INIHIBITION AND WORKING MEMORY CONTRIBUTIONS TO CHILDREN'S TOWER OF LONDON PERFORMANCE

By

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of the University of Florida in Partial Fulfillment of the
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The Tower of London (TOL), a goal directed problem solving task, is recognized as a useful tool to measure Executive Functioning (EF). The purpose of the current study was twofold. The first objective was to expand our understanding of how normally developing children perform on the TOL task as an EF measure. The second, and major focus of the study, was to examine what cognitive processes are devoted to performance on the TOL as there remains debate as to what cognitive constructs make up EF. Children 3- to 6-years-old were given the TOL, the Day-Night Stroop, and the spatial N-back to look at the extent to which inhibition and working memory (WM) contribute to TOL performance in young children. In regard to the first goal, the results demonstrated that there are age related increases in TOL performance as older children are more accurate and make fewer extra moves when solving TOL problems. To the second goal, the overall results demonstrated that the ability to successfully inhibit a prepotent response is necessary for successful TOL performance in young children. A final model showed that

inhibition but not WM significantly predicted TOL performance with age controlled. This demonstrated that at least for children, good inhibitory control may be the key to successful TOL performance.

CHAPTER 1
INTRODUCTION

To carry out flexible problem solving a host of cognitive resources are required including goal-directed behavior, selective attention, planning, response inhibition, and working memory maintenance-- or together, executive functions (EF). Tower transfer tasks (Tower of London and Tower of Hanoi) are commonly used to evaluate problem solving skills and to a larger extent EF in young children (Bull, Espy, & Senn, 2004). As the pool of EF literature swells many different higher order cognitive skills are cited as being crucial to EF skill level (Bull et al., 2004; Dowsett & Livesey, 2000; Miyake et al., 2000, for reviews). The Tower of London (TOL) measures EF through the evaluation of goal directed behavior. The TOL is a spatial object transformation task in which the participant is required to rearrange a set of three balls on pegs to match those on a goal board within the fewest number of moves (Berg & Byrd, 2002, for review).

As a complex problem solving task, the TOL likely involves the use of a number of EFs. To understand the ability to perform this task it is important to evaluate these underlying components (Welsh, Satterlee-Cartmell, & Stine, 1999). Therefore, the purpose of the present study is to identify of two distinct and important EFs, ability to inhibit prepotent responses and ability to manipulate items in working memory, that are likely to contribute to successful performance on the TOL task.

One important consideration in EF tasks is its neural underpinnings. It has been recognized that the prefrontal cortex (PFC) is the main locus of control for many EF abilities and this is most apparent when participants with damaged frontal areas are tested

on EF tasks like the TOL (Carlin et al., 2000; Shallice, 1982) and Wisconsin Card Sort (Kimberg & Farah, 1993). These deficits are also demonstrated on component processes such as inhibition (Luria, 1966) and working memory (Levin et al., 2002). The protracted development of the PFC makes incorporating and integrating the processes that make up executive functions for effective problem solving a major challenge for young children (Fuster, 1989). Similarly, poor EF performance has been noted in normal young children on EF tasks such as the TOL (Anderson, Anderson, & Lajoie, 1996), and Wisconsin Card Sort (Welsh & Pennington, 1988). However, little consideration is made to the details of children's poor EF abilities, especially concerning the component processes that may contribute to their difficulty with EF tasks. In fact, Espy, Kaufmann, Glisky, and McDiarmid (2001) advocate a need to distinguish specific cognitive profiles of young children. As Espy et al. explains, it is important to determine any detriment that may be apparent in EF ability in the critical preschool years so to provide intervention early. Further, the ability to catch delays early before the entry into formal schooling is particularly advantageous.

A wide range of behaviors seem to be affected by EF in childhood including ADHD (Sonuga-Barke, Dalen, Daley, & Remington, 2002), mathematical ability (Bull & Scerif, 2001), and certain neurodevelopmental disorders (Ozonoff & Jensen, 1999) therefore it seems necessary that its development is fully tracked and understood by researchers. However, very few studies attempt to examine EF before the age of 7-years-old; especially overlooked is the toddler to young childhood age range (Welsh & Pennington, 1988); furthermore there are even fewer studies that examine normal development in this age range. A primary reason for the lack of research is the dearth of

developmentally appropriate EF measures. It is also the case that those tasks that are used to determine EF ability, like the TOL have not been formally evaluated extensively enough to understand what cognitive components are being measured by them (Phillips, Wynn, Gilhooly, Della Sala, & Logie, 1999; Welsh et al., 1999). As researchers both continue and begin to explore the significance of the frontal cortex in EF, it is important to identify developmentally appropriate tasks that are useful to examine the development of EF and to fully understand the cognitive components of these tasks.

Fuster (1989) noted three aspects of EF that come together to interact and produce goal-directed behavior. These are working memory, planning, and inhibition. Many EF tasks are assumed to tap each of these cognitive processes, to one extent or another, to generate an estimate of the participant's overall EF ability (Miyake et al., 2000). The steps required to provide accurate and efficient solutions to TOL problems very likely include inhibition and working memory processes as well as planning components. The TOL spatial problem solving task, with its transformation from a starting position to a goal position, very likely also involves both working memory and inhibition, though to what extent they are important and there relative contributions has only begun to be assessed. Working memory is important to keep intermediate moves goal focused, while response inhibition is needed to generate correct intermediate moves, some of which may be counterintuitive, or moves into a non goal position. It is reasonable to hypothesize that the contribution of these components are needed to produce effective solutions by all participant populations including young, old, clinical, and normal.

The TOL is particularly useful as a measure of EF in children because the procedure presents researchers with the opportunity to incorporate a variety of difficulty

levels (Shallice, 1982). This keeps the game challenging for various ages, with even younger children having success at initial problems (MacDonald, Garner, & Spurgeon, 2002). Most TOL problems given to children can be solved well within two minutes. The ability to arrive at a solution quickly and receive feedback is compatible with young children's attentional capacities.

In sum, although the TOL is a common tool in use throughout the EF literature on clinical (Carlin et al., 2000; Levin et al., 2002; Levin et al., 1996) and non clinical (Anderson et al., 1996; Krikorian, Bartok, & Gay, 1994; Welsh et al., 1999) studies, very few studies have empirically evaluated the validity of the accompanying assumptions that are made concerning what cognitive processes contribute to task performance. In particular, it would be useful to know what role inhibition and working memory play on the TOL performance as these components seem to be large threads of the EF braid.

Inhibition

To demonstrate accurate goal directed behavior one must be able to ignore what may be irrelevant or extraneous information to focus on the relevant information needed to obtain the goal. Young children have difficulty exerting control over what they do and there is a fair amount of evidence that this control especially improves between the ages of 3 and 6 (Diamond & Taylor, 1996; Gerstadt, Hong, & Diamond, 1994; Kochanska, Murray, Jacques, Koenig, & Vandegeest, 1996).

