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To move or not to move: The impact of instruction on planning and the role of inhibitory control

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Table of Contents

List of Tables

List of Figures

Abstract

The purpose of this study was to investigate the impact of instructing 7- and 8-year old children to plan their moves prior to beginning Tower of London (TOL) problems and the degree to which inhibitory control ability was related to performance on the TOL. Half of the sample received explicit instructions to plan their moves while half of the sample did not. The results indicate that the two groups of children do not differ significantly in their TOL performance. Thus, prompting children to use more efficient problem solving strategies may not result in improved problem solving ability. Contrary to previous research, performance on the inhibitory control task was not related to performance on the TOL. The findings challenge the idea that executive functions cannot be considered separate processes.

To Move or Not to Move: The Impact of Instruction on Children's Planning and the Role of Inhibitory Control

Executive function is a broad term used to describe a variety of complex higher-order cognitive functions (Berlin, Bohlin, Nyberg, & Janols, 2004) such as problem solving, planning, inhibitory control (or inhibition), working memory and reasoning. Executive functions may also be described as a set of general control processes that help regulate behavior (Baughman & Cooper, 2007). Executive functions help us control our behavior through the utilization of processes such as planning behavior ahead of time, reasoning about which behavior or action is most effective, and inhibiting behavior that we know is not appropriate. For the purposes of this study, executive functions were defined as goal-directed behaviors that aid successful completion of problems and the inhibition of certain responses (e.g., inappropriate or incorrect responses; Garon, Bryson, & Smith, 2008).

As children age, their executive functions develop and mature. During the preschool and early school years, vast improvements are made in executive function ability (Best & Miller, 2010). Soon after children begin school (around age five), their thinking abilities and capacity for learning improve greatly due to mechanisms related to brain development. Performance on more complex executive functions tasks, such as those requiring integration of multiple executive functions, is not fully mature until adolescence or early adulthood when the growth and development of the prefrontal cortex (the control center of executive functions) reaches full maturity (Best & Miller, 2010). Following the major advances in executive function that are achieved early in childhood, progression of these abilities develops at a slower rate as children progress through adolescence (Best, Miller, & Naglieri, 2011). Research has shown that executive function contributes to academic achievement from childhood through adolescence (Best et al., 2011; Bull, Espy, & Wiebe; 2008, George & Greenfield, 2005; Hitch, Towse, & Hutton, 2001; Miller & Hinshaw, 2010).

Much of the research that has been conducted on executive function during childhood has not utilized theories based on research that is developmental in nature (Brocki & Bohlin, 2004). In fact, research investigating children's executive function has been a late-developing field compared with research on executive function in adults (Brocki & Bohlin, 2004). Though these problems have since been, and continue to be, addressed (e.g., Brocki & Bohlin, 2004; Best & Miller, 2010) the exact relationship that exists among the different executive functions remains unclear. The current study sought to gain greater understanding of the relationship between two specific executive functions, planning and inhibitory control, as well as how the two work together to aid children's problem-solving.

Problem Solving

Generally, problem solving can be thought of as a process that involves multiple steps that must be taken in order to reach a/the solution. Some think of problem solving as the solving of story-like mathematical word problems that are helpful to build math skills and assess math knowledge and understanding (Pagliaro & Ansell, 2012). Virtually everyone needs to be able to successfully solve problems in both their professional and personal lives, making it a vital learning outcome (Jonassen, 2002). Problem solving relies heavily on executive functions, especially in the presence of novel problems (Garon et al., 2008).

Problems consist of a start state (or the beginning state) and a goal state (the end state or state that is to be achieved) and solving problems occurs as an individual searches a problem space (Anderson, 2005). Through searching, individuals must be able to recognize the discrepancy that exists between the start and goal states (Best, 1989). Once the discrepancy is detected, problem solvers must create and follow mental steps to achieve the task and solve the problem (Best, 1989). In other words, they must plan. However, in everyday life, problems are not so structured, nor do they always have a definitive answer. In order to better understand why children make decisions the way they do and to understand how they solve problems in school settings and in their daily lives, we need to understand how children approach problems. We also need to know what skills, such as the ability to plan, they have developed by certain ages to solve problems most efficiently.

Early in development, problems are typically solved using simple trial-and-error methods (Klahr & Robinson, 1981). Children who have recently begun school (around age 5 and 6) are beginning to show more problem-solving abilities, and as children continue to develop, their strategies become more sophisticated as they begin to employ thought processes such as insight and planning to guide problem solving (Klahr & Robinson, 1981). Eight- and nine-year olds use more effective strategies to solve problems than children who have just begun school (Siegler, 2002). Most adolescents, in turn, are able to employ problem-solving strategies that enable them to solve problems more consistently than younger children (Siegler, 2002). By the time adulthood is reached, most people have acquired a variety of methods that can be used in problem solving, such as planning (Klahr & Robinson, 1981).

