Children with PKU have an inability to convert one amino acid (phenylalanine) into another amino acid (tyrosine). Tyrosine is a precursor for dopamine. Therefore, children with PKU have reduced levels of dopamine in the PFC. According to Diamond et al. (1997), PKU children are impaired on tasks thought to be dependent upon the PFC such as working memory and inhibitory control tasks.

Poor performance by toddlers on the door task may be related to PFC development. The door task could require the use of working memory and/or inhibitory control, both of which have been linked to the PFC. In the current study, children between the ages of 2 ½ - 3 years were tested on the standard door task as well as tests of

working memory and inhibitory control thought to be dependent upon to the PFC. Using a correlational approach, we compared children's performance on the standard door task with their performance on working memory and inhibitory control tests of executive function. This allowed us to examine toddler performance on the door task from both psychological (executive function) and neuroscience (PFC) perspectives.

CHAPTER II

METHOD

A. Overview

This study required that subjects make a single visit to the lab. During the visit subjects were tested on the door task as well as four other tasks. These tasks are summarized in Table 1.

Table 1 – Summary of Task Attributes

Task	Brain Area Involved	Cognitive Process Involved
Three Boxes-Stationary	PFC	Spatial Working Memory
Three Pegs	PFC	Inhibitory Control
Three Boxes-Scrambled	PFC	Non-spatial Working Memory
Delayed Recognition Span Task (DRST)	Medial Temporal Lobe	Recognition Memory

The Three Boxes-Stationary task is a spatial working memory task. The task requires the child to search for rewards in three identical boxes that differ only in their spatial location. Success on this task requires that children keep track of which box locations they have already visited and which locations they have yet to visit. Although the neural system required for successful completion of this task is unknown (Diamond et al., 1997), the PFC is believed to be activated during delayed response tasks which require spatial information to be maintained over a temporal delay (Diamond & Goldman-Rakic, 1989). Therefore it is very likely that this task involves the PFC.

The neural system required for successful completion of the Three Pegs task has not yet been empirically determined either. Nevertheless the task has been successfully

used with toddlers as an inhibitory control task which likely involves the PFC (Diamond et al., 1997). In the three pegs task children are presented with three differently colored pegs on a small child's workbench and instructed to touch the pegs out of spatial sequence. Children have to inhibit the tendency to touch the pegs in spatial sequence.

The Three Boxes-Scrambled task, which involves non-spatial working memory, has been previously linked to PFC function (Diamond et al., 1997; Petrides, 1995). In this task children search for rewards in three boxes that differ in shape and color. Success on this task requires that the child keep track of which boxes they have already visited and which they have yet to visit. However, unlike the three boxes-stationary, children must pay attention to the features of the boxes (such as box shape and color) because the boxes are scrambled after each search so location information is not reliable.

The fourth task, the Delayed Recognition Span Test (DRST) is included as a control task. The DRST is a recognition memory task that is independent of PFC function (Diamond et al., 1997). In fact, this task has been previously linked to the medial temporal lobe (Diamond et al., 1997; Levy et al., 2003). During the DRST children are shown a series of pictures on a touch screen computer monitor and asked to identify pictures that have not been previously presented. All pictures change location on the screen after presentation so children must pay attention to the features of the pictures in order to recognize the ones that have been shown previously.

Examining the relationships between performance on the door task and performance on the other cognitive tasks will allow us to determine the types of skills that children have when they acquire the ability to solve the door task. In addition, we

can determine if there is a relationship between performance on the door task and PFC-dependent abilities.

For each subject the door task was always presented first followed by the other four tasks. The Three Boxes-Scrambled, Three Boxes-Stationary, Three Pegs, and DRST tasks were presented in four different orders outlined in Table 2.

Table 2 – Order of Presentation of Comparison Tasks

Order	Tasks in Order of Presentation
A	Three Boxes-Stationary, Three Boxes-Scrambled, DRST, Three Pegs
B	Three Pegs, DRST, Three Boxes-Scrambled, Three Boxes-Stationary
C	Three Boxes-Stationary, DRST, Three Pegs, Three Boxes-Scrambled
D	Three Boxes-Scrambled, Three Boxes-Stationary, Three Pegs, DRST

B. Participants

A total of 36 subjects (16 females, 20 males) participated in the study. The mean age was 34.2 months. The mean age for males was 34.4, while the mean age for females was 33.8 months. Subjects ranged in age from 30.8 – 37.0 months. This age group was chosen because, based on the Berthier et al. (2001) study, 25% of 2.5-year-olds and 75% of 3-year-olds are able to solve the door task. We wanted to select for an age where some children would be able to solve the door task while others would not. This would allow us to make performance comparisons between children who could solve the door task and children who were unable to solve it.

Subjects were identified through county birth records. Parents were sent a recruitment letter from the Child Study Center in the Psychology Department at the

University of Massachusetts. Approximately one week after recruitment letters were sent, parents were contacted by telephone and asked if they would like to have their child participate in the study. Children received a small gift of appreciation for participating in the study.

Although 36 children participated, only 32 children provided complete data. Three subjects were unable to complete the Three Pegs task because they had not yet learned to identify colors. Children must be able to identify each peg by its color in order to complete the Three Pegs task (see procedure for the task below). One child was unable to complete the DRST due to equipment failure. Therefore, there were four subjects with incomplete data. Analyses were carried out using the 32 subjects for which there was complete data.

C. Procedure

1. The Door Task

Toddlers were brought into the laboratory by their parents. Upon arrival, the study was explained to parents in its entirety. Parents were then asked to sign the informed consent. The door task was always the first task to be presented after consent was obtained. Children sat on their parent's lap at a table facing the door apparatus (Figure 1). Prior to the test trials was a short familiarization phase. With the apparatus out of reach of the child, the doors were removed and the child watched as the experimenter rolled the ball down the ramp and it stopped at the barrier. The barrier was then moved to a new location and the experimenter rolled the ball again so that the child viewed the ball stopping at two different locations on the ramp. The barrier was then moved to a new location.

The doors were then added to the apparatus and the entire apparatus was pushed forward toward the child. The child was asked to open all of the doors. Once the child opened all of the doors the experimenter moved the apparatus out of reach and rolled the ball down the ramp. When the ball came to rest at the barrier, the experimenter pointed to the wall and commented, “Look, the ball stopped here because of this wall!” The apparatus was then pushed forward and the child was allowed to retrieve the ball. This process was repeated with the barrier at a new location.

For the last part of the familiarization the experimenter moved the apparatus out of reach of the child. The child watched as the experimenter hid a toy behind one of the doors. The child was then asked to find the toy. This process was repeated until the child successfully located the toy at all four locations. The toy was then removed and the apparatus was moved out of reach of the child. The barrier was placed in one of the four positions, the doors were closed and the test trials began.

The experimenter rolled the ball and kept the apparatus out of reach of the child until the ball came to rest at the barrier. The experimenter then pushed the apparatus forward and asked the child to retrieve the ball by opening the correct door. If the child opened the incorrect door, a second search was allowed. If the child was still unsuccessful, the experimenter moved the apparatus out of reach and opened the correct door. The experimenter then said, “The ball is here. It stopped here because of this wall,” and pointed at the barrier sticking up over the occluding panel of doors. Children were presented with eight test trials.

2. Three Boxes-Stationary

Three boxes, identical in shape and color, were used for this task (Figure 4). Each had an easily removable lid. The boxes were mounted on identical wooden bases to ensure that they would remain the same distance from each other when presented.

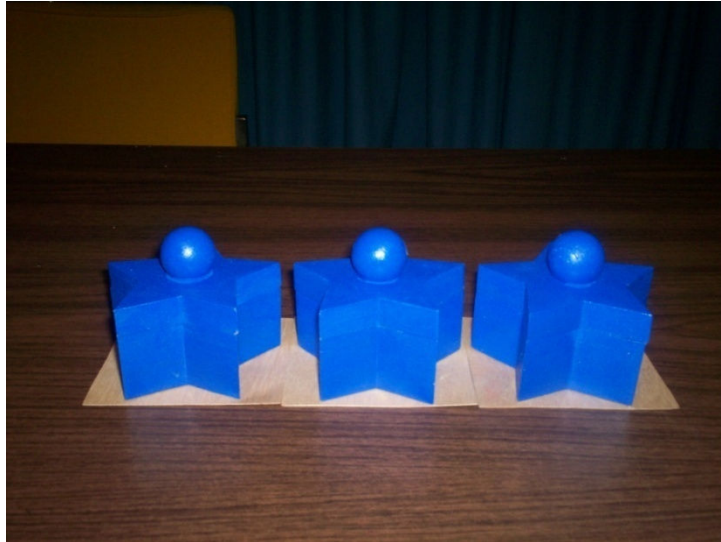


Figure 4 – Hiding Boxes used for Three Boxes-Stationary Task

Children watched as the experimenter placed a treat (a Cheerio or Goldfish™ cracker) in each of the three boxes. The three boxes were then pushed within reach of the child and the experimenter directed the child to select one of the boxes in order to locate a treat. When a child made contact with one of the boxes, the other two boxes were moved out of reach. After the child had removed the treat, all of the boxes were covered and a 5 second delay was imposed while all boxes remained out of reach. During the delay the experimenter attempted to distract the child from attending to the boxes by using a toy. After the delay, the experimenter pushed the boxes within reach of the child and the child was again directed to select one of the boxes in order to find a treat.

If the child searched incorrectly, the experimenter stated, “Oh no! It’s not in there.” The box was then covered and moved out of reach. Then, without delay, all three boxes were pushed toward the child, and the child was allowed to search again. If the child searched correctly, the experimenter stated, “Good job! You found one!” The boxes were covered and moved out of reach while a 5 second delay was imposed. The trial ended when the child had successfully found all three treats or when five errors were made in a row. Children were given three trials.

Although this task has not been empirically linked to the PFC, there is reason to believe that it involves the PFC. The PFC is believed to be involved in delayed response tasks that require spatial information to be maintained over a delay (Diamond & Goldman-Rakic, 1989). In this particular task the spatial locations of the boxes were important since the boxes were identical in shape and color. In addition, a 5 second delay was imposed after each search. Therefore, the children had to maintain the spatial information over a delay which should have activated PFC. This task is also useful because it involves spatial working memory. The inclusion of a spatial working memory task in this study allows us to examine one type of working memory that may be necessary for successful completion of the door task. In addition, this task may involve some inhibitory control. Children may have had to inhibit the tendency to return to the previously rewarded location in order to be successful.

3. The Three Pegs Task

The child sat at a table across from the experimenter. The experimenter presented a children’s workbench containing three differently colored pegs in a specific spatial

order (Figure 5). The experimenter first determined whether the child could correctly identify each peg by its color. For example, the experimenter asked, “Can you show me the yellow one?” The child was then given the opportunity to point to the correct peg. The experimenter asked the child to identify the remaining two pegs in the same manner. Children were always asked to identify the pegs in their left to right spatial order. Children who could not successfully identify all three pegs by color were not tested further on the task.