As a component of EF, inhibition is required to suppress an inappropriate immediate response or response tendency. Dowsett and Livesy (2000) suggested that because inhibition plays a role in a number of EF tasks, EF training should result in increased inhibitory control in children that initially displayed poor inhibitory control. In their study Dowsett and Livesy divided a sample of 3- to 5- year old children into

“inhibitors” and “noninhibiting” as defined by performance on a go-no-go discrimination learning task. This task consisted of an apparatus that the children were instructed to press a bar when a light was lit red (go) and not when it was lit blue (no-go). After splitting the children into groups the noninhibiting were subjected to either training on two EF tasks (Wisconsin Card Sort and a change paradigm) or practice on the go-no-go discrimination learning task. Results of their study revealed that exposure to tasks that require EF abilities significantly improved the young children’s inhibitory performance. In fact, 12 out of the 15 noninhibiting children were showing performance equal to that of the inhibitors upon retesting. It was concluded by the researchers that inhibitory skills are central to EF processes.

A task commonly used to measure inhibition in adults and older children is the classic color/ word Stroop task (Stroop, 1935). The color/word Stroop takes a relatively automatic response, reading, and pits it against the perceptual cue of the words ink color. Inhibition is required during the interference condition in which the participant is required to name the ink color when the color word is conflicting. Therefore, the inhibition can be measured as the number of incorrect responses given by the participant and/or the slower responding during the interference condition.

The original Stroop task was designed to measure inhibition of a verbalized reading response, as the participant reads the ink color of the word aloud. Variations of the original color/ word Stroop have been developed that do not involve a reading response and instead requires inhibition of a motor response (Carlson & Moses, 2001). The use of a pictured stimulus rather than a word in this task improves the task for use with younger children in that it removes the reading requirement. The Day/ Night Stroop is a simplified

version of the original Stroop in which during the interference condition the participant is shown “day” cards instructed to respond by pointing to a picture of night, and shown “night” cards and instructed to point to a picture of day. Therefore, a Stoop effect is produced in that the participant must inhibit a natural tendency to select the visually matching stimulus and instead select the opposite stimulus. The Day/ Night Stroop task was originally used by Passler, Issac, and Hynd (1985) to demonstrate the development of inhibitory ability of children 6- to 12-years-old. Passler et al. (1985) suggested that inhibition develops in a stepwise multistage process that achieves control contemporaneously with the maturity of the frontal lobes.

To allow for successful planning when solving the TOL motor inhibition is required before most moves, but particularly to repress the desire to move the balls directly in the goal position when this is not optimal response. That is, the response inhibitory process is especially taxed when solving problems involving such counterintuitive moves. The counterintuitive problems, although they may contain as little as three moves, are ones that require the initial placement of a ball in a non-goal position before being able to place that ball in its final goal position on a subsequent move. This is counterintuitive because it may temporarily move the problem solver away from the goal. The failure to inhibit the more obvious move due to poor inhibitory control will result in excess moves or inaccurate solutions. These types of problems also create situations in which rule violations are common because the child seems unable to try the counterintuitive alternative and instead chooses to attempt a perhaps more intuitive albeit illegal solution to the dilemma.

Working Memory

Working memory (WM) is involved on a number of executive or frontal lobe tasks, particularly those that require planning. Most EF tasks require the participant to actively monitor his or her progression throughout the task, holding a subset of events in memory, and then making updates to those events to optimize their responses (Phillips et al., 1999; Roberts, Hager, & Heron, 1994). In the TOL task, planning toward a goal requires the WM on-line revision mechanism to constantly maintain the goal relative to the starting position.

Age differences in the role of WM in TOL performance among adults was examined by Phillips, Gilhooly, Logie, Della Sala, and Wynn (2003) in a comparison of older (60- to 76-yeas old) and younger adults (18- to 30-years old). Phillips et al. (2003) used a dual task paradigm to analyze different three aspects of WM (Baddeley, 1986 for review), executive, phonological (articulatory suppression and verbal random generation), and visospatial (spatial pattern and spatial random tapping) for effects on TOL performance. They hypothesized that age differences in the role of WM would suggest that the TOL makes different cognitive demands on different age groups. The results showed that TOL performance was impaired more for younger adults when the dual task was high on executive load whereas for older adults executive load did not impair TOL performance. This pattern of results were opposite when looking at the visospatial dual task disruption. Here older adults faired worse than younger under dual tasks of TOL solving and spatial memory tasks. The results supported their hypothesis and showed when cognitive limitations are pushed there are developmental differences in the detriments on TOL performance for older and younger adults. These data demonstrate

that TOL performance may extract different cognitive abilities depending on the age of the participant.

The N-back is a WM task that requires the participant to process some information or rule that dictates the response to a given set of task stimuli (i.e., letters, numbers, or objects). The objective of the task is to test the ability to hold and monitor information, like a rule, as while assessing each piece of subsequent information. The rule can be manipulated to create different levels of difficultly; 0-back, l-back, or 2-back. For example, Levin et al. (2002) tested traumatic brain injured children ages 6- to 8-years-old using a letter identity N-back. The rule in this case depended on the condition either being that a target letter must be responded to (0-back condition), or a response must be made when a match appears to a letter displayed 1-back, 2-back, or 3-back. Levin and colleagues concluded by noting the applicability of the N-back task for use with children to test prefrontal WM abilities. Instead of a letter identity N-back, Thomas et al. (1999) used a spatial N-back to test WM in 8- to 10-year old children. For this task, participants were presented with a screen displaying four squares and a button box with four corresponding keys. The rule given was to match the location in which the dot appeared *n* trials back in the middle of any given square upon presentation by pressing the correct corresponding button. This method is similar to the one being used in the current study as described below.

There is evidence that spatial WM in particular makes a considerable contribution to TOL performance. A link with TOL performance and spatial working memory in children was established by Lehto, Juujarvi, Kooistra, and Pulkkinen (2003). Here, Lehto et al. tested 8- to 13-year-olds and found a significant correlation between proportion of

perfect solutions of the TOL and spatial working memory. Although not the main goal of the study, age effects were found with the TOL but not spatial working memory. However, a significant correlation between age and spatial working memory demonstrated that there were improvements with age.

Contributions of Inhibition and Working Memory

Welsh et al. (1999) examined the proportional contribution of inhibition and working memory to EF performance for adults as measured by the TOL. For this study, participants received 4- to 6-move problems on the TOL, two tests of inhibition and two tests of working memory. The inhibition tasks used color/word Stroop and the Contingency Naming Test. The working memory tasks used were the Visual Memory Span and the Spatial Working Memory Test. In general the study found that both inhibition and working memory performance explained over half of the TOL performance variance. Although both inhibition and working significantly contributed to TOL performance the relationships among the tasks were uniquely different. First it should be noted that spatial working memory (r = .61) held a higher correlation than visual working memory (r = .49). Also it is interesting to point out that of the two inhibition tasks used by Welsh et al., the color/ word Stroop task (r = .40) held a significant relationship whereas the Contingency Naming Test was not related (r = .06) with TOL performance. The authors suggested that this difference may be because the inhibition tasks selected for were measuring different *kinds* of inhibition. I will return to this issue in the Discussion.