Planning

Planning is important to many everyday tasks ranging from meal preparation to scheduling (Phillips, Wynn, McPherson, & Gilhooly, 2001) and being able to plan and search ahead is an essential part to solving problems in everyday life (Kaller, Rahm, Spreer, Mader, & Unterrainer, 2008). Planning is the ability to determine actions in advance and to approach a task in an organized, strategic, and efficient manner (Anderson, 2002). In other words, it is a critical part of problem solving that involves the formulation and execution of goal-directed behavior. The ability to plan allows us to have cognitive control over our behavior by aiding the selection of appropriate responses or steps (Asato, Sweeney, & Luna, 2006). This higher-order cognitive skill is critical to academic achievement (Best et al., 2011; Sikora, Haley, Edwards, & Butler, 2002). Planning may also be important to children's emotional self-regulation, and therefore, may impact their social functioning in addition to school success (Blair & Diamond, 2008).

Measures of Planning

Planning has been assessed using several different tasks that tap into planning ability at different ages and use a variety of different mediums and formats. One common type of task is a route-planning task requiring participants to map routes that will be used to obtain objects (McCormack & Atance, 2011). One version of a route-planning task is the model grocery store task in which participants must plan routes for obtaining grocery items from a model store (Guavain & Rogoff, 1989; Parent, Gosselin, & Moss, 2000; Szepkouski, Gauvain, & Carberry, 1994). Simpler route planning tasks have been developed and used for studying planning in preschoolers, such as one that requires children to load a toy truck bed efficiently based on the order of delivery (Fabricius, 1988; McCormack & Atance, 2011). Route-planning tasks assess children's ability to plan routes for completing tasks efficiently as well as the extent to which they scan or search problem spaces (McCormack & Atance, 2011).

Similar to a route-planning task, another type of planning task is a "real-world" planning task (McCormack & Atance, 2011). Using this task, an experimenter asks a child to describe a plan for doing something familiar to them (Hudson & Fivush, 1991). An example of this would be asking a child to make a plan to go to the grocery store and to get items for a birthday party (Hudson & Fivush, 1991). The appropriateness or relevance of children's shopping plan or list for their assigned task (e.g., birthday party) can then be evaluated. This type of task has been used to study the beginnings of planning ability in preschool age children (Hudson & Fivush, 1991; Hudson, Shapiro, & Sosa, 1995). Through use of "real-world" planning tasks, researchers believe they are able to tap into children's early planning capabilities by asking them to construct a plan for carrying out a scenario they are familiar with, such as going to the grocery store and buying groceries on a list (Hudson & Fivush, 1991).

Another common planning task is the Tower of Hanoi (TOH) task. In the TOH, participants rearrange a set of disks of graduated size (a tower) on three pegs of the same size (Welsh, Satterlee-Cartmell, & Stine, 1999). Participants must rearrange the disks in their starting position to match the configuration of disks in a goal position in the fewest number of moves possible. In doing so, only one disk may be moved at a time and a larger disk may not be placed on top of a smaller disk. Also, a participant may not set a disk on the table while moving another disk (if not administered on a computer). To complete the TOH, participants must move the tower from one peg to a designated goal peg (Borys, Spitz, & Dorans, 1982). Researchers often examine the number of extra moves required to complete a TOH trial and the number of correctly solved trials, giving a total score given based on the number of trials solved (e.g., Welsh et al., 1999). The TOH was later adapted into one of the most commonly used planning tasks: the Tower of London.

The Tower of London (TOL) requires participants to rearrange a set of three colored balls in a start state to match the arrangement of balls in a goal state (Shallice, 1982). The TOL requires participants to make varying numbers of moves, with increasing difficulty, to reach the goal state. Participants' *planning time* is defined as the latency between the presentation of the trial and the amount of time it takes to make the first move. *Execution time* is the time it takes for a participant to complete a trial measured as time of the first move through the time of completion. To complete TOL trials successfully, participants must plan how they will rearrange the balls in the most efficient way that will not exceed the minimum number of moves allowed.

The Development of Planning

Previous research indicates that as children age, they become more efficient at planning (Asato et al., 2006; Best et al., 2011; Borys et al., 1982; De Luca, Wood, Anderson, Buchanan, Proffitt, Mahony, & Pantelis, 2003; Gauvain & Rogoff, 1989; Hudson & Fivush, 1991; Hudson et al., 1995; Huizinga, Dolan, van der Molen, 2006; Kaller et al., 2008; Klahr & Robinson, 1981; Levin, Culhane, Hartmann, Evankovich, Mattson, Harward, Ringholz, Ewing-Cobbs, Fletcher, 1991; Szepkouski et al., 1994). Children as young as three years of age are able to complete planning tasks but with some difficulty (Best et al., 2011; Bull et al., 2008; Fabricius, 1988; Gauvain & Rogoff, 1989; Klahr & Robinson, 1981; Szepkouski et al., 1994). One of the reasons children this age struggle on planning tasks is because they have a tendency to make moves directly to the goal without considering other steps that may be necessary (Klahr & Robinson, 1981). This could be because children focus only on the immediate move and not on subsequent moves (Kaller et al., 2008; Klahr & Robinson, 1981). Although young children are able to plan, it seems that the inability to search ahead and anticipate the implications of their actions keeps their performance at an immature level.