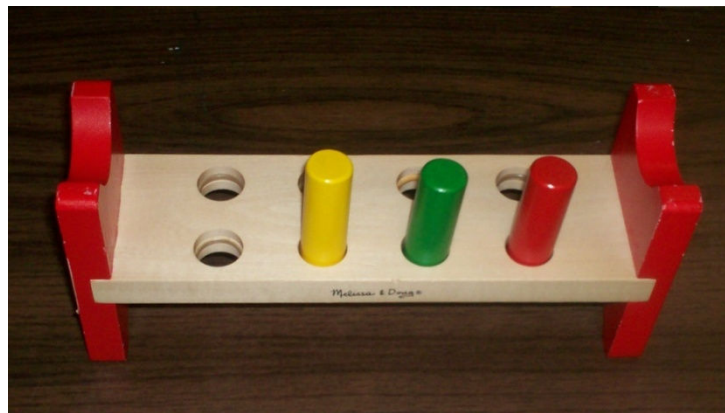


Figure 5 – Work Bench and Pegs used for Three Pegs Task

There were three levels of testing for this task: *verbal instruction*, *demonstration plus verbal*, and *verbalizing instruction*. After correctly identifying the pegs by color, children were first tested on the *verbal instruction* level. Children were only tested on the *demonstration plus verbal* level if they failed the initial *verbal instruction* test. Furthermore, children were only tested on the *verbalizing instruction* level if they failed at both the *verbal instruction* and *demonstration plus verbal* levels. Each of the testing levels are described below.

During *verbal instruction* the experimenter held the work bench out of reach of the child and said, “When I ask you to, I’d like you to touch the pegs in the order that I tell you.” The experimenter then asked the child to touch each of the pegs in an order that was different from their spatial sequence. For example, if the spatial sequence was YELLOW, GREEN, RED (as in Figure 5), the experimenter said, “I’d like you to touch the yellow one, then the red one, then the green one.” The experimenter repeated the instructions again and then pushed the work bench towards the child. If the child responded correctly, the experimenter rearranged the pegs and the child was given a confirmation trial. If the child responded correctly on the confirmation trial, testing ended.

If the child responded incorrectly on the first *verbal instruction* trial or the confirmation trial, the experimenter presented the *demonstration plus verbal* level. The experimenter said, “This time I’m going to show you how I’d like you to touch the pegs. Can you touch them like me? I’m going to touch the yellow one, then the red one, then the green one, like this...” The experimenter then touched the pegs to demonstrate how the child should touch them. The instructions and demonstration were repeated once more before the experimenter pushed the work bench towards the child and said, “Now it’s your turn. Can you touch them like I did?” If the child responded correctly the experimenter rearranged the pegs and the child was given a confirmation trial. If the child responded correctly on the confirmation trial, testing ended.

If the child responded incorrectly on the first *demonstration plus verbal* trial or the confirmation trial, the experimenter presented the *verbalizing instructions* level. The experimenter said, “This time I’d like you to say the colors out loud, while you touch

them. I'd like you to touch them in the same order as me. Like this..." The experimenter then demonstrated the order that the pegs should be touched while saying each color out loud. The experimenter repeated the sequence once more while saying each color before pushing the work bench towards the child and saying, "Now it's your turn. Can you touch them like I did?" If the child did not say the colors aloud while touching the pegs, the experimenter stopped and reminded the child to say the colors aloud. If the child successfully completed the trial the experimenter rearranged the pegs and presented a confirmation trial after which testing ended. If the child was unsuccessful on the first trial, testing ended.

The neural basis for successful performance on this task has yet to be determined empirically (Diamond et al., 1997). Nevertheless, this is a useful task for the purposes of this study because it requires two processes believed to be served by the PFC: working memory and inhibitory control. In order to successfully complete this task, children must remember the instructed sequence as well as inhibit the tendency to tap the pegs in their spatial order. There is evidence that suggests that inhibitory control is important for successful completion of the door task (Hood et al., submitted). This task allows for the examination of inhibitory control as well as verbal working memory.

4. Three Boxes-Scrambled

The Three Boxes-Scrambled task was tested much like the Three Boxes-Stationary task. Three boxes differing in shape and color were used (Figure 6). The boxes were mounted on wooden bases to ensure they remained the same distance apart during presentation.



Figure 6 – Hiding Boxes used during the Three Boxes-Scrambled Task

Children watched as the experimenter placed a treat (a Cheerio or Goldfish™ cracker) in each of the three boxes. The three boxes were then pushed within reach of the child and the child was directed to select one of the boxes in order to find a treat. When the child made contact with one of the boxes, the experimenter pulled the other two boxes out of reach. After the child removed treat from the box, the experimenter replaced the lid and moved the box out of reach of the child. The child watched as the experimenter scrambled the order of the boxes. Again, the experimenter pushed the boxes within reach of the child and the child was directed to select one of the boxes in order to find the treat. Testing continued in this manner until the child successfully located all three treats or made five errors in a row.

Children were given three trials with a maximum of eight searches per trial. Table 3 shows the pseudo-random order used for positioning the hiding boxes during each trial. Since the boxes are continually changing location throughout each trial, it is

possible that a child could find all three treats by repeatedly visiting the same spatial location. The pseudo-random order prevents children from finding all three treats in the minimum three searches when they are repeatedly searching the same spatial location. It allows us to distinguish between children who are perseverating to a spatial location and children who are actually solving the task.

Table 3 – Position of Boxes during the Three Boxes-Scrambled Task

	TRIAL 1	TRIAL 2	TRIAL 3
1	WBR	BWR	RWB
2	RWB	RBW	BRW
3	WBR	RBW	BRW
4	RBW	WBR	WRB
5	WRB	RWB	RBW
6	BRW	WRB	WBR
7	BRW	BWR	RWB
8	RWB	WRB	WBR

*W=White, B=Blue, R=Red

This task was chosen because of its previously shown dependence upon PFC function (Diamond et al. 1997; Petrides, 1995). This task is also beneficial because it is a non-spatial working memory task. Like Three Boxes-Stationary, this task also involves some inhibitory control. Children have to inhibit the inappropriate response of returning to the box where the reward was previously located.

5. Delayed Recognition Span Test (DRST)

Children were seated at a touch-screen computer monitor. Yerkes Cognitive Battery software was used to administer the DRST. At the start of testing a single picture displayed on the screen. The experimenter directed the child to touch the picture. When the picture was touched, the screen went blank for one second. Next, two pictures

displayed on the screen; the picture previously shown was presented in a new location along with a second picture not previously displayed. The experimenter asked, “Which one is the new one? Which one wasn’t there before?” and directed the child to touch the screen.

If the child selected correctly, the screen went blank for a second and three pictures were presented: the two previously shown pictures both in new locations, and a third picture not previously displayed. The experimenter again directed the child to touch the “new” picture. Testing continued in this manner with a picture being added each time the child selected correctly. The trial ended when the child selected incorrectly or correctly selected nine pictures in a row. Children were given three trials. All pictures were randomly selected by the software program from a library of 50 pictures. Samples of pictures included in the library are shown in Figure 7.

This task was chosen as a control task because it has previously been linked to the medial temporal lobe and not the PFC (Diamond et al., 1997; Levy et al., 2003). We expected that performance on the door task would not correlate with performance on this task. This task is also useful because it does not require working memory or inhibitory control like the other PFC-dependent tasks that were tested.

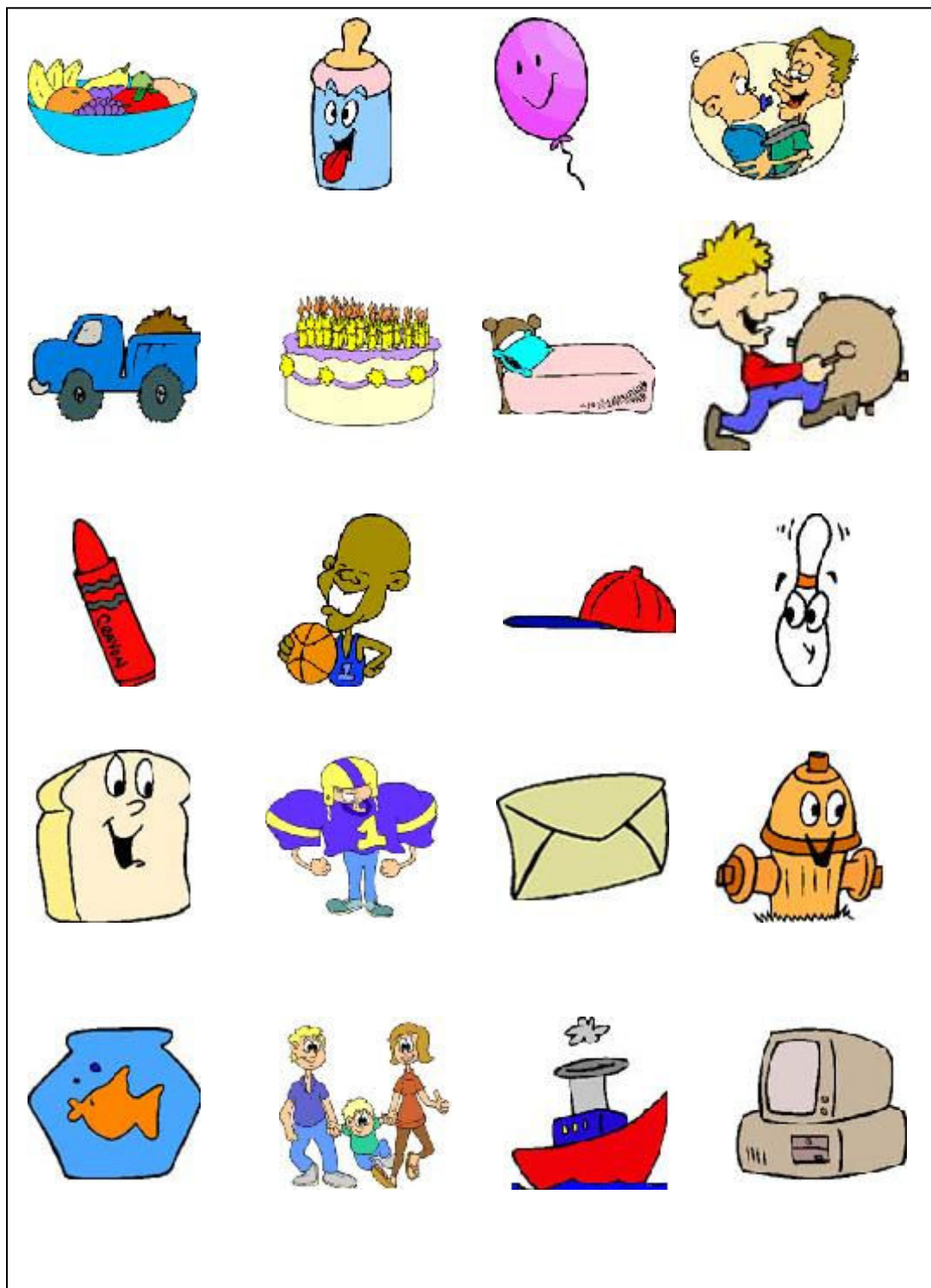


Figure 7 – Sample Pictures used for Delayed Recognition Span Test

D. Data Scoring

In the case of the door task, children were given a percentage score based on the number of times the ball was successfully retrieved on the first attempt out of the total number of trials (8 trials). Since the goal of both the three boxes-stationary and three boxes-scrambled tasks was to locate all three treats using the fewest number of searches, both tasks were scored in the same way. These tasks were scored by determining the number of searches required to successfully locate all three treats. Children were given three trials for each task. For each trial the number of searches required was determined and the final score given for the task was the average number of searches required across the three trials.

The Three Pegs task was scored based on the level at which the child successfully completed the task (*verbal instruction, demonstration plus verbal, or verbalizing instructions*). Three points were given for successfully completing the *verbal instruction* level, 2 points for *demonstration plus verbal* and one point the *verbalizing instructions* level. In order to receive the full amount of points for a level, a child had to successfully complete the first trial of that level and a confirmation trial. Children who successfully completed the first trial, but not the confirmation were given half the points for that level. For example, a child who touched the correct sequence of pegs on the first *verbal instruction* trial, but failed on the confirmation was given a score of 1.5.