This study by Welsh et al. (1999) demonstrates the cognitive contribution to TOL performance in normal adults, whom are generally noted to have high EF abilities as maturation has reached a relatively pinnacle state. It is important to understand the

development of EF as it begins early in life and continues throughout adulthood. This expansive developmental period is due to the ongoing cognitive changes that occur as the frontal lobes mature, leading to improved inhibition, planning, mental representation of tasks and goals, and hence improved general EF performance. This maturational process presents the opportunity to study EF and how the behaviors and responses under its control are affected by development.

In a recent study Rebbeca Bull et al. (2004) sought to replicate the Welsh et al. (1999) study with a sample of preschoolers. Here Bull et al. gave normal children between the ages of 3- and 6-years-old TOL and TOH (Tower of Hanoi, a similar tower transfer task) problems along with a short term memory task, and an inhibition and shifting task. The main focus of this study was not developmental, but was, like the Welsh et al. study, to explore the contributions short-term memory and inhibition make to TOL and TOH performance. Because working with young children imposes greater session length time constraints than working with young adults, instead of giving participants two of each memory and Inhibition tasks like Welsh et al. did, this study gave one of each. The WM task given was a short-term memory digit span task, and the inhibition task was a task that combined an inhibition and shifting condition. The inhibition condition resembles a go-no-go task in which the child must name (based on the color of the character) a line of characters that show expressions of happiness in the picture, but not the ones that express sadness as fast as they can. The shift condition added another dimension to the response contingency, shape. Here the children had to name the character based on the color if the character without a hat and based on shape if the character had a hat. Results showed that inhibition and shifting successfully predicted

TOL performance, whereas short-term memory performance did not. In contrast, the Welsh et al study with adults described earlier suggested that for adults it was WM that was the greater contributor. Unfortunately, the two studies used quite different measures of inhibition and WM. Therefore, although this study yielded interesting results, it would be important to see what kinds of comparisons can be made when the tasks more closely resemble those given by Welsh et al. (WM instead of short-term memory) so that conclusions can be better compared across development.

Overall, from the data presented it is reasonable to suggest a contribution of both spatial WM and inhibition to TOL performance in adults. However, there is still insufficient evidence to confidently conclude that there is a significant contribution of both inhibition and WM to TOL performance in young children. Furthermore, the question remains as to what similarities in children's TOL performance could be drawn that from that reported previously for adults. The reason for the paucity of evidence for children is twofold. First, most studies that involve EF, inhibition, and WM are not based on normal populations and consequently include small sample sizes. The second reason is that most EF, inhibition, and WM studies do not include very young children in the sample. The majority of these studies begin the youngest sampling at 7-years-old although tasks such as the TOL, Day-Night Stroop, and spatial N-back are noted as suitable for children much younger (Gerstadt et al., 1994; Levin et al., 2002; Welsh & Pennington, 1988).

Therefore, the current study will explore the extent to which two main cognitive processes, inhibitory control and spatial WM, contribute to EF performance as measured by the TOL. Although the TOL is frequently used as a task to measure EF ability, many

questions remain regarding the cognitive components that contribute to task performance. The study will also fill a gap in the current literature by providing normal developmental data for children younger than 7-years-old. The current study will contribute by attempting to answer a number of questions, including: (a) How does inhibition and spatial WM contribute to TOL performance for young children? (b) Will young children's TOL performance show higher correlations with WM than inhibition performance as the adults' did according to Welsh et al. (1999) findings? And (c) how does development affect TOL performance within the 3- to 6-year-old age range?

CHAPTER 2
METHOD

Participants

Participants between 3- to 6-years-old (*N* = 43, range from 41 months to 69 months) were recruited from preschools throughout the local Gainesville community. The preschools sampled were chosen in an effort to represent of a wide range of socio economic and education levels. There were slightly fewer girls (*n* = 16) than boys (*n* = 27) sampled. Children were excluded if they have ever been professionally diagnosed with ADHD, a learning disorder, or tested as gifted based on prescreening questions on the participant consent form filled out by the child's guardian. The participant was tested for handedness at the beginning of the session and then encouraged to use the dominant hand throughout the session. All participants were treated according to the published APA recommendations for ethical treatment of participants (American Psychological Association, 1992).

Procedure

The total procedure took no longer than 45 minutes per participant. Participants were rewarded with stickers at the end of each session. All participants were presented the tasks in the order of Spatial N-back, Boxes task, TOL, and finally Day/Night Stroop. Through pilot testing it became apparent that the Spatial N-back was the most challenging task for the children. By placing it first the author thought it would be minimally affected by fatigue. Also placing the TOL in the middle allowed a break from the computer tasks to help keep the children interested. All tasks, with the exception of

the TOL, were presented on a touch screen computer. The screen was placed directly in front of the child on the floor while the child sat with their legs crisscrossed. This was a natural, comfortable position for the child.

TOL

All participants performing the TOL were videotaped for later scoring of details of moves made. The camera was arranged behind the participant with an over-the-shoulder view to record the action of both hands and to reduce distraction.

The TOL consisted of two identical game boards and one “done” button. The two game boards, one participant board and one experimenter board, were each made up of three descending pegs tall, medium, and short, which accommodated three, two, and one, equally sized wooden balls colored, red, green, and blue, respectively (7.62 cm in diameter). The pegs were mounted on a wooden game board (40 cm x 9 cm). To play, the participant moved the balls on the pegs of the participant board to mach the goal state as shown by the experimenter’s board. After solving a problem the child was instructed to press the “done” button. The “done” button is a dummy button that served two functions. First, during the testing session, it indicated to the experimenter that the participant was finished solving the problem, and it also became important for subsequent scoring from video tape (Results section). The button was placed to the right or left of the game board depending on the child’s handedness as tested at the beginning the session.

There were 12 TOL test problems, ranging in difficulty from problems that take 2-moves to 5-moves to solve. The 12 test problems were presented in 3 blocks. Each block contained four problems increasing in difficulty level (2-move, 3-move, 4-move, and 5-move). Each move level is indicative of the minimum number of moves it takes to solve each problem. The participant had a maximum of 2-minutes to solve each problem. If the

child could not finish within the 2-minute period they skipped that problem and moved on to the next.