By age five, planning abilities are more advanced and children are able to complete planning tasks more often (Kaller et al., 2008). This improvement in ability is likely due to the development of core components of executive function that takes place during the preschool years (ages three to five; Garon et al., 2008). Also, synaptic density in the prefrontal cortex reaches a peak around age 4 (Lenroot & Giedd, 2006). From age five to seven, the magnitude of changes made in planning ability is large (Best et al., 2011). These changes appear to coincide with significant changes in the structure and function of the prefrontal cortex during this period (Espy, Kaufmann, Glisky, & McDiarmid, 2001). At approximately age nine, planning is much more effective and efficient (Borys et al., 1982; Szepkouski et al., 1994).

After age nine, planning ability still improves, though not as rapidly as during early childhood yet improvements are still evident until age 15 (Best et al., 2011; Huizinga et al., 2006). There are mixed findings regarding changes in planning ability beyond age nine. One study revealed that from age seven to age 15, seven- & eight-year olds performed significantly worse on a planning task than 13- to 15-year olds, but nine-to 12-year olds did not differ significantly from either group (Levin et al., 1991) and another showed that planning performance of children ages eight to 14 did not differ significantly (De Luca et al., 2003). After children reach age 15, changes in ability begin to stabilize (Best et al., 2011) and studies have shown that age-related differences in planning ability are not evident after age 17 (Romine & Reynolds, 2005; Taylor, Barker, Heavey, & McHale, 2012). Others have found no significant differences in ability from around age 15 to 29 (e.g., De Luca et al., 2003; Huizinga et al., 2006). Gray matter in the prefrontal cortex reaches maximum thickness around puberty (age 11-12) then decreases and this part of the brain is considered "under construction" for another decade and does not reach maturity until the 20s (Giedd, 2004). Thus, the differences in performances reported after age nine could be due to individual differences associated with onset of puberty and because developmental changes in function still occur into early adulthood but at a much slower rate.

By using the Tower of London as a planning assessment, researchers can obtain a number dependent measures. One commonly studied dependent measure of the TOL is planning time. Research focusing on planning time has yielded mixed results. Previous studies have shown that adults explicitly instructed to plan show significantly longer planning times than those not told to plan, but that execution times do not differ (Unterrainer, Rahm, Leonhart, Ruff, & Halsband, 2003; Phillips et al., 2001). However, others have found that planning time does not have a significant effect on accuracy on the TOL and believe that it may be best to use intermittent bursts of planning during execution of the trial rather than creating a full plan before beginning (Phillips et al., 2001).

While the impact of instructions has been investigated in adult populations (e.g., Newman & Pittman, 2007; Unterrainer et al., 2003; Phillips et al., 2001), the same effect has not been studied in child populations who may be approaching mature planning ability. Perhaps the reason children have not reached maturity of planning is not because they are unable to plan. Based on previously mentioned studies, it is evident that children as young as three years of age are capable of planning. If children are prompted to plan before beginning a task, it seems likely that their ability to solve the problem would improve as it did for adults. If so, planning ability may be improved by explicitly instructing children to plan instead of assuming, or hoping, they will do so on their own. This would suggest that the issue might be children's inability to inhibit beginning a task as soon as they are able. If children were able to inhibit beginning immediately, perhaps performance on planning tasks would improve and their true planning ability could be seen earlier. Recently, planning time was found to significantly correlate with number of extra moves for difficult problems and the authors conclude that making a plan to use on TOL trials is possible, but the effect of a plan may be dependent on problem difficulty (Newman & Pittman, 2007). Although there is evidence that the effect of planning time may depend on problem difficulty (see Newman & Pittman, 2007), it is possible that the effect may be stronger for children who have not yet reached mature planning ability.

Inhibitory Control

Inhibitory control is the ability to inhibit or resist responses during a cognitively represented goal (Carlson & Moses, 2001) or to inhibit a prepotent response (Berlin, & Bohlin, 2002; Berlin et al., 2010). More generally, inhibitory control is the ability to withhold inappropriate responses (Carver, Livesey, & Charles, 2001). Inhibitory control is considered foundational for executive functions (Best & Miller, 2010; Miyake et al., 2000) and, thus, may play an integral part in planning ability.