All data were scored by a primary observer and a secondary observer who scored one third of the data. When the scorers disagreed the primary observer's score was used. Observers agreed 100% on the door task, 91.7% on the three boxes scrambled, 91.7% on the three boxes stationary and 83.3% on the three pegs task.

The DRST was scored automatically by the Yerkes Cognitive Battery software. The program calculated a span for each child based upon the largest number of pictures that could be distinguished from the “new” picture. A span was calculated for each trial. Since children were given three trials, the final score was the average span across the three trials.

CHAPTER III

RESULTS

A. Description of the Data

Thirty-six children participated in the study, although complete data was collected from only 32 children. The scores on the door task ranged from 0.0 to 1.0. The scores on the three boxes-scrambled task ranged from 3.0 to 5.0, while the scores on the three boxes-stationary task ranged from 3.0 to 6.3. The scores on the three pegs task ranged from 0.0 to 3.0 and the scores on the DRST ranged from 1.3 to 6.3. Table 4 shows the means and standard deviations for each of the tasks.

Table 4 – Means and Standard Deviations

	N	MEAN	STANDARD DEVIATION
Door Task	36	.465	.248
Three Boxes-Stationary	36	3.67	.805
Three Boxes-Scrambled	36	3.58	.551
Three Pegs	33	.864	1.17
DRST	35	2.67	1.36

For the door task, three pegs task, and DRST, higher scores indicate better performance. However, on the three boxes-stationary, and three boxes-scrambled tasks, it is the lower scores that indicate better performance. The goal of these tasks is to find all three treats in the least number of searches and a perfect score on these tasks is 3.0. The distributions for each of these tasks are presented in Figure 8.

The strip chart shows individual scores for the Door Task (Door), three Pegs (Pegs), three boxes-scrambled (scram), three boxes-stationary (stat) and DRST tasks. Age was also included by subtracting the 32 months from each individual age and on the strip chart is centered at 32 months. The data are jittered to allow us to see individual scores.

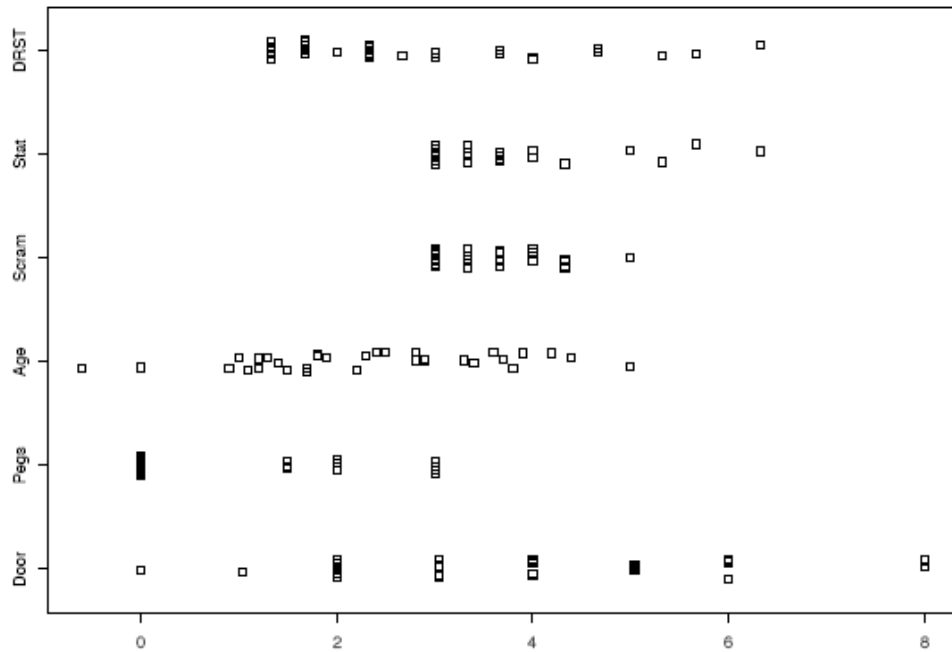


Figure 8 – Strip Chart Showing Individual Task Scores

The DRST, three boxes-scrambled, and three boxes-stationary tasks are positively skewed and in further statistical analyses they are logarithmically transformed.

In addition, an examination of the three pegs task scores revealed a separation in the data. Out of the 32 children to be used for analysis, twenty received a score of zero on the task, meaning they did not touch the correct sequence of pegs at any time. The remaining twelve children selected the correct sequence at least once. Therefore, we decided to dichotomize the data rather than using the level at which children passed on the pegs task. Children received a score of zero if they never selected the correct sequence, and a score of one if they selected the correct sequence at any time. The dichotomized scores were used for further analysis.

B. Correlations

Most of the relationships between the variables involved in this study were examined by using the Pearson Product Moment correlation. Since the scores from the three pegs task were dichotomized, correlations with the three pegs task are actually point-biserial correlations. It is important to note while examining these correlations that higher scores on the three pegs and DRST tasks reflect better performance, while lower scores on the three boxes-stationary and three boxes-scrambled tasks reflect better performance. Therefore, in order to improve clarity, the scores on the three boxes-stationary and three boxes-scrambled tasks were reverse coded. The initial correlations are shown in Table 5.

There are a number of relationships that emerge in Table 5. Only one task, the three pegs task, was significantly correlated with the door task. Nevertheless, there are significant correlations between other variables. Although the pegs task correlates with the door task it also correlates with age. The three boxes-stationary and three boxes-

scrambled task scores correlate with each other as well as with the DRST and three pegs task scores.

Table 5 – Correlations

	Door	Age	Sex	Stationary	Scrambled	DRST	Pegs
Door	1.00						
Age	.280	1.00					
Sex	.013	.215	1.00				
Stationary	.248	.281	.086	1.00			
Scrambled	.232	.061	.054	.403*	1.00		
DRST	.221	.123	.031	.440**	.322	1.00	
Pegs	.510**	.348*	.113	.395*	.326	.110	1.00

**Correlation is significant at the .01 level

*Correlation is significant at the .05 level

In order to more deeply examine the relationships between the variables, partial correlations were obtained. Table 6 shows the correlations between variables with all other variables being held constant. When all of the variables are held constant, most correlations drop out and only one remains. The three pegs task no longer correlates with age and the correlation between the three boxes-stationary and three boxes-scrambled also drops out. Neither the three boxes-stationary task nor the three boxes-scrambled task correlates with the three pegs task. The only remaining correlation is between the three boxes-stationary and the DRST.

Table 6 – Partial Correlations

	Age	Sex	Stationary	Scrambled	DRST	Pegs
Age	1.00					
Sex	.212	1.00				
Stationary	.180	.273	1.00			
Scrambled	.165	.133	.259	1.00		
DRST	.036	.104	.397*	.197	1.00	
Pegs	.274	.125	.297	.198	.150	1.00

*Correlation is significant at the .05 level

Since we are interested in the relationships between the door task and the other variables, the partial correlations were repeated with the door task included. Table 7 shows these correlations. With all of the other variables controlled for, the three pegs task is the only one that correlates with door task performance. A correlation also exists between the three boxes-stationary and the DRST.

Berthier et al. (2000) have shown that children’s performance on the door task improves with age. Between the ages of 2 ½ and 3 years there is a dramatic improvement in children’s ability to solve the task. Therefore, in the current study one might expect to see a correlation between door task performance and age that remains even after all other variables are controlled for. Although this was not the case, it is not surprising. The age

range used in the current study was quite restricted and probably explains why such a correlation was not seen.

Table 7 – Partial Correlations with Door Task

	Door	Age	Sex	Stationary	Scrambled	DRST	Pegs
Door	1.00						
Age	.056	1.00					
Sex	-.132	.218	1.00				
Stationary	.091	-.184	.283	1.00			
Scrambled	-.050	.167	-.138	.263	1.00		
DRST	.191	.024	.127	-.406*	-.183	1.00	
Pegs	.459*	.217	.171	-.308	-.153	-.218	1.00

*Correlation is significant at the .05 level

A partial regression plot was obtained (Figure 9) to further investigate the relationship between the three pegs task and the door task. The partial regression plot is the result of a linear regression and shows the door task residuals plotted against the three pegs task residuals while all other variables are controlled for. Therefore, the plot shows the unique relationship between the door task scores and the three pegs task scores. Since partial correlation is the correlation between sets of residuals, the partial regression plot allows us to visualize the relationship between the door task and three pegs task described by the partial correlation above (Table 7).

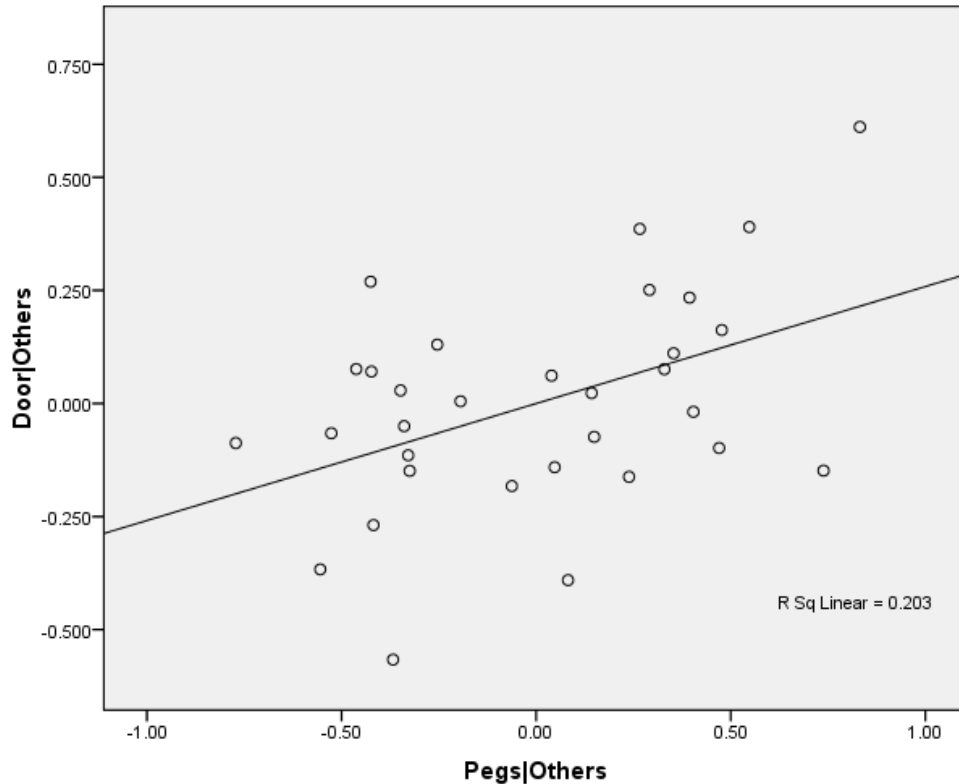


Figure 9 – Partial Regression Plot

C. Logistic Regression

Although the correlations above show a relationship between the three pegs task and the door task, the analysis was taken further in order determine the best predictor of door task performance. More specifically, we were interested in which variable(s) could predict success on a door task trial for an average child. The above correlations were performed using percent success for door performance, but because on any given trial the children either succeeded or failed, the following regressions were performed using logistic regression. To this end, the dependent variable was rescored. For each subject all 8 door task trials were examined. Children were given a score of 0 when they failed to find the ball on their first search and were given a score of 1 when they were

successful in finding the ball. The data were dichotomized in this way in order to be able to use the logit function for binomials in the regression in an attempt to predict success on the door task. In addition, the regression takes into account the random effects of subjects. The data from 32 subjects resulted in 256 observed door task trials.