The experimenter first explained all instructions and gave examples of the rule violations as they were explained (Appendix for full task procedure). The experimenter then walked through a demonstration of how to solve a 2-move problem with the child while specifically explaining the goal of task, how to move toward the goal, and the rule violations. There were three rules the participants were required to adhere to: (a) only one ball can be moved at a time; (b) a ball can be placed only on a peg, and; (c) each peg is limited to the number of balls that can be placed on it: three balls on the largest peg, two balls on the middle peg, and one ball on the smallest peg. Then the participant is given two practice problems to do on their own, one 2-move and one 3-move. The child was required to pass both of the practice problems within two attempts before moving to the test session. If the child failed after the second try, they were excluded from TOL testing. However, no children in the current study that failed either practice problem.

During the testing session, each problem proceeded until either the child hit the “done” button, the maximum time elapsed, or the child violated a rule. If a child did begin to violate a rule, the child’s movement was immediately stopped and redirected. For example, if a child began to move two balls at one time (a rule violation), the experimenter stopped the child after the balls were picked up, but before the action was completed. The balls were then returned to the original position and the child was verbally reminded of the violation and asked to continue solving without making another violation. This method restricted the participant from using violations to solve the

problems, but allowed the researcher to track their occurrence. Movements during the violation did not contribute to any time or move measures.

Day-Night Stroop

The participant performed this task entirely on a touch screen computer (Figure 2-1). For the current study only the interference condition, being the condition which required a non-matching versus a matching response when shown a “day” or night” card, was presented (Appendix for full task procedure).

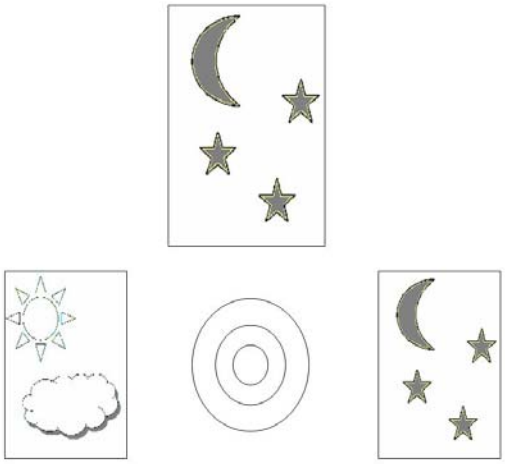

Figure 2-1 Day-Night Stroop presentation on computer

The following Day-Night Stroop testing methods were an adaptation of Carlson and Moses (2001) and Gerstadt et al. (1999). Following an explanation of the task to the child, there were two (one Day, one Night) practice trials that included the prompt “What do you touch when you see this card?” and feedback. The next two trials (one Day, one Night) were pre-test trials. Like the subsequent test trials, these did not include a prompt, but the pre-test trials did include verbal feedback. The participant had to pass both of the pre-test trials, thus demonstrating knowledge of task instructions, to be included in the testing session. If a child failed any pre-test trials, they were excluded from the Day-

Night Stroop testing, but were included in other tasks. There were no children in the current study that failed the pre-test. The pretest was followed by 16 test trials.

The computer program presented an equal number of each “day” and “night” cards in a pseudorandom order identical to that given in Gerstadt et al. (1999). The position of the day and night cards, right or left side, on the touch screen for the participant to choose was also randomized to reduce response biases. A bulls-eye was positioned between and below the cards on the screen. The children were instructed to rest the selection finger in the middle of the bulls-eye in between trials. This served to avoid anticipatory responding and to standardize the distance through which the response was made. Response timing for the selection of a card on each trial began when a new card appeared and ended when the child selected a day or night card.

Spatial N-back

The version of the spatial N-back was adapted from Thomas et al. (1999) and Levin et al. (2002) with the modifications made for use with younger children (Appendix for full task procedure). The stimuli for this task are three squares centered in the middle of the touch screen (Figure 2 for an accurate depiction of the screen layout).

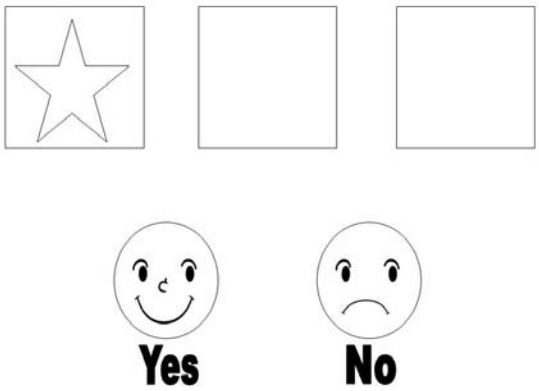

Figure 2-2 Spatial N-back presentation on touch-screen computer

The response buttons, one green smiley face and one red unhappy face, were centered under the squares on the screen. Inside any one of the squares, a star can appear. For the 0-back condition, a randomly defined “target” square was identified for the child as being in the right, left, or middle location. The target remained the same throughout the 0-back condition. After the child was shown which square was their target square, they were asked to indicate if the current spatial location of the star matches the target square identified at the beginning. This served as a check to determine if the child could remember the target location. Under this 0-back condition, if the star showed up in the target square the child was instructed to press the green smiley face. If the star was not in the target square the red unhappy face must be selected. For the 1-back condition, no predesignated star position was indicated. Instead, the child was instructed to press the green smiley face when the star, “stayed still” and was in the same square as on the previous trial. If the star “moved” and was in a different square than the previous trial the child was instructed to press the red unhappy face. For all trials, the star appeared every two seconds for 500 ms maximum or until the child made a response by selecting either the smiley face or unhappy face. Thus, all conditions a response was required on every trial. The conditions followed sequentially in order of increasing difficulty beginning with 0-back and proceeding through 1-back. Please see the Appendix for details of task administration.

The general N-back task instructions were followed by the 0-back condition instructions and 10 practice problems. The practice problems differed from the test problems in that they included verbal feedback from the experimenter and they did not have the 500 ms response time restraint. Following the practice problems, 21 test trials

were given of the 0-back condition. Then, instructions and10 practice problems were given for the 1-back condition, followed by the corresponding 21 test trials. Of the 21 test trials in each condition, 9 were target (location matched) trials and 12 were distracter (location not matched) trials.

Boxes Task

Although the Boxes task was presented, due to technical limitations the task results were not analyzed. See the Appendix for a full description of the task.

CHAPTER 3
RESULTS

Generally, analyses consisted of t-tests and ANOVAs to examine age effects within all tasks. The participants were placed by age at testing into three groups; 3-year-olds (range: 41- 47 months, *n* = 7), 4-year-olds (49-59 months, *n* = 25), and 5-year-olds (60-69 months, *n* = 11). Regressions and correlations were run to determine the relationships between and within tasks and specifically to assess the contribution of inhibition and working memory to TOL performance. Not all children were included in each analysis. One child did not want to play the TOL, and three children refused to play the N-back. All children completed the Stroop. Specific ns are provided below for the various sets of analyses.