Deficits in inhibitory control lead to incorrect performance of tasks because it is much more difficult for a person to "shut-off" a response that seems obvious or intuitive. This results in an increased likelihood that a response will be executed rather than withheld (Dowsett & Livesey, 2000; Schachar & Logan, 1990; Schachar, Tannock, & Logan, 1993). Inhibitory control deficiencies are also revealed through impulsive behavior such as responding before a task is understood, answering a question before sufficient information is given or distractibility (Schachar & Logan, 1990). In the past, studies have shown that measures of inhibitory control are strongly related to performance on the TOL (e.g., Welsh et al., 1999; Zook, Davalos, DeLosh, Davis, 2004; Asato et al., 2006). Perhaps, those who exhibit greater inhibitory control are better able to inhibit themselves from starting the TOL right away and, instead, make a plan for completing the task before beginning. The current study seeks to further investigate the dynamic that exists between planning and inhibitory control in order to better understand how they work independently and interdependently to aid problem solving during childhood.

Measuring Inhibitory Control

Researchers utilize a variety of tasks to assess individual's inhibitory control ability. One example of an inhibitory control task is the stop-signal paradigm. This is a laboratory analog of a situation that requires inhibitory control (Schachar & Logan, 1990). The purpose of the stop-signal paradigm is to distinguish stimuli that elicit impulsive behaviors from stimuli that inhibit impulsive behaviors (Schachar & Logan, 1990). For example, a participant might be engaged in a task but is occasionally presented a stop-signal stimulus such as a flash of light or a tone, which signals the participant to stop the task they were previously engaged in.

Another commonly used measure of inhibitory control is the go/no-go task. In a go/no-go task, participants are asked to make a certain response to one cue (go) but to inhibit that response to another cue (no-go; Berlin et al., 2010). For example, a participant may be told to press the spacebar on a computer keyboard when they see an "X" appear on a computer screen but to withhold pressing the spacebar when a "Y" appears.

The Stroop task (Stroop, 1935) is also common in inhibitory control research. This task requires individuals to respond to one specific part of a stimulus while suppressing a competing part of a stimulus (Zysset, Muller, Lohmann, von Cramon, 2000). An example of this would be seeing the word "blue" written in red ink and being instructed to name the ink color and ignore the word (Zysset et al., 2000).

There are other tasks and adaptations of tasks that also tap into inhibitory control apart from those previously described. One common problem surrounding executive functions is that the tasks generally used to assess them tap into more than one of these processes (Brocki & Bohlin, 2004). Many inhibitory control tasks fall into this category because they require such a high level of working memory for successful completion (Brocki & Bohlin, 2004). In fact, most inhibitory control tasks require individuals to hold an arbitrary rule in mind in addition to withholding an automatic response (Brocki & Bohlin, 2004).

For these reasons, the current study will utilize an inhibitory control task that has been adapted from the task used by Davidson and colleagues (2006). In this task, participants will click either the left button or right button on a computer mouse based on where an arrow points. Though this task is not a commonly used task such as go/no-go, stop-signal, or Stroop, it was chosen because it requires a high level of inhibitory control and requires little to no working memory because the arrows point to the correct response button on trials (Davidson et al., 2006). Performance on the inhibitory control task was measured by examining the number of errors participants made on the task. Participants' response time was measured as the time it takes to respond to the stimuli presented.

The Development of Inhibitory Control

Researchers have reported improvements in inhibitory control take place as children mature (Brocki & Bohlin, 2004; Carlson & Moses, 2001; Carver et al., 2001; Davidson et al., 2006; Huizinga et al., 2006; Dowsett & Livesey, 1999; Levin et al., 1991; Luna, Garver, Urban, Lazar, & Sweeney, 2004; Pennequin, Sorel, & Fontaine, 2010; Wiebe, Sheffield, & Espy, 2012; Williams, Ponesse, Schachar, Logan & Tannock, 1999). Children between age three and four are capable of inhibitory control depending on the task being used (Bull et al., 2008; Dowsett & Livesey, 1999; Pasalich, Livesey, & Livesey, 2010; Simpson & Riggs, 2006). Some researchers associate the beginnings of inhibitory control with improved language capabilities (Wiebe et al., 2012). This may be because once children have improved language skills they comprehend what inhibitory control tasks more clearly require. In a recent study, children ages four and five were not able to successfully complete a variation of the stop-signal task but were able to complete both a Stroop and a go/no-go task (Pasalich, Livesey, & Livesey, 2010). The difficulty younger children have with inhibitory control may partly be due to the fact that they have to guide their behavior using an abstract rule and children at this age are not always capable of that (Garon et al., 2008). Additionally, the lack of solidity and activity in the prefrontal cortex at this age likely contributes to children's difficulty. Some have found no improvements in inhibitory control between age four and six (Davidson et al., 2006), while others have found that marked improvements occur between the ages of three and six (Carlson & Moses, 2001; Wiebe et al., 2012). This discrepancy could potentially be because the formerly mentioned study used an inhibitory control task that required very little working memory load for successful completion while the latter ones employed inhibitory control tasks that required children to hold abstract rules in mind during the tasks. This could have been more taxing on working memory capacity which may explain why differences in performance were reported. It is also possible that working memory follows a different developmental trajectory than that of inhibitory control and using tasks with younger children that requires more working memory ability may mask their true inhibitory control ability.