The regression was conducted using the Generalized Linear Mixed Model with the logit link function. The results of the regression are shown in Table 8. Parameter estimates and standard errors are given as well as the z-values and p-values. The three pegs task is the only significant predictor of success on the door task ($z = 2.87$, $p = .004$).

Table 8 – Regression using Generalized Linear Mixed Model

	Estimate	Std. Error	Odds	Probability	z value	p-value
Intercept	-1.18	2.18	.307	.235	-.541	.589
Age	.044	.148	1.05	.511	.299	.765
Sex	-.278	.367	.757	.431	-.758	.449
Pegs	1.19	.415	3.29	.767	2.87	.004
Scrambled	-.837	3.01	.433	.302	-.278	.780
Stationary	1.41	2.63	4.10	.804	.537	.591
DRST	1.12	1.02	3.05	.753	1.09	.275

In addition to the parameter estimates the odds and probabilities were also included. As the three pegs score increases, the odds of being successful on a door task trial increases by 3.29. Therefore a child is three times as likely to be successful on a door task trial with a unit increase in the three pegs score. The table also includes the predicted probability. The predicted probability of .767 tells us that there is approximately $\frac{3}{4}$ probability of success on a door trial if the subject passed the pegs task.

D. Inhibitory Control Errors

The three pegs task is thought to require inhibitory control. The preceding analyses have revealed a relationship between the door task and the three pegs task. Next, we wanted to determine whether there was a relationship between the types of errors children made on each task and their scores on the three pegs task. Specifically, we wanted to determine if inhibitory errors on the door, three boxes-scrambled, and three boxes-stationary tasks were correlated with performance on the three pegs task. If the three pegs task measured inhibitory control, we expected that children who performed poorly on the three pegs task would make more inhibitory errors across the other three tasks.

The number of inhibitory errors made by each subject on each of the tasks (door, three boxes-stationary and three boxes-scrambled) was determined. An inhibitory error was coded when the child searched incorrectly and either searched the location where the object/treat was found on the immediately preceding trial, or searched the same location/box repeatedly. Each subject received an inhibitory error score for each of the tasks.

Partial correlations were obtained for the inhibitory control scores and the three pegs task scores (Table 9). None of the correlations were significant. However, there was a tendency for pegs scores to improve as the number of inhibitory errors on each of the tasks decreased.

Table 9 – Partial Correlations of Inhibitory Errors and Pegs Scores

	Subject	Door Inhibitory Errors	Scrambled Inhibitory Errors	Stationary Inhibitory Errors	Pegs Scores
Subject	1.00				
Door Inhibitory Errors	-.027	1.00			
Scrambled Inhibitory Errors	.017	.182	1.00		
Stationary Inhibitory Errors	-.161	.280	.320	1.00	
Pegs Scores	-.116	-.170	-.088	-.220	1.00

CHAPTER IV

DISCUSSION

Although the door task has been studied extensively (Berthier et al., 2000; Butler, Berthier, & Clifton, 2002; Mash, Keen, & Berthier, 2003; Kloos & Keen, 2005; Mash, et al. 2006) there as yet are no clear answers as to why toddlers perform so poorly on it. Previous research has led to some ideas concerning what does not seem to be important in solving the door task. For example, we know that object permanence is not what leads to toddler failure on the door task. Toddlers do have object permanence as they do search for the ball. They simply search incorrectly.

The problem doesn't seem to be one of hidden displacement either. When toddlers were given an intermittent view of the ball's movement (Butler, Berthier, & Clifton, 2002) their performance improved, but not greatly. They still had a hard time with the task overall. Furthermore, in another study (Mash, Keen, & Berthier, 2003) children watched as the ball was rolled down the ramp and came to rest at the barrier. Only after the ball had come to rest was the occluding panel with four doors added to the apparatus. Once again, performance improved, but was limited by whether or not the child kept his/her gaze locked on the correct location. This study also suggests that hidden displacement is not the main problem that toddlers have in solving the door task.

The study by Mash, Keen, & Berthier (2003) also removed the necessity of reasoning about a solid barrier from the task. The children watched the ball come to rest at the barrier and so did not have to reason about whether or not the ball would pass through it. The fact that children still struggled with the task suggests that reasoning about solidity is not the main problem either. This is further supported by the Shutts,

Keen, & Spelke study (2006). Even when the barrier was visible through a small window in the apparatus, it did not cue the children to the ball's location. If reasoning about the solid barrier was the main problem children faced, it would be expected that having a view of the barrier would improve performance. However, it did not.

Recently another set of studies has examined the role of the solid barrier in solving the door task in more detail (Keen et al., 2008). In this study children were tested under three different conditions that sought to draw children's attention to the barrier which is a major cue for where the ball is located. In one instance the door apparatus was modified so that the ball made a 'ratta-tatta' noise as it rolled down the ramp and then a 'clunk' as it came into contact with the barrier. Neither 2-year-olds nor 2.5-year-olds were helped by this condition. Both groups still performed at chance.

In the second condition, the experimenters used a modified barrier which allowed the children to see the entire edge of the barrier unlike in previous studies where only the top half of the barrier was visible over the occluding panel of doors. Out of the twenty-four 2.5-year-olds tested in this condition only 8 performed significantly above chance. Therefore, being able to see more of the barrier did help some 2.5-year-olds, but most still performed at chance. Keen et al. (2008) also tested a third condition where the barrier was removed and instead an experimenter placed their hand on the ramp to catch the ball. Under this condition 2.5-year-olds performed slightly better than chance. These studies support the idea that toddler failure on the door task is probably not the result of failure to attend to the barrier. Even when there was an improvement in performance by 2.5-year-olds it was only marginal.

The above studies investigated the door task by making manipulations to the door apparatus itself or the way in which the task was presented. Unlike those studies, we used a correlational method and compared children's performance on the standard door task with their performance on working memory and inhibitory control tests of executive function. This allowed us to examine toddler's performance on the door task from both psychological (executive function) and neuroscience (PFC) perspectives. The goal was to determine if working memory and/or inhibitory control skills are related to solving the door task. Furthermore, we wanted to determine if there is a relationship between door task performance and development of the PFC.

With the use of four different tasks for comparison a number of different outcomes were possible. All children could have performed at ceiling on one or more of the tasks indicating that the task was too easy. Alternatively, all children could have shown floor performance on one or more of the tasks indicating that the task was too difficult. Neither of these situations occurred. As Figure 8 shows, there was a great deal of variability in the scores for each of the tasks suggesting that the tasks were given at an appropriate difficulty level.

Since we used tasks believed to tap into executive function, we must take into consideration that previous research has resulted in conflicting results about the nature of executive function. In one study (Wiebe, Espy, & Charak, 2008) children between the ages of 2 ½ and 6 years old were tested on a variety of working memory and inhibitory control tasks. The responses required to complete each task varied greatly. In one working memory task, the delayed alternation task, children were required to find a treat in one of two locations. The treat alternated locations each time the child successfully

found it. Therefore children had to remember the previously rewarded location over a delay. Children were also given the six boxes-scrambled task as another working memory task. This was carried out like the three boxes-scrambled in the current study. The only difference was that more boxes were used. Overall the children in the Wiebe et al. (2008) study completed three working memory tasks (they completed a digit span task also).

In addition to the working memory tasks, children were tested on 7 inhibitory control tasks. These tasks differed in their response requirements as well. For example in one task, the Whisper task, children had to whisper the names of both familiar and unfamiliar characters that they were shown as pictures. This was believed to require inhibitory control since children tend to shout the names of characters, particularly those that are familiar to them. In another inhibitory control task, the child continuous performance test, children pressed a button when they saw they saw pictures of target animals appear on the screen, but were to withhold the button press with all other pictures. In addition to the two described inhibitory control tasks, subjects also completed a delayed response task, a statue task, a visual attention task, the shape school task, and the tower of Hanoi task.

The researchers found significant low to moderate correlations between tasks that required similar cognitive abilities. In other words, those tasks that were believed to be working memory tasks correlated with each other while tasks believed to require inhibitory control correlated with one another. There were also significant low to moderate correlations across tasks that required different cognitive abilities. Some working memory tasks correlated significantly with some of the inhibitory control tasks.

The researchers next performed a confirmatory factor analysis to determine if there were underlying factors that could account for the variability in the data. After testing seven different models they found that the best fitting model was a unitary one. All ten working memory and inhibitory control tasks loaded onto a single factor. Therefore, despite the tasks being different, they all appeared to measure a single underlying cognitive ability.

This result differs from most research studies on executive function which have found multiple factor models to be the best fitting when tests of working memory and inhibitory control were given. Only one such study was done with preschool children (Espy et al., 1999). In that study toddlers between the ages of twenty-three and sixty-six months were tested on a variety of working memory and inhibitory control tasks (A-not-B, Spatial Reversal, Color Reversal, Delayed Alternation, and Self-Control).

In this case a principal components analysis revealed that the five tasks loaded onto four different factors. The A-not-B task loaded on two different factors. In one case it loaded with the delayed alternation task, a working memory task. In the second case the A-not-B loaded with the self control task, a test of inhibitory control. The color reversal and spatial reversal tasks each loaded onto separate factors. Unlike the study by Wiebe et al. (2008) the results of this study suggest that executive function can be fractionated into multiple underlying cognitive abilities. Studies of executive function in adults as well as older children have found similar results (see Wiebe et al., 2008 supplementary table for a comprehensive list). Working memory and inhibitory control tasks have been found to load onto different factors even when the tasks demands seem similar.

In the current study all four tasks were believed to target different cognitive abilities. However, there was the possibility of overlap across tasks. The three boxes-stationary is a spatial working memory task. In spite of being labeled as such, this task could also involve inhibitory control. Children needed to inhibit the tendency to return to the previously rewarded location. This is also true for the three-boxes-scrambled task which involves non-spatial working memory. Children have to inhibit the tendency to return to the location or box color which was previously rewarded. The three pegs task requires inhibitory control but may also involved aspects of working memory as children have to recall the order in which to touch the pegs.

Unlike the study by Wiebe et al. (2008), our data suggests that the three boxes-stationary, three boxes-scrambled, and three pegs tasks measure different things. If these tasks all measured the same underlying process we would expect them to correlate with one another. The three boxes-scrambled and three boxes-stationary did initially correlate when a Pearson Product Moment correlation was used.

However, it is important to note that these two working memory tasks both have a possible overlap with inhibitory control. The inhibitory control component within each task could be the cause of an inflated Pearson correlation between the two tasks. Performing a partial correlation removes the area of overlap between the two tasks and gives a better idea of their true relationship. In fact, when we performed a partial correlation we found that the correlation between the three boxes-scrambled and three boxes-stationary was no longer significant. Therefore, we did not ultimately find a significant correlation between the three boxes-stationary, three boxes-scrambled, and three pegs task.

There was, however, a significant correlation between the three boxes-stationary and the DRST. The three boxes-stationary requires that children attend to the location of the boxes rather than the box characteristics. The DRST, on the other hand, requires that children attend to the characteristics of the pictures shown on the screen. The spatial locations of the pictures in the DRST are not informative because the location of the pictures changes after each selection. The correlation showed that as children's performance improved on the three boxes-stationary it also improved on the DRST. Even when all other variables were controlled for, this correlation remained significant.

The DRST was chosen as a control task because of its link to the medial temporal lobe rather than the PFC. The hippocampus is the area of the brain known to be involved in declarative memory, the memory of facts and events. The hippocampus is also known to be involved in spatial memory. This type of memory is different than what has been described as spatial working memory in the current study. The spatial memory linked to the hippocampus involves memory that gives an individual the ability to navigate an environment.