Tower of London

All test problems were video taped and subsequent to testing were coded by having a trained laboratory assistant "play along" with the video to replicate the child's moves. Watching the tape, the assistant did the "play along" using a computerized simulation of the TOL task. This then provided a computer record of not only which moves were made, but also the timing of each move. Rule violations including picking up two balls at one time, putting a ball somewhere other than on a peg, or exceeding the maximum amount of balls that the peg can hold were manually recorded during video replays. Violations were coded as either present or absent on each problem. The interrater reliability was determined from a sample subset of 17. Interrater agreement for timing accuracy to within 1.0 s per move was calculated at 97% for this sample. Interrater reliability at 100

% agreement was achieved for the sample in determining the execution of rule violations and 99% for the number of moves that were made.

For analysis of variance, the independent variables were age and problem difficulty level consisting of four levels. The difficulty level was determined by minimum number of moves (2- move, 3- move, 4- move, and 5- move) required to solve the problem. The primary dependent variables are percent perfectly solved (that is, solved within the minimum amount of moves), and on those problems solved perfectly or not, extra moves, latency to the first move, total time, and frequency of rule violations. The sample size for this analysis was 42. See Table 3-1 for TOL results overview.

Table 3-1 TOL average results by difficulty level

	TOL Difficulty Level (Minimum Number of Moves)			
	2	3	4	5
Percent Solved Correctly	.89 (.19)	.68 (.29)	.66 (.38)	.44 (.34)
First Move Time	6.09 (2.77)	7.46 (4.26)	9.17 (6.28)	8.41 (4.35)
Extra Moves	.37 (.89)	.26 (.56)	.63 (1.33)	.99 (2.24)

Perfect Solution Accuracy

An age by difficulty level repeated measures ANOVA revealed both a main effect of difficulty level, $F(3, 117) = 18.05$, $p < .001$, and of age, $F(2, 39) = 4.54$, $p < .05$, but no interaction effect (Figure 3-1).

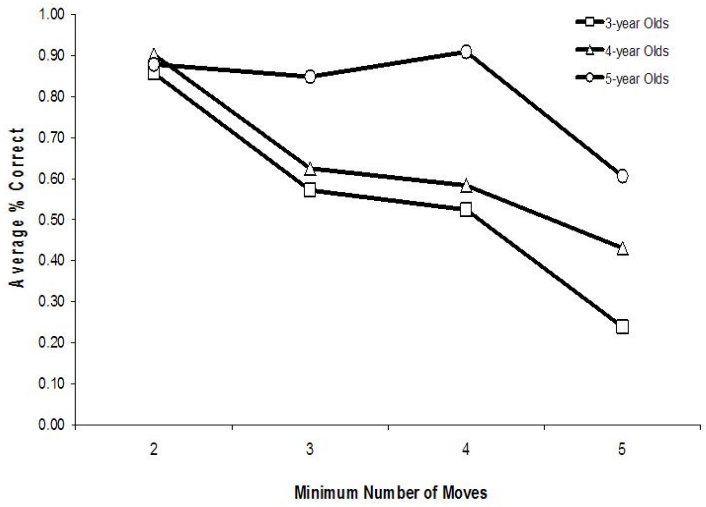

Figure 3-1 Average percent correct by difficulty level for each age group

Follow-up t-tests were run to analyze the overall differences in performance between successive difficulty levels. Results generally suggested that accuracy decreases as difficulty level goes up at each level, $p < .01$, with the exception of 3-move and 4-move problems (Table 3-1).

When the effects of age were analyzed more closely it was revealed that significant differences existed among 3- and 5-year-olds' performance, $t(16) = 3.51$, $p < .01$, and between 4- and 5-year olds' performance $t(16) = 2.50$, $p < .05$.

First Move Time

As with the perfect solves analysis, first move time the analysis revealed a main effect of difficulty level ($F(3, 81) = 3.70$, $p < .05$), a main effect of age ($F(2, 27) = 3.99$, $p < .05$), but unlike the analysis of perfect solves, there was a significant interaction of age and difficulty level ($F(6, 81) = 2.86$, $p < .05$).

In general, as difficulty level increases all children took more time to begin problem solving. However, overall the older the children took less time before beginning

to solve. To explain the interaction, t-tests were run to compare 3-, 4-, and 5-year-olds first move time at each difficulty level. It was noted that differences in first move time occur on 2-move and 3-move problems between 3- and 4-year-olds and between 3- and 5-year-olds and on the easiest 2-move problems for 4- and 5-year-olds (all $p < .05$). Interestingly there were no significant differences between first move times on 4- or 5-move problems upon each age comparison. However, there is a marked decrease in first move time for those 3-year-olds who solved 5-move problems from their 4-move first move time. Only 5 of the 7 three year-olds were able to solve the 5-move problems which may have dampened a potential significant effect.

Extra Moves

When extra moves were considered, more extra moves were made on the most difficult problems ($F(3, 87) = 5.41$, $p < .01$). As predicted, a main effect of age shows that younger children also made more extra moves overall ($F(2, 29) = 7.44$, $p < .01$). However, follow up t-tests showed that this difference was significant for 3- and 4-year-olds, and 3- and 5-year-olds, but not for 4- and 5-year-olds. There were no interactions produced between age and difficult level for extra moves.

Rule Violations

The occurrence of violations did not follow the expected trend as there were no significant effects of age or difficulty level.

Day-Night Stroop

For these analyses, age served as the independent variable ($n = 43$) and the dependent variables were percent correct and average latency of the last eight trials of the session. Preliminary analysis showed that the last half of the test trials represented the most challenging trials (Figure 3-2).

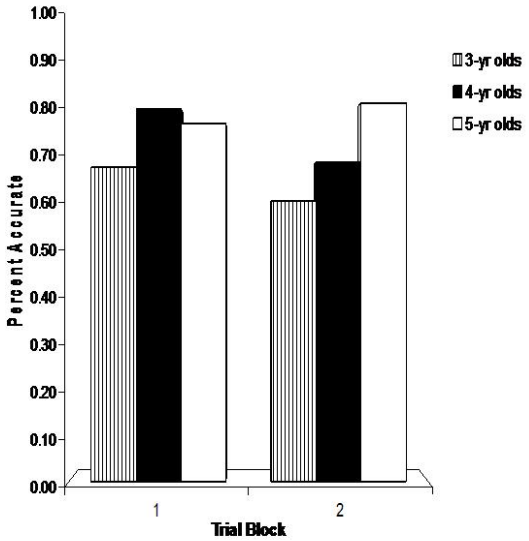

Figure 3-2 Average percent correct for each trial block by age group

This was shown by a significant effect of trial block when it was found that the participants were significantly more successful on the first 8 trials (M = .77, SD = .24) compared to the last eight trials (M = .71, SD = .32), $t(42) = 2.08$, $p < .05$. Furthermore, the first 8 trials did not produce an age effect. Taking this information into consideration all remaining analysis was conducted on the last 8 trials of the Stroop. No age effects were demonstrated upon an Analysis of Variance of age on these last eight trials ($F(1, 39) = .096$, $p > .05$), though mean data did suggest that older children performed outperformed younger children on these trials, 3-year-olds (M = .61, SD = .32), 4-year-olds (M = .69, SD = .34), and 5-year-olds (M = .82, SD = .32) (Table 2).