It seems as though there are not vast improvements from age six to age nine, after which inhibition capabilities improve significantly (Brocki & Bohlin, 2004; Davidson et al., 2006; Levin et al., 1991; McAuley & White, 2011; Williams et al., 1999). These results suggest that children ages seven and eight perform equally on measures of inhibitory control (e.g., Brocki & Bohlin, 2004; Levin et al., 1991).

Some studies have reported that stable performance in inhibitory control tasks is achieved as early as 12 and 14 years of age (e.g., Huizinga et al., 2006; Levin et al., 1991; Luna et al., 2004; Romine & Reynolds, 2005). One study examining executive function in adolescents found no differences in inhibition ability between 17 and 19 years of age, suggesting that stability had been reached by age 17 (Taylor, Barker, Heavey, & McHale, 2012). The fact that maturity on tasks measuring inhibitory control is not reached until sometime during adolescence is likely because the part of the brain that is responsible for inhibitory control also continues to develop into adolescence (Giedd et al., 1999; Romine & Reynolds, 2005; Wiebe, Sheffield, & Espy, 2012). Differences in ages reported for stability of inhibitory control may be a result of the tasks used to measure this process. Because inhibitory control tasks may also require input from other executive functions, it is likely that processes with different developmental trajectories are being assessed and causing the variability in ages reported regarding performance (Williams et al., 1999).

Purpose and Hypotheses

The purpose of this study was twofold. First, we investigated the impact of being instructed to make a mental plan on children's planning ability. It is possible that children are quite effective planners earlier than has previously been reported due to lacking inhibitory control. We believed that by emphasizing planning time before beginning a planning task, children's true planning abilities would be revealed. Second, we examined the relationship between planning and inhibitory control. We used Davidson et al.'s (2006) inhibitory control task because it is a purer measure of inhibitory control. By using this purer measure of inhibitory control, it could reveal a clearer relationship between inhibitory control and planning.

The current study employed the TOL task as a measure of planning and an adapted version of a task used by Davidson and colleagues as a measure of inhibitory control (Davidson et al., 2006). To assess planning, children were randomly assigned to one of two conditions—instruction or no-instruction—to reveal whether being explicitly told to plan impacts seven- and eight-year-olds' planning ability. Perhaps younger children are equally capable of performing well on the TOL as their older peers and just need explicit instructions to plan until they develop greater inhibitory control and, thus, greater ability to inhibit starting before planning their actions. This would indicate that the problem is not a lacking ability to plan ahead but in inhibiting the urge to start the task immediately rather than take the time to plan out one's moves on the TOL.

The age range of seven- to eight-years of age was chosen primarily because at this age, no major developmental improvements in executive function are made, thus, performance on planning and inhibitory control tasks at these ages should be similar (Brocki & Bohlin, 2004; Davidson et al., 2006; Levin et al., 1991; McAuley & White, 2011; Williams et al., 1999). We wanted to use an age group of children who could successfully complete both planning and inhibitory control tasks in order to closely examine what helps them perform better, not simply whether they can complete the task. We also chose this age group because performance on planning and inhibitory control tasks has not yet fully matured. This allows us to further investigate whether children's immature performance (compared to adults) on a planning measure is simply due to immaturity of this cognitive skill or if inhibition is what is immature and prevents children from taking the time to plan before beginning something.

Hypotheses

Hypothesis 1: We expected that children in the instruction condition would show differences in planning times, execution times, and number of extra moves on the TOL task than children in the no-instruction condition. In other words, children in the two conditions will display differences on this set of TOL performance variables.

Hypothesis 2: We expected that performance on the inhibitory control task would be correlated with TOL performance, despite instruction condition. Specifically, we anticipated that proportion of errors on the inhibitory control task would be negatively correlated with planning time and execution time, and positively correlated with the number of extra moves on the TOL.

Methods

Participants

Twenty-seven seven- and eight-year-old children were recruited from Harrisonburg and the surrounding areas. Of those, data for nine participants were excluded from analyses because of failure to complete all tasks and for one participant because of a prior diagnosis of ADHD. The remaining sample (17) consisted of both males (10) and females (7) representing whites/Caucasians (76.5%), Hispanics (17.6%) and Asians (5.9%). Participants ranged in age from 7.11 years to 8.73 (M = 7.98, SD = .45).