The three boxes-stationary, on the other hand, is believed to rely on PFC. The PFC is involved in spatial working memory tasks. Spatial working memory refers to the ability to both hold in mind and manipulate information about the location of an object. This type of task probably involves what Newcombe & Huttenlocher (2000) term 'place learning'. In place learning individuals use distance and direction information in order to locate an object. In the case of the three boxes-stationary subjects are presented with three identical boxes which are the same distance apart. It is still possible that children encoded distance and/or direction information by considering the relationship between

the boxes and the edge of the table on which the boxes were presented. For example, one box would be considered closer to the left edge of the table while another would be considered closer to the right edge of the table. This type of spatial coding could also exist in terms of the relationship of the boxes to each other.

The DRST does not require this type of spatial consideration. Therefore, it was not expected that these two tasks would correlate. One possible explanation for this result is that the DRST did in fact activate PFC rather than the medial temporal lobe, making it more of a working memory task. Both the DRST and three boxes-stationary tasks required children to hold information in mind over a delay, which is a characteristic of working memory tasks which are dependent on PFC.

In addition, one study (Stern, Sherman, Kirchoff, & Hasselmo, 2001) has shown that the stimuli used during working memory tasks may determine the part of the brain that is activated. In this study adult subjects were asked to complete two versions of the two-back working memory task. In two-back tasks subjects are presented with a series of pictures and must report by pressing a button whether the currently viewed picture matches the picture viewed two slides previously. In one version of the task subjects were shown pictures that they were familiar with while in the other version they were shown novel pictures.

Functional magnetic resonance imaging (fMRI) was then used to determine the brain areas activated during each version of the task. During the novel version of the task, the researchers found that there was more activation within the medial temporal lobe. On the other hand, when familiar pictures were used, there was more prefrontal activation.

In the current study, the pictures used for the DRST could be considered familiar in the sense that they were easily recognizable by children. In fact, some children verbally identified the pictures as they appeared on the screen. It is possible that the DRST results would have been different if abstract shapes were used rather than pictures that children could easily identify. Perhaps no correlation would have been found between the three boxes-stationary and DRST in this case.

It was a bit surprising that the DRST did not correlate with the three boxes-scrambled. In the three boxes-scrambled task children must attend to the color or shapes of the boxes because the locations of the boxes switch after each search. This seems to be more in line with what children must do on the DRST. The locations of the pictures change after each selection and the children must pay attention to the features of the pictures rather than their location on the screen. If the DRST is simply a measure of non-spatial working memory, it would be expected to correlate with the three boxes-scrambled.

Although the task requirements seem similar on the surface they may be differences in how space is encoded in each task. For the three boxes-scrambled children may use what is Huttenlocher & Newcombe (2000) termed ‘cue learning’. In this case the object is found by association with landmark. This is different from ‘place learning’ in that it does not depend on distance and direction from a landmark but an actual association with a searchable place. In the case of the three boxes-scrambled an association might be formed between the treat and a box of a certain color so that the child knows the treat can be found in the “red” box, for example. This may also hold true for box shape since in the three boxes-scrambled all of the boxes are shaped differently.

The DRST likely does not involve ‘cue learning’. In the case of the DRST the stimuli are presented on the computer screen rather than being 3-dimensional objects that the child must search. Therefore, it is unlikely that the children used landmarks in the same way as they might be used on the three boxes-scrambled. The child only had to remember whether or not the images presented had been viewed previously. In spite of the fact that in both tasks object features were relevant, possible difference in task approach may have resulted in the lack of correlation between the two tasks.

Alternatively, the lack of correlation between these two tasks could be due to the task requirements. Although both tasks require that children pay attention to object features, the three boxes-scrambled leaves more room for error. It is possible for a child to return to the location he/she previously visited and still be rewarded. This is not the case for the DRST nor is it the case for the three boxes-stationary. If a child returns to the same location in either of these tasks, there is no reward. In fact, for the DRST the trial ends completely and the child must start again with a single picture in a new location. If the DRST is in fact a non-spatial working memory task it may be a more reliable measure than the three boxes-scrambled because it doesn’t take in errors of returning to the same location. Another possible explanation is that the DRST and three boxes-stationary simply reflect children’s ability to avoid the previously rewarded location.

Regardless of the cognitive abilities reflected by each of the tasks, the task scores seem to be good measures of task performance. The scores children received on the three boxes-stationary, three boxes-scrambled and DRST are not one-time measurements. For each of these tasks children were given three trials and their score was an average of their

performance across those three trials. Therefore, the data seemed to clearly separate good performers from poor performers on each of the tasks.

If the three boxes-stationary, three boxes-scrambled, and DRST are indeed measures of working memory it suggests that working memory does not play a large role in performance on the door task, as none of these tasks were found to correlate with door task performance. Only performance on the three pegs task was found to correlate with performance on the door task. Furthermore, the three pegs task was the only significant predictor of door task performance.

As mentioned above the three pegs task is believed to be a measure of inhibitory control. A recent study by Simpson & Riggs (2007) sought to determine the task conditions under which inhibitory control is activated. Children between the ages of 3 and 4 years old were presented with boxes and told that the boxes with stickers on the lids contained stickers while the boxes without stickers on the lid were empty. Children were then instructed to find stickers by opening the appropriate boxes. Children performed successfully in terms of opening boxes with stickers on the lid. However, they made many errors of opening boxes that did not contain stickers. The authors suggested that these errors were the result of a lack of inhibitory control; the children failed to inhibit the prepotent response of opening boxes.

The authors then sought to determine what exactly made the action of “opening boxes” prepotent. They offered two possibilities: opening boxes is the habitual action associated with boxes or opening boxes is prepotent because of the children’s desire to find stickers. They tested this difference by having a condition where children did not open boxes, but rather placed hoops over the boxes they desired the experimenter to

open. The expectation was that if opening boxes became prepotent because the action is a habitual one, children should not show these types of errors when they are no longer the ones opening the boxes. This is exactly what the researchers found. When children placed hoops on the boxes they wanted the experimenter to open they no longer made inhibitory errors. The authors suggested that habitual actions are ones that may be prepotent. However, it is not solely being habitual that makes an action prepotent.

Opening boxes may be a habitual action, but the presence of boxes was not enough to cause children to err when they were placing hoops over boxes. The difference between the hoop condition and the normal condition was that in the normal condition children planned to open the boxes. They did not plan to open the boxes in the hoop condition. Therefore, the authors concluded that in order for a response to become prepotent it must be habitual and involve planning. The authors also tested whether or not box opening became prepotent when there was no reward involved. They found that box opening remained a prepotent response even when the boxes were not baited. It is not the possible reward that makes an action prepotent. The action must only be habitual and planned.

It is possible that the door task involves inhibitory control as it involves both of the components found to be important by Simpson and Riggs (2007). The act of opening the apparatus doors could be seen as habitual. Often when children arrived for the study they attempted to open the apparatus doors without even being instructed to do so. This suggests that the act of opening the doors is habitual as was the act of opening of boxes in the Simpson and Riggs (2007) study. The task also involves planning. Children are

instructed to open one of the doors and find the ball on each trial. Therefore, children are planning to open a door during each trial.

Nevertheless, a previous set of door task studies (Mash et al., 2006) contradicts the idea that toddler's problems on the door task stem from the habitual action of opening doors. In one experiment children were given a 'looking time' version of the door task. As in the standard door task, children watched as the ball was rolled down the ramp behind the occluding panel of doors. However, rather than being asked to open a door and find the ball, children watched as a puppet searched and opened the doors. Children watched both consistent and inconsistent events. On consistent trials the puppet opened an incorrect door and the ball was not located. On inconsistent trials the puppet opened the correct door, but the ball was not present. Looking time was measured and the researchers found that children looked longer during inconsistent events.

In another condition, children were introduced to a puppet which they could help to find the ball during the standard door task. After the puppet examined the apparatus for 4 seconds, the child was given the opportunity to help the puppet by opening one of the doors to find the ball. Therefore, unlike previous door studies and the current study, a delay was imposed after the ball had come to rest. If children erred because they opened doors habitually, the imposed delay should have helped their performance. However, children performed at chance in spite of the additional time given for response. This study suggests that habitual door opening is not the main problem for toddlers completing the door task.

Although the study by Mash et al. (2006) suggests that habitual door opening may not be a factor in toddler failure of the door task, it does not rule out the possibility that

children did know where the ball was located in spite of searching incorrectly. In the same study toddlers were presented with a looking time version of the door task. The authors found that children were able to predict where the ball should end up. It may prove useful to test toddlers on the door task by having them direct a puppet to open the correct door. If toddlers are able to verbally identify the correct door it suggests that the problem lies in the actual execution of the search.

Hood et al.'s (unpublished) investigation of the door task suggests that toddlers may indeed know the location of the ball. In that study the experimenter pointed to a specific door location and asked the child whether or not the toy was behind that door. Children were asked to respond yes or no. In addition, children complete the standard version of the task. The results showed that children performed well on the verbal version of the task in spite of poor performance on the standard task. The authors concluded that although the children know the location of the toy they are unable to inhibit inappropriate responses. The errors made by the children in Hood et al. were also examined. The authors found that children often perseverated to a favorite door or chose the previously correct door.

An examination of the types of door task errors made in the current study revealed a similar pattern. Of the errors made on the door task, over half (58%) were classified as inhibitory control errors; children returned to the previously rewarded location or repeatedly searched a favorite door. To further break this down, of the errors made on the door task, 22% were due to searching the previously rewarded location, while 36% were due to searching the same door repeatedly. There were 42% of the errors could not be classified as inhibitory control errors.

Hood et al. (unpublished) proposed that when children don't know the location of an object they will employ a 'search everywhere' strategy. However, children who do know the location of the hidden object, but yet search incorrectly, do so due to an inhibitory control failure.

The idea that inhibitory control is involved with door task performance is consistent with the findings of the current study. Performance on the three pegs task and an observation of the types of errors children made on the door task suggests the involvement of inhibitory control. Furthermore, when completing the three pegs task, five of the children who failed the task were able to state the colors correctly on the *verbalizing instructions* level in spite of tapping the incorrect sequence. This suggests that at least some of the children knew the correct answer but were unable to inhibit the inappropriate response.

If inhibitory control is indeed involved it may explain why very young infants appear to have an understanding of objects and their properties yet fail the door task as toddlers. It is possible that toddlers yet have the understanding they had as infants; however, as toddlers there is a search failure due to underdeveloped inhibitory control ability. Two-year-olds perform very poorly on the door task while 75% of 3-year-olds are able to pass the task (Berthier et al., 2000). Previous research (Huizinga, Dolan, & van der Molen, 2006) has shown that inhibitory control abilities continue to develop into adulthood.

The data in the current study suggests a relationship between inhibitory control ability and performance on the door task. It is possible that children who perform poorly on the door task lack inhibitory control and therefore respond inappropriately when

searching. However, it is also possible that children simply don't know where the hidden object is located. In this case, they do not fail because of inhibitory control, but rather because they are employing the 'search everywhere strategy' suggested by Hood et al. (unpublished).

Furthermore, since the current study is correlational, there is the possibility that the relationship between the door task and performance on the inhibitory control task (three pegs) moves in the opposite direction. Rather than children's performance on the door task being influenced by inhibitory control ability, there may be something about the nature of the door task which influences performance on the three pegs task. Poor performance on the door task could result in poor performance on the three pegs task. This is one of the limitations to this correlational study. If there is a direction of influence we are unable to determine it with the methods we have employed.