As with percent correct, there were no significant differences in response latency upon analysis.

Spatial N-back

Like the Stroop, for all children the easier 0-back condition (*M* = .69, *SD* = .21) proved to be significantly easier than the more challenging 1-back (*M* = .52, *SD* = .27), *t* = 3.63, *p* < .01. Therefore, the N-back was analyzed using only performance on the most challenging level, the 1-back (*n* = 40). The age analysis a Univariate ANOVA examined the dependent variable percent correct responses on the 1-back and age. The analysis revealed a trend for age, $F(2, 43) = 2.98$, $p = .06$. Descriptive statistics for means showed that 5-year-olds (*M* = .65) performed better than both 3- and 4-year-olds (*Ms* = .43, .48; respectively) (Table 3-2). Due to program error, the response times were not recorded accurately and were not analyzed.

Table 3-2 Average results for all tasks by age group

Measure	3-year-olds n = 7	4-year-olds n = 25	5-year-olds n = 11	Total n = 43
TOL (Percent Solved Correctly)	.55 (.22)	.64 (.22)	.81 (.10)	.68 (.21)
Stroop	.61 (.27)	.69 (.34)	.82 (.32)	.71 (.33)
Spatial N-back	.44 (.26)	.49 (.19)	.65 (.20)	.55 (.21)

Inter-Task Relationships

If the TOL task requires both an ability to inhibit ineffective moves and working memory, as predicted, performance on the Day-Night Stroop and the spatial N-back

should correlate positively with TOL performance. If the TOL demands similar cognitive processes in children as for adults, a test of regression model that includes both Stroop and N-back regressions on TOL should indicate that both inhibition and WM explain a significant amount of TOL performance variance replicating the results of Welsh et al. (1999) with adults. There are no hypotheses regarding the extent to which either inhibition or WM contribute independently.

For all inter-task relationships the most challenging aspects of each measure was examined, last 8 trials of the Stroop, the 1-back level of the N-back, and percent of perfectly solved 4-and 5-move TOL. This approach was taken so that difficulty level between tasks could be relatively controlled. This is not to say that there are still no inherent difficulty differences between the tasks, but that this difference will be minimized. Percent correct for all tasks were run under bivariate correlations to examine the relationship among all tasks.

Cross correlations of all three tasks variables (Table 3-3) showed that though all bivariate correlations were positive, only Stroop and TOL correlation was significant, $r = .39$, $p < .05$.

Table 3-3 Correlation matrix for all tasks and age

	TOL	N-back	Stroop	Age (months)
TOL		.245	.391*	.450**
N-back			.202	.281
Stroop				.173
Age (months)				

*p < .05
**p < .01

Because age and TOL are highly correlated (r = .45, p <.05), a partial correlation was performed to see if the relationship still held with the effects of age controlled. TOL and Stroop remained positively correlated, r = .41, p < .05, and slight improvement over the simple bivariate correlation. Performance on the N-back held a positive, but non-significant relationship with both Stroop, r = .20, and TOL, r = .25 without controlling for age. The correlation coefficients are even further reduced when age is controlled, N-back and Stroop, r = .11, and N-back and TOL, r = .15.

To assess the combined effects of variables as predictors of TOL performance, age, percent accuracy for Stroop, and percent accuracy for N-back were analyzed in a forced entry linear regression model for their ability to predict perfect solution accuracy on the most difficult TOL, 4-move and 5-move, problems. First the variables were considered for any independent contribution. Analysis revealed that performance on the Stroop

significantly predicted 15% of TOL performance variance, $R^2 = .15$, $F(1, 42) = 7.22$, $p < .05$, $\beta = .35$.

N-back performance did not predict TOL performance, $R^2 = .06$, $F(1, 39) = 2.36$, $\beta = .34$, $p > .05$. To remove any effect of age the analysis were run again with age in included in the model for each variable independently. A forced entry method was chosen so age could enter in the first position and the $R^2\triangle$ could be examined to determine the amount of variance in TOL performance is explained after removing age. The model with age included showed that Stroop now contributed 31%, $R^2\triangle = .10$ to the variance observed in TOL performance when age was removed. This model is significant, $F(2, 41) = 5.77$, $p < .05$. A test of the model's standardized regression coefficients showed that they are significantly different than zero, Age: $\beta = .02$, $p < .01$; Stroop: $\beta = .29$, $p < .05$. Like the Stroop, when age effects were removed first, N-back contributed more to TOL performance variance, $R^2 = .19$ with age removed, resulting in a significant model, $F(2, 38) = 4.08$, $p < .05$, showing a significant standardized regression coefficient for, Age: $\beta = .02$, $p < .05$; but not for N-back: $\beta = .20$, $p > .05$ (Figure 3-3)

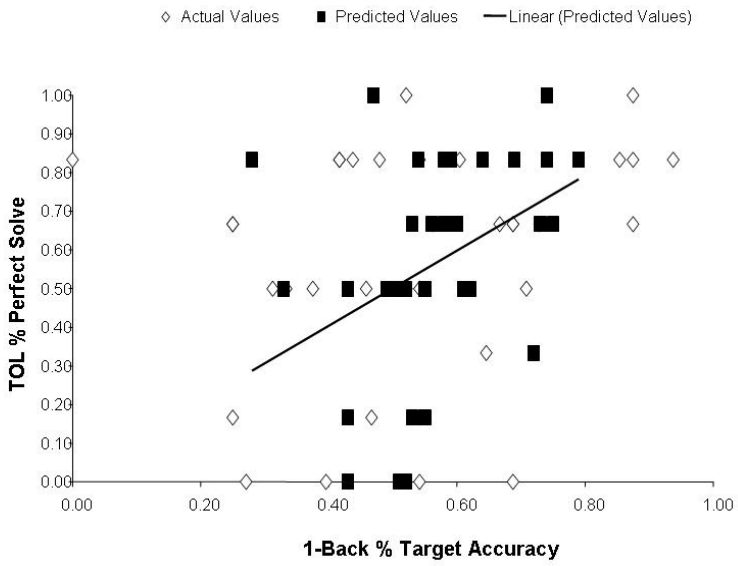

Figure 3-3 Working memory and TOL performance regression plot. Predicted values are unstandardized predictions of working memory with age removed

Finally the full model was tested using the forced entry method. This model tested the effect of Stroop on TOL performance with Age and N-back accounted for:

1. TOL = Constant + Age + N-back + Stroop

This model was significant and explained 32% of the TOL variance, $F(3, 39) = 5.39$, $p < .01$ (Figure 3-4).