Materials

Tower of London Task. We assessed planning using the computer-based form of the Tower of London (TOL) task developed by Shallice (1982; See Figure 1). For this task, participants were required to rearrange a set of 3 different colored balls in a workspace to match the ball arrangement of a goal space (or target space) in a limited number of moves. The TOL consisted of 2-move, 3-move, 4-move, and 5-move problems. There were a total of 12 trials consisting of two 2-move problems, two 3-move problems, four 4-move problems and four 5-move problems. The 2-move problems were practice problems and were not included in calculation of performance variables or any analyses. The order and progression of TOL problems was identical for each participant. The number of extra moves for each solved problem were summed to obtain the total number of extra moves participants made. The total average planning time and total average execution time for participants on solved problems was also calculated.

Inhibitory Control Task. We measured inhibitory control using an inhibitory control task that had been adapted from one used by Davidson and colleagues (Davidson et al., 2006; see Figure 2). This task, also computer-based, consisted of six blocks with eight trials in each block. The first block was a practice block and, thus, not included in analyses. The task required participants to inhibit making a more intuitive response and, instead, make the correct response using a computer mouse. The goal of this task was to click the side of the mouse to where the arrow points. Participants were presented a large arrow either on the left or right side of the computer screen. Some arrows pointed straight down (90°) and some pointed diagonally across the screen (45°). Participants were instructed to make a different response depending on which arrow appeared. For arrows pointing straight down (90°), participants were told to click whatever side of the mouse the arrow appeared on (e.g., if the arrow was pointing straight down on the left side of the screen, the participant was to click the left side of the mouse). However, if the arrow was angled (45°), participants were told to click the opposite side of the mouse (e.g., if the arrow was presented on the right side of the screen pointing diagonally across to the left, the participant was to click the left side of the mouse). The presentation of the arrow (either right or left side) as well as the type of arrow (90° or 45°) was counterbalanced within each block of the task. The arrows appeared on the screen for 750 ms. The inter-trial interval (time between arrow presentations) time varied from 500, 1000 and 1500 milliseconds. The order in which arrows were presented was randomized for each participant.

Procedure

Upon arrival to the lab, the experimenter explained the study and procedure to both the participants and their parent/guardian. After any questions were answered, and the consent and child assent forms were signed, participants followed the experimenter to the experiment room. The experimenter explained each task in detail. For the inhibitory control task, instructions were the same for all participants. Participants were instructed to click the side of the mouse based on where the arrow pointed and to make their responses as quickly and accurately as possible.

For the TOL, participants were randomly assigned to one of two conditions: one that received instructions to plan moves before beginning TOL trials and one that did not receive instructions to plan. Participants in the instruction condition were told to construct a mental plan before making their first move on each of the twelve problems; the experimenter said, “Plan your moves!” to the participant as the words appeared on the screen. In the no-instruction condition, participants were told to begin each trial when they were ready; the experimenter will said, “Get Ready!” to the participant before each of the twelve problems as the words appeared on the screen. The order in which each participant completed the tasks was also randomized. After completing both tasks, participants were allowed to choose a small toy to take home and parents were allowed to choose one from a variety of coupons redeemable at local businesses.

Data Analysis

For the TOL, only data from problems that were completed were included in the analyses. Also, data from practice trials were removed (2-move problems). The variables that were analyzed were planning time, execution time and number of extra moves. A total average planning and total average execution time was calculated for all solved 3-, 4-, and 5- move problems. Number of extra moves on each TOL problem was recorded by summing the number of moves after the allotted moves (3, 4 or 5) that participants made. This number was then summed across all TOL solved problems, creating a total number of extra moves variable. These three dependent measures were calculated for all TOL problems that were solved, regardless of whether participants used extra moves. When the data were analyzed, results were split by instruction condition (instruction versus no instruction).

To test hypothesis 1, total average planning time, total average execution time, and total number of extra moves were entered into a multivariate analysis of variance (MANOVA) as dependent measures and condition (instruction versus no-instruction) as independent measures.

For the inhibitory control task, data from the practice block (block 1) were not included in the analyses. Proportion of errors on the inhibitory control task was calculated by summing the total number of errors made in block 2 through block 6 of the inhibitory control task for each trial type (inhibition or non-inhibition) and then dividing that number by the total number of trials completed. Mean response times were also calculated for each trial type. Inhibition trials were trials in which the arrow pointed diagonally across (45°) and non-inhibition trials were trials in which the arrow pointed straight down (90°). Response time was the latency between arrow presentation and when the participant clicked their response on the mouse.

Using three separate correlation analyses, total proportion of errors on inhibition trials was correlated with total number of extra moves, total average planning time and total average execution time on the TOL. Using a paired-samples *t*-test, mean response times for the inhibition and non-inhibition trials were compared to see if participants took longer to respond when the arrow was diagonal (45°). A second paired-samples *t*-test was also used to investigate differences in proportion of errors for inhibition and non-inhibition trials.