Another possibility for explaining children's failure on the door task is that children don't know where the ball is because they lack an underlying cognitive ability other than inhibitory control. However, this seems unlikely. As mentioned previously, all of our tasks appear to be measuring different things. If they were measuring some underlying cognitive ability we would expect them to correlate and they did not. Furthermore, we chose the cognitive abilities we believed were most likely to be involved in solving the door task. Our data shows that working memory does not likely play a large role in door task performance. If there is an underlying cognitive ability other than inhibitory control it must be identified.

It is also possible that there is not a causal relationship between door task performance and performance on the three pegs task. Perhaps the ability to solve the

door task simply appears at the same time as the ability to solve the three pegs task. This possibility seems unlikely as well. When we examined the errors children were making on the door task we found that over half (58%) could be classified as inhibitory control errors. In addition, we examined the relationship between errors on the other tasks and scores on the three pegs task. We found that as scores increased on the three pegs task there was a tendency for children to make fewer inhibitory errors across the other tasks as well. These data give support to the idea that inhibitory control may be an important element in solving the door task.

Since this is a correlational study we are unable to draw conclusions about the involvement of inhibitory control and PFC. Working memory and inhibitory control have been previously linked to PFC. However, in the current study the working memory and inhibitory control tasks did not correlate with one another. One study (Tsujimoto, Kuwajima, & Sawaguchi, 2007) suggests that working memory and response inhibition become fractionated in the PFC during childhood. Young children are believed to have a common neural system for working memory and inhibitory control. According to this hypothesis, as children become older working memory and inhibitory control recruit different systems enabling more efficient processing.

More research must be done in order to determine what is taking place in the brain. Unfortunately studies that would yield direct answers about the brain are difficult to do with young children due to the requirements of brain imaging protocols. The correlational study may be one of the best ways to show a relationship between the door task, inhibitory control, and the PFC. Another alternative is to examine children who have been diagnosed with phenylketonuria (PKU). These children have an amino acid

deficiency which results in reduced levels of dopamine in the PFC. Previous research has shown that PKU children are impaired on tasks thought to be dependent upon PFC (Diamond et al., 1997). It would be interesting to test older PKU children on the door task and compare their performance with control children. A study like this may give more insight into what the PFC contributes to door task performance.

In conclusion, the data suggests a role for inhibitory control in completing the door task. There was a correlation between door task performance and performance on the three pegs task, a task believed to involve inhibitory control. Furthermore, the three pegs task was able to predict door task performance. Future research may assess children's performance on other inhibitory control tasks to determine if the relationship between the door task and inhibitory control is limited to this particular (three pegs) task or if it is a general relationship with inhibitory control task. More research is also needed to determine the brain areas involved.

APPENDICES

APPENDIX A
RECRUITMENT LETTER

Dear Parent,

The University of Massachusetts has been studying children's development for more than twenty years. Some of you may have visited us with your children in the past, or have read about our research. Some of our work is described at <http://www.umass.edu/devpsych>. This work has only been possible through the generous participation of area families, to whom we are very grateful. We are contacting you at this time to invite you to participate in a study currently being conducted at our Child Study Center in Springfield.

As part of a project on perception and reasoning, we are looking at toddlers' ability to locate a hidden object. During the visit, children will be asked to perform five tasks. These include: finding a ball that has rolled behind a door, tapping pegs into their holes in the workbench (a popular children's toy), finding objects in small boxes (2 exercises here) and even watching and responding to a touch-response video screen. How toddlers complete this variety of tasks will help us understand if the skills used in finding the hidden ball rely on a particular area of the brain.

Participation in this study involves one visit of approximately 60 minutes to the Center, located at 130 Maple Street in Springfield. We have very flexible hours (including weekends), to accommodate busy schedules and we are happy to entertain siblings who are not participating in the study in our playroom. Each session will be videotaped. We are always happy to show you the videotape after the session and to discuss with you the findings of this study as well as other research we have conducted. A parent is with his or her child at all times during the session. All of the data we collect will remain strictly confidential. Participation in the study is entirely voluntary, and if at any point during your visit you wish to end the session, you may do so. Children also receive a small gift as a token of our appreciation.

Our work has led to new insights about children's development in infancy and early childhood. Clearly, none of it would be possible without the assistance of parents in the community. We are deeply grateful to all who have helped us in the past, and will appreciate it if you (or any of your friends) are able to participate in this study. Sandi Harris-Graves, the Center's manager, will be calling you soon to answer any questions you may have, and to see if you are interested in participating. If you would prefer to contact us, please feel free to call the Center at 734-4909, or email at sandi@psych.umass.edu. Thank you very much for considering our project.

Neil Berthier, Ph.D.
Professor of Psychology
Phone: (413) 545-0535
Email: berthier@psych.umass.edu

Iris Price, M.S.
Graduate Research Assistant

APPENDIX B
CONSENT FORM

Consent Form

The Human Studies Research Committee has approved the recruitment of subjects for this study.

Purpose of study. The study is designed to investigate the ability of toddlers to use visual information to help them retrieve a hidden object and how this ability relates to development of a particular brain region.

Procedure. Your child will sit in a seat while a ball rolls across the table and out of view. After the ball has come to rest your child will be asked to open one of the four occluding doors and retrieve the ball. Your child will then be given 4 more tasks: tapping pegs into their holes in the workbench (a popular children's toy), finding objects in small boxes (2 exercises here) and watching and responding to a touch-response video screen. We will videotape the session. You are welcome to view the videotape at the end of the session. Should you decide you would not like the videotaped session to be used for the purposes of this study, the videotaped session of your child will be destroyed. Testing will last approximately one hour.

Possible risks and benefits. There is no risk to your child and no expected benefit.

Confidentiality of records. The records generated by this study will be confidential. Videotapes and paper records will be stored in a locked room and will only be available to researchers involved in this study. Your child will not be individually identified in any publication or presentation that results from this experiment.

Request for more information. Feel free to ask any question about our study. We will be happy to show you the videotape of your child at the end of the session. If you wish to speak with someone involved in this study regarding any problems or concerns you may have, contact the principal investigator, Professor Neil Berthier, at (413) 545-0535 or if you would like to discuss your rights as a participant in a research study or wish to speak with someone not directly involved in the study, you may contact the department chair, Melinda Novak at (413)545-2387. You may also contact the Human Subjects Review Board at HumanSubjects@ora.umass.edu; (413) 545-3428.

Voluntary nature of participation. Your participation in this study is purely voluntary. You may withdraw at any time for any reason without penalty.

I have explained to _____ the purpose of the research, the procedures required, and the possible risks and benefits to the best of my ability.

Researcher's Signature _____

Date _____

I confirm that _____ has explained to me the purpose of the research, the study procedures that I will undergo and the possible risks and discomforts as well as benefits that I may experience. I have read and I understand this consent form. Therefore, I agree to give my consent to have my child, _____, participate as a subject in this research project.

Parent's Signature _____

Date _____

APPENDIX C
INDIVIDUAL TASK SCORES

Table 10 – Individual Task Scores

Subject	Age in Months	Sex	Testing Order	Door Task Score	Three Boxes - Scrambled	Three Boxes - Stationary	Three Pegs	DRST
1	30.8	F	A	2	3.667	4.333		2.667
2	36.4	M	B	2	3.000	3.333	2.0	2.667
3	33.8	M	C	3	5.000	5.667	0.0	1.333
4	32.0	F	D	8	3.667	4.000	1.5	1.333
5	36.2	M	A	6	4.333	3.333	3.0	1.667
6	37.0	M	B	4	3.667	3.667	0.0	2.333
7	33.7	F	C	5	3.000	3.667	0.0	2.333
8	34.4	M	D	3	3.000	3.000	3.0	2.333
9	34.9	M	A	8	3.000	3.000	3.0	4.667
10	33.1	M	B	2	4.000	6.333	0.0	1.667
11	33.3	M	C	3	3.333	5.000	0.0	1.333
12	33.0	F	D	1	3.000	3.000	0.0	1.667
13	31.6	M	A	2	3.667	3.667		1.333
14	32.9	M	B	4	3.333	3.333	0.0	4.000
15	33.2	F	C	0	3.333	3.000	0.0	5.333
16	33.7	M	D	4	3.667	3.333	0.0	2.333
17	33.9	F	A	6	3.000	3.000	2.0	4.000
18	33.5	M	B	2	4.333	3.333	2.0	3.000
19	34.9	F	C	3	3.667	3.333	1.5	1.333
20	33.4	F	D	2	4.333	3.000	0.0	1.667
21	31.4	F	A	3	3.667	4.333	0.0	2.333
22	34.5	M	B	4	3.000	4.000	0.0	5.667
23	33.2	M	C	3	3.000	3.000	0.0	2.333
24	34.2	F	D	2	4.000	5.333	0.0	1.667
25	35.6	M	A	6	3.000	3.667	1.5	2.333
26	35.7	F	B	6	4.333	3.333	0.0	2.000
27	35.4	F	C	5	3.000	3.333	3.0	1.333
28	35.3	M	D	5	3.000	3.000	3.0	3.667
29	35.8	F	A	2	3.667	3.667	0.0	2.333
30	34.5	M	B	3	4.500	3.667	0.0	
31	35.9	M	C	4	3.667	3.000	1.5	3.667
32	35.3	M	D	4	3.333	3.667		1.333
33	33.8	M	A	2	3.333	3.667	0.0	1.667
34	34.8	F	B	8	3.000	3.000	1.5	6.333
35	34.3	F	C	5	4.000	3.000	0.0	4.667
36	34.8	F	D	2	4.333	4.000	0.0	3.000

APPENDIX D
TASK SCRIPTS

Door Task Script

Familiarization

Children were shown the door apparatus with the occluding panel of doors removed. The apparatus was out of reach of the child. The experimenter placed the barrier in one of the four locations and said, "I'm going to roll this ball." When the ball had come to rest at the barrier the experimenter pushed the apparatus towards the child and said, "Look, the ball stopped at the wall, can you get the ball for me?" The child then removed the ball from beside the barrier. The experimenter then said, "Good job!" and pulled the apparatus out of reach of the child again. When the ball was returned to the experimenter, the experimenter repeated the process with the barrier in a different location.

After the child had retrieved the ball from next to the barrier two times, the experimenter said, "Now, let's try something different." The experimenter then removed the barrier from the apparatus and placed it in view of the child on the table. Next, the experimenter added the occluding panel of doors to the apparatus. The experimenter produced a small toy figurine of Dora The Explorer and said, "I'm going to hide Dora behind one of these doors. I'd like you to find her." The experimenter then opened one of the doors, placed Dora inside and closed the door. The experimenter pushed the apparatus towards the child and said, "Can you open one of the doors and find Dora?" If the child searched correctly the experimenter clapped and said, "Great job, you found her!" can you find Dora again? The experimenter then repeated the process hiding Dora at a different location. If the child was unsuccessful the experimenter commented, "Uh oh, she's not in there!" and then opened the door revealing Dora's location. This process

was repeated until the child found Dora four times successfully. Dora was then removed from the table.

The experimenter then said, “Now, let’s try something different. We’re going to use the ball again.” The experimenter removed the occluding panel of doors and placed the barrier at one of the four locations on the ramp. The occluding panel of doors was then added again and the experimenter said, “Can you help me open all of the doors?” After the child had opened all of the doors, the experimenter moved the apparatus out of reach of the child and said, “Now I’m going to roll the ball.” After the ball had come to rest at the barrier the experimenter pushed the apparatus toward the child and said, “Can you get the ball for me?” When the child successfully retrieved the ball the experimenter said, “Great job!” This process was repeated until the child had successfully retrieved the ball four times with the barrier in different locations.