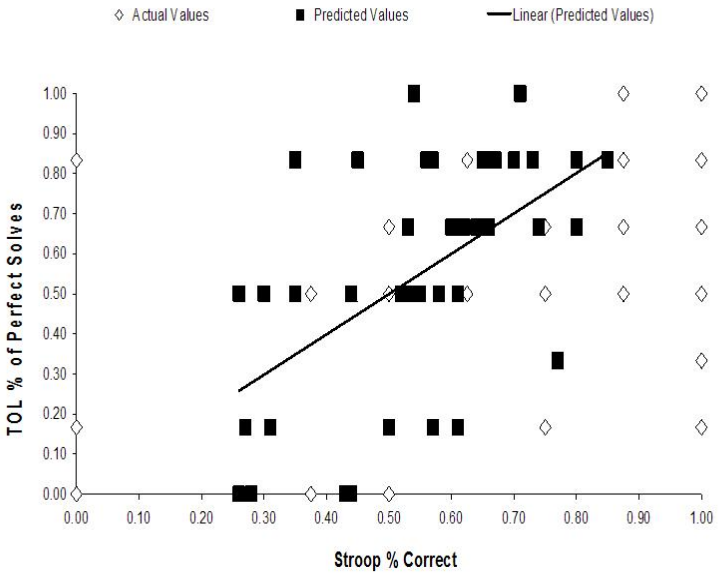

Figure 3-4 Inhibition and TOL performance regression plot. Predicted values are unstandardized predictions of inhibition with age removed

However, upon examination of the $R^2\triangle$ statistic it was noted that the model did not significantly benefit with the addition of the N-back. Therefore, the best predictors of TOL performance in young children seem to be Age and Stroop performance. It should be noted that the model can be run to test the effects of N-back with Age and Stroop accounted for, however the results are similar; the model does not benefit with the addition of N-back.

CHAPTER 4
DISCUSSION

The purpose of the current study was twofold. The first objective was to expand our knowledge of how normally developing children perform on the TOL task as an EF measure. The second, and major focus of the study, was to examine what cognitive processes are devoted to performance on the TOL as there remains debate as to what cognitive constructs make up EF. Overall results demonstrated that the ability to successfully inhibit a prepotent response is necessary for successful TOL performance in young children. These results are inconsistent with what is found with adults (Welsh et al., 1999), but, as discussed below, are consistent with what is found in one report with children (Bull et al., 2004). Taken together it seems that TOL performance may rely on different cognitive mechanisms for adults and children.

With regard to the first goal, several aspects of the results suggest that executive functioning can be successfully measured in preschoolers. This was especially illustrated in the current study when using graded difficulty levels to capture the change in these higher level cognitive processes. The TOL proved to be particularly useful to examine the qualitative differences in problem solving by age. This was also true for the Day/Night Stroop inhibition task. By carefully examining performance over all presented trials there was a clear indication that only the last half of the trials were challenging for the children. Surprisingly this result was distinguishable with only 8 Stroop trials. These results reveal the importance of looking at a range of difficulty when examining EF in children.

To help illustrate the differences in young children's TOL performance the TOL was subjected to discrete quantitative analysis. Analysis of the accuracy performance showed the expected trend in that 2-move problems were easier than 3-move, 4-move and 5-move. Also, as expected, older children outperformed younger children overall. This is especially exemplified in that the oldest children solved an average of 26% more problems than the youngest children.

Like the accuracy measure, the amount of time taken before executing the first move showed a general increase with difficulty level. As indicated by the interaction, as the difficulty level increased from 2-move problems to 3-move problems the latencies of older children were shorter than those of younger children were but this difference was not significant for 4- or 5-move problems. This could be because there were only five 3-year-olds that solved the 5-move problems accurately suggesting there may have been lack of statistical power. Overall, older children started problem solving faster than younger. This result combined with the accuracy result, suggests that the older children are taking a more efficient approach to problem solving in that they are not comprising accuracy for speed.

With regard to the second goal, determining the contribution of inhibition and working memory to children's planning, the results demonstrated that inhibition was more closely related to planning performance as measured by the TOL than was working memory. This held true even after controlling for age and working memory. Working memory, on the other hand, did not produce any significant contribution independently, nor when age was controlled, nor when age and inhibition was controlled. This is an important finding since working memory is a cognitive construct thought to be a central

aspect of EF (Baddeley, 1996; Miyake et al., 2000). The results from the current study can be compared to similar studies conducted with adults to shed light on their developmental significance. Welsh et al. (1999) found that the model that included both WM and inhibition significantly predicted TOL performance in young adults. Adults showed a similar pattern of results in a separate study conducted by Phillips et al. (2003). Taken together it seems that for young adults planning as assessed by TOL performance is best predicted by a conglomerate of higher level cognitive components. However, this may not be true for normal young children.

The study conducted by Bull and colleagues (2004) complement those found in the current study in that inhibition, and not WM was proven to be the predictive factor for TOL performance for normal young children. In fact, this result was amplified for those problems that were the most complex in the subset given. Moreover, Bull et al. found no relationship between TOL performance and short term memory. However, it can be argued that the digit span task the researcher chose may not show a relationship because it is not tapping the *kind* of working memory used for TOL solving. A short term memory task that tests the ability to recall digits in the correct order may not be the same as a working memory task that tests for the ability to hold, manipulate, or update information pertaining to the repercussions of some future move in your memory. The current study used a version of the spatial n-back which requires that the participant hold a piece of information related to the spatial location of an object (which square the star was in the previous trial) to use for the current trial. This information, if held correctly, is then updated in relation to the current trial and used to make an accurate response (same square, press smiley face; different square, press unhappy face). This task is more closely

related to the spatial working memory task given in the Welsh et al. study. In this study, the WM task required the participants to generate as many unique spatial sequences as possible by touching four white squares. To generate all 24 unique sequences within the session required that the participant hold and update information about the sequences already generated and those that still exist. The typed of tasks used in the current study and the Welsh et al study were used specifically to assess the *kind* if working memory that is more likely tapped in TOL performance.

Although Bull et al. (2004) found inhibition to be a significant contributor to TOL performance, their discussion suggests that the correlation between inhibition and TOL performance may be misleading because for the TOL the children were given move information prior to beginning to solve. Specifically they suggest that this added information may have somewhat forced an inhibiting response that was used to successfully monitor the number of moves being made for the TOL. The current study can speak directly to that hypothesis and suggest that the relationship between inhibition and TOL is not artificial as there was no move information given to the participants.