Results

To test hypothesis 1, a multivariate analysis of variance (MANOVA) was conducted with condition (instruction versus no-instruction) as the independent variable and total number of extra moves, average planning time, and average execution time as dependent variables.

Prior to running the analysis, assumptions of normality and homogeneity of variances and covariances were assessed. Skewness and kurtotsis values were obtained for each dependent variable and revealed that for average execution time, the results may be positively skewed and show excessive peaking (both values were greater than |2|, which exceeds the typical cut-off for a normal distribution). For total number of extra moves and average planning time, the normality assumption was not violated. The assumption of homogeneity of variances and covariances yielded satisfactory results as Box's M test was non-significant, $p > .05$. It was deemed acceptable to proceed with the MANOVA despite higher skewness and kurtosis values for average execution time because this statistical test is robust to violations of non-normality (see Tabachnick & Fidell, 2001). The multivariate analysis revealed that groups (instruction versus no-instruction) did not differ significantly on the three TOL variables (Λ = .941, X^2 (3) = .884, *p* = .829, R^2_C = .059; Table 1). In other words, total average planning time (instruction: *M* = 5787, *SD* = 2126; no-instruction: *M* = 5027, *SD* = 2605), total average execution time (instruction: *M* = 35137, *SD* = 26564; no-instruction: *M* = 26521, *SD* = 13670) and total number of extra moves (instruction: *M* = 12.2, *SD* = 17.4; no-instruction: *M* = 9.5, *SD* = 12.7) did not differentiate the two groups. The variability in planning and execution times and number of extra moves is typical of child data (e.g., Asato et al., 2006; Albert & Steinberg, 2011; De Luca et al., 2003; Luciana et al., 2009).

A medium effect size for group differences was expected. In order to have enough statistical power to detect a medium effect, a total of 30 participants (15 in each group) were required. The observed power, with eight participants in the no-instruction condition and nine participants in the instruction condition, was .253 meaning there was a 25% chance that we would detect differences if they truly existed. The effect size was quite small (R^2_C = .059) indicating that only 5.9% of the variance in TOL performance was explained by instruction group.

To test hypothesis 2, correlation analyses were conducted including all participants, regardless of which condition they were assigned to. Average planning time, average execution time, and total number of extra moves on TOL trials was correlated with total proportion of errors on the inhibitory control task. The analysis revealed no significant correlations among the four variables. Errors on the inhibitory control task were not significantly related to extra moves (*r* = .310, *p* = .243), average planning time (r = -.168, p = .535), or average execution time (r = .287, p = .281) on the TOL.

Paired-samples *t*-tests were conducted to investigate differences in mean response times and proportion of errors on the inhibitory control task for each trial type. Mean response times for the inhibition (in milliseconds; M = 910, SD = 515) and non-inhibition (M = 804, SD = 254) trials did not differ significantly (t (15) = .996, p = .335, d = .243). Proportion of errors made on inhibition (M =15.14, SD = 14.72) and non-inhibition (M = 1.16, SD = 1.84) trials were statistically significantly different (t (15) = 3.654, p = .002, d = .891), indicating that significantly more errors were made on inhibition trials than on non-inhibition trials (see Table 2).

Discussion

Hypothesis 1 stated that children in the instruction condition would differ in planning times, execution times and number of extra moves than children in the no-instruction condition. The results of the MANOVA revealed that children did not differ significantly in their performance on the TOL. In other words, the two groups did not differ significantly on the composite of TOL performance variables.

Theses results suggest that explicitly telling children to make a mental plan prior to beginning a planning task does not result in improved planning ability. In the sample of adults we tested using the identical methods as those used with child participants, adults in the planning condition had significantly longer planning times, indicating that the manipulation of instruction was effective. Phillips et al. (2001) found that when adults were instructed to plan, they spent significantly longer planning but that those plans did not aid in efficiency of solving TOL problems. They assert that though instruction to plan does increase time spent planning, adults were able to plan for no more than two moves on TOL problems, at which point their mental preplans no longer aided TOL problem completion (Phillips et al., 2001).

The results from our child sample, though none were significant, reveal that the pattern of performances in children follow the same patterns found by Phillips et al. (2001; see Table 1). That is, children in the planning instruction tended to plan longer but were not more efficient at solving TOL problems. Thus, it is conceivable that telling 7- and 8-year old children to plan truly does not enhance problem solving efficiency on the TOL but that it may lead to increased planning times. Also, it may be likely that children employ other problem solving techniques when solving the TOL problems rather than strictly planning. According to the overlapping waves theory of learning, children typically use a variety of strategies rather than a single strategy to solve a given problem (Siegler, 1996). While children were told to use a specific strategy for solving TOL problems – planning – it is possible that they also utilized other, less efficient problem solving strategies, such as trial-an-error methods, to guide their problem completion (Klahr & Robinson, 1981).