Testing

The experimenter said, “We’re going to try something different again.” The experimenter removed the occluding panel of doors and placed the barrier in one of the four locations on the ramp. The experimenter pointed at the barrier and said, “See the wall?” After the child acknowledged seeing the wall, the experimenter said, “Now I’m going to add the doors” and added the occluding panel of doors. The experimenter then said, “The wall is here” while pointing at the barrier sticking up over the occluding panel of doors and, “I’m going to roll this ball,” while holding the ball up in view of the child. The experimenter rolled the ball. When the ball came to rest at the barrier, the experimenter pushed the apparatus towards the child and said, “Can you open one door and find the ball?”

If the child searched correctly, the experimenter clapped and said, “Yay, you found it! Great job!” The experimenter then removed the occluding panel of doors and moved the barrier to a new location, repeating the process again. If the child searched incorrectly, the experimenter commented, “Uh oh, it’s not in there!” and allowed the child to open a second door. If the child was correct on the second search, the experimenter said, “You found it!” then pointed at the wall and said, “It stopped there because of this wall.” If the child searched incorrectly on the second search, the experimenter pulled the apparatus out of reach of the child, opened the correct door and said, “The ball is here. It stopped here because of this wall,” while pointing at the wall. Children were given 8 trials.

Three Boxes - Stationary Script

Three boxes, identical in shape and color were positioned in a row and placed on a table in full view, but out of reach of the child. The experimenter said, “We’re going to play a game. I’m going to put one Cheerio (or Goldfish cracker) in each box. Like this.” The child then watched as the experimenter opened all three boxes and placed a treat in each one. After all of the boxes had been baited with a treat, the experimenter said, “Now I’m going to close them up,” and replaced the lids on the boxes. The experimenter then pushed the row of boxes within reach of the child and said, “Can you open one box and find a Cheerio (or Goldfish)?”

When the child selected a box, the experimenter pulled the remaining boxes out of reach, keeping them in their relative positions. The experimenter encouraged the child to remove the treat from the selected box. After the treat was removed and the lid was replaced on the box, the experimenter moved it out of reach of the child and back into its position in the row of boxes.

The experimenter then held up a small, toy, Dora figurine in front of the child’s face for five seconds. When the experimenter presented the Dora figurine, one of the following questions/comments was used to attract the child’s attention to the toy:

- Look, it’s Dora! Can you say hello to her?
- Look, Dora has a backpack, what do you think she has in there?
- What color is Dora’s backpack?
- What’s Dora carrying in her hands?
- Dora’s back to say hello again!
- It’s Dora time! Say hello to Dora!
- What color shoes does Dora have on?
- Look, Dora’s doing a funny dance!
- Here comes our friend, Dora! What’s she doing?
- Dora’s carrying a birthday cake. Where do you think she’s going?
- Here’s Dora again, she likes playing with you!
- What’s that picture on Dora’s shirt?

A timer was used which beeped when five seconds had passed. When the timer beeped, the experimenter said, "That sound means that it's time for Dora to sit here." The experimenter then placed Dora off to the side of the table. The experimenter then pushed the row of boxes toward the child and said, "Can you find another Cheerio (or Goldfish)?" When the child selected a box, the experimenter moved the remaining boxes out of reach while keeping them in their relative positions.

If the child selected correctly s/he was encouraged to remove the treat from the box. The lid was then replaced and the box was moved out of reach of the child back to its position in the row of boxes. Then, another five second delay was imposed using the Dora figurine as described above. If the child selected incorrectly, the experimenter said, "Oh no! It's not in there!" The lid was replaced on the box and the experimenter moved the box out of reach of the child and back into its position in the row of boxes. The three boxes were then immediately pushed towards the child and the experimenter said, "Can you find another Cheerio (or Goldfish). This process continued until the child found all three treats or until they made five consecutive search errors.

Three Boxes – Scrambled Script

Three boxes, which differed both in shape and color were positioned in a row and placed on a table in full view, but out of reach of the child. The experimenter said, “We’re going to play a game. I’m going to put one Cheerio (or Goldfish cracker) in each box. Like this.” The child then watched as the experimenter opened all three boxes and placed a treat in each one. After all of the boxes had been baited with a treat, the experimenter said, “Now I’m going to close them up,” and replaced the lids on the boxes. The experimenter then pushed the row of boxes within reach of the child and said, “Can you open one box and find a Cheerio (or Goldfish)?”

When the child selected a box, the experimenter pulled the remaining boxes out of reach, keeping them in their relative positions. The experimenter encouraged the child to remove the treat from the selected box. After the treat was removed and the lid was replaced on the box, the experimenter moved it out of reach of the child and back into its position in the row of boxes.

The experimenter then rearranged the boxes in a different spatial order and once again pushed them toward the child. The experimenter said, “Can you open one box and find another Cheerio (or Goldfish)?” After the child selected this time (regardless of whether they selected correctly or not) the experimenter again scrambled the boxes and allowed the child to search again. This process was repeated until the child found all three treats or searched incorrectly five times in a row.

Three Pegs Task Script

The child sat at a table across from the experimenter. The experimenter presented a children's workbench containing three differently colored pegs in a specific spatial order. The experimenter first determined whether the child could correctly identify each peg by its color. For example, the experimenter asked, "Can you show me the yellow one?" The child was then given the opportunity to point to the correct peg. The experimenter asked the child to identify the remaining two pegs in the same manner. Children were always asked to identify the pegs in their left to right spatial order. Children who could not successfully identify all three pegs by color were not tested further on the task.

There were three levels of testing for this task: *verbal instruction*, *demonstration plus verbal*, and *verbalizing instruction*. After correctly identifying the pegs by color, children were first tested on the *verbal instruction* level. Children were only tested on the *demonstration plus verbal* level if they failed the initial *verbal instruction* test. Furthermore, children were only tested on the *verbalizing instruction* level if they failed at both the *verbal instruction* and *demonstration plus verbal* levels. Each of the testing levels are described below.

During *verbal instruction* the experimenter held the work bench out of reach of the child and said, "When I ask you to, I'd like you to touch the pegs in the order that I tell you." The experimenter then asked the child to touch each of the pegs in an order that was different from their spatial sequence. For example, if the spatial sequence was YELLOW, GREEN, RED, the experimenter said, "I'd like you to touch the yellow one, then the red one, then the green one." The experimenter repeated the instructions again

and then pushed the work bench towards the child. If the child responded correctly, the experimenter rearranged the pegs and the child was given a confirmation trial. If the child responded correctly on the confirmation trial, testing ended.

If the child responded incorrectly on the first *verbal instruction* trial or the confirmation trial, the experimenter presented the *demonstration plus verbal* level. The experimenter said, “This time I’m going to show you how I’d like you to touch the pegs. Can you touch them like me? I’m going to touch the yellow one, then the red one, then the green one, like this...” The experimenter then touched the pegs to demonstrate how the child should touch them. The instructions and demonstration were repeated once more before the experimenter pushed the work bench towards the child and said, “Now it’s your turn. Can you touch them like I did?” If the child responded correctly the experimenter rearranged the pegs and the child was given a confirmation trial. If the child responded correctly on the confirmation trial, testing ended.

If the child responded incorrectly on the first *demonstration plus verbal* trial or the confirmation trial, the experimenter presented the *verbalizing instructions* level. The experimenter said, “This time I’d like you to say the colors out loud, while you touch them. I’d like you to touch them in the same order as me. Like this...” The experimenter then demonstrated the order that the pegs should be touched while saying each color out loud. The experimenter repeated the sequence once more while saying each color before pushing the work bench towards the child and saying, “Now it’s your turn. Can you touch them like I did?” If the child did not say the colors aloud while touching the pegs, the experimenter stopped and reminded the child to say the colors aloud. If the child successfully completed the trial the experimenter rearranged the pegs and presented a

confirmation trial after which testing ended. If the child was unsuccessful on the first trial, testing ended.

Delayed Recognition Span Test (DRST) Script

Children were asked to have a seat at a small table containing a touch screen monitor. At the start of testing a single picture was displayed on the screen. The children were asked to touch the picture. When the picture was touched, the screen went blank for one second. Next, two pictures displayed on the screen; the picture previously shown picture was presented in a new location along with a second picture not previously displayed. The experimenter asked, “Which one is the new one? Which one wasn’t there before?” and directed the child to touch the screen.

If the child selected correctly, the screen went blank for a second and three pictures were presented: the two previously shown pictures both in new locations, and a third picture not previously displayed. The experimenter again directed the child to touch the “new” picture. Testing continued in this manner with a picture being added each time the child selected correctly. Each time a new picture was added to the screen the experimenter asked, “Which one’s new this time?” The trial ended when the child selected incorrectly or correctly selected nine pictures in a row.

APPENDIX E
COPYRIGHT PERMISSIONS

Permission for Figure 1

Door Apparatus from Berthier, N.E., DeBlois, S., Poirer, 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.

*Permission not required under APA Permissions Policy

APA Permissions Policy

APA supports the dissemination of information to aid in the development of science and scholarly research. APA also values and respects its own intellectual property as well as the intellectual property of others. As a result, APA believes it is essential for publishers of scholarly and other proprietary material to develop an efficient and consistent system, based on mutual trust, for granting permissions for both electronic and print publication of proprietary works. Therefore, APA adopts the following guidelines for the use of APA copyrighted content.

1. Permission Is Required for the following:

- A measure, scale, or instrument
- A video
- Full articles or book chapters
- Single text extracts of more than 400 words
- Series of text extracts that total more than 800 words
- More than three figures or tables from any one journal article
- More than three figures or tables from any one book chapter
- Placement of an abstract of a journal article in a database for subsequent redistribution
- Reuse of content from the public APA web site unless there is a copyright notice on that material stating otherwise
- Content essential to the character of the previously published book or article, when reuse could compromise the sale of the APA publication. Examples include complex illustrations, cartoons, maps, works of art, creative photographs.

This list is illustrative rather than exhaustive.

2. Permissions Not Granted

APA will not grant permission for use of the *Publication Manual of the American Psychological Association* or any portion of the Manual with the exception of the "Guidelines to Reduce Bias in Language" (pages 61–76).

3. Permission is Not Required for the following:

- a maximum of three figures or tables from a journal article or book chapter
- single text extracts of less than 400 words
- series of text extracts that total less than 800 words

No formal requests to APA or the author are required for the items in this clause.

Permission for Figure 2

From: Journals Rights [jrights@wiley.com]
Sent: Thursday, October 09, 2008 5:59 AM
To: Iris L. Price
Subject: RE: Permission to use Figures

Dear Iris L. Price,

Thank you for your email request. Permission is granted for you to use the material below for your thesis/dissertation subject to the usual acknowledgements and on the understanding that you will reapply for permission if you wish to distribute or publish your thesis/dissertation commercially.

Best wishes,

Lina Kopicaite

*Permissions Assistant
Wiley-Blackwell
9600 Garsington Road
Oxford OX4 2DQ
UK
Tel: +44 (0) 1865 476158
Fax: +44 (0) 1865 471158
Email: lkopicaite@wiley.com*

-----Original Message-----

From: Iris L. Price [mailto:irisprice@nsm.umass.edu]
Sent: 17 September 2008 16:45
To: Journals Rights
Subject: Permission to use Figures

Hello,

I am a graduate student at the University of Massachusetts in Amherst, MA USA. I am writing to request permission to use two figures from an article for my dissertation. In discussing the background of my own research I would like to include one figure from the following article.

Shutts, K., Keen, R., & Spelke, E.S. (2006). Object boundaries influence toddler's performance in a search task. *Developmental Science*, 9, 97-107.