There were certain limitations in the current study that should be addressed. First, there was a lack of the expected age differences in inhibition and WM. This may be due to the unequal age distribution in the sample (Figure 12). The majority of the sample consisted of 4-year-olds which was the middle age group. This left little statistical power for the 3-year-old age group. On the other hand, there were age differences found for the TOL. This may suggest that the inhibition and WM tasks used in the current study were not sensitive enough to detect age differences as the TOL was.

Secondly, it should also be noted that there are still questions that remain about the cognitive components that make-up successful TOL problem solving. While inhibition explained over 30% of the variability in TOL performance, there was still a large part that remained unexplained. For example, one component that could explain a large amount of the variability is strategy use. A more detailed analysis of TOL problem solving and strategy use could further distinguish problem solvers into those that make efficient choices and those that do not. The current study does not attempt to dissolve these differences as both efficient and inefficient solvers can end up with an accurate solution and so they are treated equally in the current method of analysis.

In conclusion, EF is often criticized for its lack of a clear definition. Researchers agree that the array of EF tasks (e.g., TOL, WCST) may tap into different cognitive components and that this differential may even be pronounced depending on the cognitive limitations that age presents (Bull et al., 2004; DeLuca, et al., 2003; Lehto et al., 2003; Phillips et al., 2003; Welsh et al., 1999). Results from this study help bridge the gap that exists between measurement and definition when it comes to EF. Particularly this study answered some fundamental questions that exist concerning children's performance on the TOL, an EF task, through revealing which cognitive components are best predictors of TOL performance. Further, a comparison of the pattern of results obtained from the current study and those conducted by others added to the paucity of knowledge pertaining to the nature of task demands and whether they are similar or different in adults and children.

APPENDIX A
N-BACK FORMAT AND VERBAL INSTRUCTIONS

The session will progress increasing in memory load blocked by condition, from the 0-back condition to the 1-back condition. Each condition will have a set of instructions, eight practice problems, reminder of the rules, and then proceed with 21 test trials. For the test trials, the star will appear in a new location every two seconds for 500 ms; the experimenter will manually forward practice trials for learning to take place.

1. General introduction to task format–child is shown boxes with stars in the center.

    a. On the screen you will see three boxes. Inside one of the boxes there will be a blue star (point to star in middle of box)

2. Zero back condition

    a. Instructions

    To play this game I want you to press the “yes” smiley button when the star is in the ____ box (location will be randomly selected as center, left, right box. In explanation it will be “center box” or “this (point) box” to avoid using right, and left terms.

    I want you to press the “no” unhappy button when the star is not in the ____ box like in this one (point).b. Practice problems (10)

    No specific criteria to proceed, but child must demonstrate adequate understanding of at least the 0- back condition to proceed to any other conditions.

    c. Brief reminder of instructions

    d. Test trials (21)

3. One- back condition

a. Instructions

To play this game I want you to press the “yes” smiley button when the star is in the same box as *one* just before it and press the “no” unhappy button when the star is not in the same box as the *one* just before itb. Practice problems (10)

c. Brief reminder of instructions

d. Test trials (21: 9 target and 12 distracters)

APPENDIX B
TOL FORMAT AND VERBAL INSTRUCTIONS

1. Demonstration Problem. After goal board is set, set participants board to start position.

All problems will begin like this.

> This is called the puzzle game, do you think you can point to and name all of the colors of the balls to the puzzle game?

2. If child successfully names all colors, proceed.

> I am going to show you how to play. I have one puzzle that's all finished, see? (experimenter points to their board) You have one just like it, but the balls are all mixed up. To win the puzzle game you have to fix your puzzle so it looks just like mine.

3. Go around to child's side of the table and move the balls to match the goal state (2-move problem)

> Watch how I move them to make yours look like mine.

4. Reset the puzzle and allow the child to do the same problem by itself.

> Now let's see if you can do that.

5. Explain the Rules by demonstrating them

> Before we start there are some rules about how to move the balls. First, you can only move one ball at a time. Second, you cannot put a ball down anywhere else but on a stick. The third rule is that the shortest stick can have 1 ball, the medium stick can have 2 balls, and the big stick can have 3 balls.
>
> When you are done with your problem I want you to press the white button (show) to tell me you are ready for another problem, OK?
>
> There are a couple of things I want you to try and do while we play the game, OK? Try to use one hand only (prevents the child from picking up more than one ball at a time). Try to move only the balls you really need to fix and try to work as fast as you can. You win the game when your puzzle is fixed exactly like mine and then you can pick out some stickers.

6. Practice Trials. Set up practice trials using a 2-move problem for the first trial and a 3-move problem for the second.

Before we start let's do some practice ones, OK?

7. If the child did not successfully the complete practice problem, the experimenter shows the child how to do it and lets the child try the same problem again, until successful completion.

APPENDIX C
BOXES FORMAT AND VERBAL INSTRUCTIONS

Like the N-back, the Boxes task will begin with the least difficult 2-box condition and proceed through the 6-box condition. The Boxes task involves searching through a set of boxes (3-6 boxes) until a reward (a star) is found. There was one trial presented in the 3-box condition, two in the 4-box condition, and three each of the 5- and 6-box condition. The one key rule was that once a star is found in a particular box, that box will never contain another star over that particular set of boxes. The task was presented on a touch screen computer and the child "opened" each box by touching it (Figure 3). The box opened for the child for a duration of 1000 ms to expose whether it was empty or contained a star on that particular search sequence. If the child found a star, it was automatically moved to the side of the screen once the box was touched. The stars were collected at the side of the screen until all stars were found for that particular trial (the number of stars to be found is equal to the number of boxes presented for the trial). The child was then verbally praised for finding all of the stars and the next trial started.

In a 6-box condition, the participant must search through all the boxes to find where the star is hidden without returning to a box that has already been searched and/ or a star has been found in.

The verbal instructions were as follows:

We are going to play a game where you have to touch some picture boxes on the screen here, OK? See these boxes? Each box will have one star inside of it, see? To play this game, you have to touch the boxes to open and find the stars inside. The stars will line up on the side here. You have to find all the stars to fill up the side and then we will play

again. There is just one rule though. Once there is a star found in a box it can never be used again to hade a star.

APPENDIX D
STROOP FORMAT AND VERBAL INSTRUCTIONS

1. Training

We are going to play a game where you have to touch a picture on the screen as fast as you can, OK? See these pictures? This is day (point), and this is night (point). We are going to play two different games with these pictures

To play this game when you see Day (point) I want you to press the Night picture (point) and when you see Night (point) I want you to press the Day picture (point).

While you are playing, I need you to keep your pointer finger right in the middle of the pictures, on the bull's eye. Do you see the bull's eye? Can you put your finger on it? GOOD!

2. Test Trials

Remember when you see day, touch night and when you see night, touch day.

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