The figure appears on page 100 of the original article. There are two columns of photographs there. I would only like to use the first two pictures in column 1 without altering them.

This would not be used for publication, but as a part of my dissertation.

My contact information is below. Please let me know if you need any more information.

Iris L. Price, Neuroscience & Behavior Doctoral Candidate
Psychology Department
524 Tobin Hall
University of Massachusetts - Amherst
135 Hicks Way
Amherst, MA 01003

E-mail: irisp@nsm.umass.edu

Telephone: 413-204-6759

Permission for Figure 3

Door Apparatus from Mash, C., Keen, R., & Berthier, N.E. (2003). Visual access and attention in two-year-olds' event reasoning and object search. *Infancy*, 4, 371-388.



Title: Visual Access and Attention in Two-Year-Olds' Event Reasoning and Object Search

Author: Clay Mash, Rachel Keen, Neil E. Berthier

Publication: *Infancy*

Publisher: Taylor & Francis

Date: Jan 8, 2003

Copyright © 2003 Psychology Press

Thesis/Dissertation Reuse Request

Taylor & Francis is pleased to offer reuses of its content for a thesis or dissertation free of charge contingent on resubmission of permission request if work is published.

REFERENCES

- Allain, P. Le Gall, D., Etcharry-Brouyx, F., Aubin, G., & Emile, J. (1999). Mental representation of knowledge following frontal-lobe lesion: dissociations on tasks using scripts. *Journal of Clinical and Experimental Neuropsychology*, 21, 643-665.
- Baddeley, A.D., & Hitch, G. J. (1974). Working Memory, In G.A. Bower (Ed.), *Recent advances in learning and motivation (Vol. 8, pp. 47-90)*, New York: Academic Press.
- Baddeley, A.D. (2000). The episodic buffer: A new component of working memory? *Trends in Cognitive Sciences*, 4, 417-422.
- Baillargeon, R., Spelke, E.S., & Wasserman, S. (1985). Object permanence in five-month old-infants. *Cognition*, 20, 191-208.
- Baird, A.A., Kagan, J., Gaudette, T., Walz, K.A., Hershlag, N., & Boas, D.A. (2002). Frontal lobe activation during object permanence: data from near-infrared spectroscopy. *Neuroimage*, 16, 1120-1126.
- Berthier, N.E., Bertenthal, B.I., Seaks, J.D., Sylvia, M.R., Johnson, R.L., & Clifton, R.K. (2001). Using Object Knowledge in Visual Tracking and Reaching. *Infancy*, 2, 257-284.
- Berthier, N.E., DeBlois, S., Poirer, 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.
- Butler, S.C., Berthier, N.E., & Clifton, R.K. (2002). Two-year-olds' search strategies and visual tracking in a hidden displacement task. *Developmental Psychology*, 38, 581-590
- Burnod, Y. (1991). Organizational levels of the cerebral cortex: an integrated model. *Acta Biotheoretical*. 39, 351-361.
- Damasio, A. R. (1995). In Structure and functions of the human prefrontal cortex. Grafman, J., Holyoak, K.J., & Boller, F. (Eds.)
- Della Sala, S., Gray, C., Baddeley, A., Allamano, N., & Wilson, L. (1999). Pattern span: a tool for unwinding visuo-spatial-memory. *Neuropsychologia*, 37, 1189-1199.
- Diamond, A., & Goldman-Rakic, P.S. (1989). Comparison of human infants and infant rhesus monkeys on Piaget's AB task: Evidence for dependence on dorsolateral prefrontal cortex. *Experimental Brain Research*, 74, 24-40.

- Diamond, A., Prevor, M.B., Callender, G., & Druin, D.P. (1997). Prefrontal cortex cognitive deficits in children treated early and continuously for PKU. *Monographs of the Society for Child Research*, 62 (4, Serial No. 252).
- Duncan, J. (2001) An adaptive coding model of neural function in prefrontal cortex. *Nature Reviews Neuroscience*, 2, 820-829.
- Durston, S., Thomas, K.M., Yang, Y., Ulug, A.M., Zimmerman, R.D., & Casey, B.J. (2002). A neural basis for the development of inhibitory control. *Developmental Science*, 5, F9-F16.
- Espy, K.A., Kaufmann, P.M., McDermid, M.D., & Glisky, M.L. (1999). Executive functioning in preschool children: Performance on A-not-B and other delayed response format tasks. *Brain and Cognition*, 41, 178-199.
- Funahashi, S., Bruce, C., & Goldman-Rakic, P. (1989). Mnemonic coding of visual space in the monkey's dorsolateral prefrontal cortex. *Journal of Neurophysiology*, 61:331-349.
- Fuster, J.M. (1997). *The Prefrontal Cortex: Anatomy, Physiology, and Neuropsychology of the frontal Lobe*. Raven: New York
- Gulgon, E., Grandguillaume, P., Otto, I., Boutkhal, L. & Burnod, Y. (1994). Neural network models of cortical functions based on the computational properties of the cerebral cortex. *Journal of Physiology*. 88, 291-308.
- Hood, B.M. (1995). Gravity rules for 2- to 4- Year-Olds? *Cognitive Development*, 10, 577-598.
- Hood, B.M., Santos, L., & Fieselman, S. (2000). Two-year-olds' naive predictions for horizontal trajectories. *Developmental Science*, 3, 328-332.
- Hood, B.M., Gjersoe, N. L., Waskett, J., & Leslie, A. M. (submitted). Minds and bodies: why do children fail search tasks in the physics and psychology domains?
- Huizinga, M., Dolan, C.V., & van der Molen, M.W. (2006). Age-related change in executive function: developmental trends and a latent variable analysis. *Neuropsychologia*, 44, 2017-2036.
- Huttenlocher, P., & Dabholkar, A.S. (1997). Developmental anatomy of prefrontal cortex. In N.A. Krasnegor, G.R. Lyon & P.S. Goldman-Rakic (Eds.), *Development of prefrontal cortex* (pp.69-83). Baltimore: Brookes.
- Johnson, M.H. (2005). *Developmental Cognitive Neuroscience* (pp146-157). Malden: Blackwell.

- Keen, R., Berthier, N., Sylvia, M.R., Butler, S., Prunty, P.K., & Baker, R.K. (2008). Toddler's use of cues in a search task. *Infant and Child Development*, 17, 249-267.
- Kloos, H., & Keen, R. (2005). An exploration of toddler's problems in a search task. *Infancy*, 7, 7-34.
- Koechlin, E., Corrado, G., Pietrini, P., & Grafman, J. (2000). Dissociating the role of the medial and lateral anterior prefrontal cortex in human planning. *Proceedings of the National Academy of Sciences*, 97, 7651-7656.
- Levy, D.A., Manns, J.R., Hopkins, R.O., Gold, J.J., Broadbent, N.J. & Squire, L.R. (2003). Impaired Visual and Odor Recognition Memory in Patients with Hippocampal Lesions. *Learning and Memory*, 10, 531-536.
- Luciana, M., & Nelson, C.A. (1998). The functional emergence of prefrontally-guided working memory systems in four-to-eight-year-old children. *Neuropsychologia*, 36, 273-293.
- Macdonald, A.W., Cohen, J.D., Stenger, V.A., & Carter, C. (2000). Dissociating the role of dorsolateral prefrontal and anterior cingulate cortex in cognitive control. *Science*, 288, 1835-1838.
- Mash, C., Keen, R., & Berthier, N. E. (2003). Visual access and attention in two-year-olds' event reasoning and object search. *Infancy*, 4, 371-388.
- Mash, C., Novak, E., Berthier, N.E., & Keen, R. (2006). What do two-year-olds understand about hidden-object events? *Developmental Psychology*, 42, 263-271.
- Miller, E.K., & Cohen, J.D. (2001). An integrative theory of prefrontal cortex function. *Annual Review of Neuroscience*. 24, 167-202.
- Murray, E.A., Bachevalier, J., & Mishkin, M. (1989). Effects of rhinal cortical lesions on visual recognition memory in rhesus monkeys. *Society for Neuroscience Abstracts*, 15, 342.
- Newcombe, N.S., & Huttenlocher, J. (2000). *Making Space: The development of spatial representation and reasoning*. The MIT Press: Cambridge.
- Norman, W., & Shallice, T. (1986). Attention to Action. In: Davidson RJ, Schwartz GE, Shapiro, D., editors, *Consciousness and self regulation: Advances in research and theory*, vol. 4. New York: Plenum, p. 1-18.
- Petrides, M. (1995). Impairments on nonspatial self-ordered and externally ordered working memory tasks after lesions of the mid-dorsal part of the lateral frontal cortex in monkey. *The Journal of Neuroscience*, 15, 359-375.

- Piaget, J. (1954). *The Construction of Reality in the Child* (M. Cook, Trans.). New York: Basic Books.
- Postle, B. (2006). Working memory as an emergent property of the mind and brain. *Neuroscience*, 139, 23-28.
- Quintana, J., & Fuster, J.M. (1999). From perception to action: Temporal integrative functions of prefrontal and parietal neurons. *Cerebral Cortex*, 9, 213-221.
- Repos, G., & Baddeley, A.D. (2006). The multi-component model of working memory: Explorations in experimental cognitive psychology. *Neuroscience*, 139, 5-21.
- Shallice, T. & Burgess, P. (1993). Supervisory control of action and thought selection. In Baddeley, A., editor, *Attention: Selection, awareness, and control: A tribute to Donald Broadbent*, pages 171-187. Oxford University Press.
- Shutts, K., Keen, R., & Spelke, E.S. (2006). Object boundaries influence toddler's performance in a search task. *Developmental Science*, 9, 97-107.
- Simpson, A., & Riggs, K.J. (2007). Under what conditions do young children have difficulty inhibiting manual actions? *Developmental Psychology*, 43, 417-428.
- Sirigu, A., Zalla, T., Pillon, B., Grafman, J., Aqid, Y., & Dubois, B. (1996). Encoding and boundaries of scripts following prefrontal lesions. *Cortex*, 32, 297-310.
- Spelke, E.R., Breinlinger, K., Macomber, J., & Jacobson, K. (1992). Origins of knowledge. *Psychological Review*, 99, 605-632.
- Squire, L.R., Zola-Morgan, S., & Chen, K.S. (1988). Human amnesia and animal models of amnesia: Performance of amnesic patients on tests designed for the monkey. *Behavioral Neuroscience*, 102, 210-221.
- Stern, C.E., Sherman, S.J., Kirchoff, B.A., Hasselmo, M.E. (2001). Medial temporal and prefrontal contributions to working memory tasks with novel and familiar stimuli. *Hippocampus*, 11, 337-346.
- Tsujimoto, S., Kuwajima, M., & Sawaguchi, T. (2007). Developmental fractionation of working memory and response inhibition during childhood. *Experimental Psychology*, 54, 30-37.
- Wang, S., Baillargeon, R., & Brueckner L. (2004). Young infants' reasoning about hidden objects: Evidence from violation-of-expectation tasks with test trials only. *Cognition*, 94, 167-198

- Wiebe, S.A., Espy, K.A., Charak, D. (2008). Using confirmatory factor analysis to understand executive control in preschool children: I. Latent structure. *Developmental Psychology*, 44, 575-587.
- Wood, J.N., & Grafman, J. (2003). Human prefrontal cortex: Processing and representational perspectives. *Nature Reviews Neuroscience*, 4, 139-147.
- Zola-Morgan, S., Squire, L.R., & Amaral, D.G. (1989). Lesions of the perirhinal and parahippocampal cortex that spare the amygdala and hippocampal formation produce severe memory impairment. *Journal of Neuroscience*, 9, 4355-4370.