Knowing that instructions to plan may not improve problem solving performance is important in part because it allows us to understand that children may not be capable of planning approaches to problems, thus, they should not be instructed to do so. In other words, if a teacher were to give similar instructions to her class of 7- and 8-year olds on how to complete a class assignment, she may be asking the children to do something they cannot do. Until children's prefrontal cortices are more mature, they may need to receive direct and explicit instructions on how to proceed with problems and projects. It might also be beneficial to assist children in planning projects and assignment completion by providing them detailed feedback and praise when they go about the process in an efficient manner. That way, they may be able to identify better ways of planning and approaching problems and use them again in the future. It is also important to note that even though children may in fact hold rules, such as "plan your moves" in mind while completing tasks, this does not necessarily mean they will follow those rules.

Research has shown that preschool curricula designed to promote executive function improves performance on executive function tasks (Diamond, Barnett, Thomas, & Munro, 2007). Perhaps encouraging children to utilize planning and other executive function strategies early on in schooling could lead to enhanced executive functions abilities and improved TOL performance in children. These improved cognitive abilities would then likely lead to increased academic achievement (Best et al., 2011).

Hypothesis 2 stated that performance on the inhibitory control task would be correlated with TOL performance. Specifically, it was expected that number of errors on the inhibitory control task would be positively correlated with number of extra moves and negatively correlated with average planning time and average execution time on the TOL. Correlation analyses revealed no significant relationship between performance on the TOL and the inhibitory control task.

The lacking relationship between inhibitory control and planning ability is quite intriguing, especially considering the number of studies that have found significant relationships between performances on such tasks (e.g., Welsh et al., 1999; Zook et al., 2004; Asato et al., 2006). However, rarely are the same inhibitory control tasks used in conjunction with planning tasks, resulting in inconsistent findings regarding the relationship between inhibitory control and planning. For instance, both the Stroop inhibitory control task and the antisaccade inhibition task have been found to predict TOL performance (Welsh et al., 1999; Asato et al., 2006; Zook et al., 2004; Luciana, Collins, Olson, & Schissel, 2009; Albert & Steinberg, 2011), while the Colorado Card Sort task (an adapted version of the more popular Wisconsin Card Sort Task) was not found to be predictive of TOL performance (Zook et al., 2004). The go/no-go inhibitory control task has also been found to predict overall problem solving ability but not the ability to plan TOL moves prior to making the first move (Kaller et al., 2008). There is also variation in how inhibitory control tasks are administered; some use computerized tasks while others use standard, non-computerized tasks. In a study that utilized both computerized and non-computerized inhibitory control tasks, only performance on the non-computerized task significantly predicted planning (Zook et al., 2004).

Most previously used inhibitory control tasks have been faulted for not being pure measures of inhibitory control. Findings regarding TOL performance and inhibitory control using inhibition tasks that place a higher demand on working memory may not accurately portray the relationship between planning and inhibitory control. If our results are replicated, it may suggest that planning as measured by the TOL is not related to inhibitory control. If so, this would challenge the idea that the TOL taps into many executive functions, such as inhibitory control, as well as provide more evidence in support of planning and inhibitory control truly being distinct processes.

If planning and inhibitory control are repeatedly found to not be related using a purer inhibitory control task, this would provide a great deal of support for those who argue that executive functions are, in fact, distinct and separable cognitive processes that operate independently of one another. If so, it could be said that children's inability to plan their behavior in advance, whether on a controlled TOL problem or on a school assignment, is not due to their inability to inhibit their behavior. Instead, it seems as though 7- and 8-year old children are simply not efficient planners and that their planning capabilities cannot be improved through instructions. Though children might potentially spend a bit more time planning when told to plan, it does not seem as though their problem solving becomes more efficient as a result. Additionally, inhibitory control does not appear to be a mediator in the amount of time spent planning or problem solving efficiency.

While others have found there to be significant relationships between planning and inhibitory control, our results did not support this claim. If planning and inhibitory control were believed to be related, poor performance on the TOL or other planning tasks might suggest a simultaneous lack in inhibitory control. While a lack in planning ability may not necessarily seem problematic during childhood, a lack in inhibitory control might be perceived as indicative of a bigger problem. Poor inhibitory control may lead teachers or parents to believe that a child may have attention-deficit hyperactivity disorder (ADHD). Again, if we equate the TOL with a problem or a puzzle in a classroom setting, inefficient solving of the problem might lead teachers to conclude the child has lacking planning and inhibitory control. However, our results suggest that the only immature cognitive process at play may be planning.

Limitations

An increased sample size might have revealed a more accurate relationship between performance on the inhibitory control task and the TOL. Additionally, the sample consisted mostly of Caucasian children living in a rural area of Virginia. Even if the sample had been larger, the results might still not be generalizable to the entire population of 7- and 8-year old children. Finally, some of the children in our sample had previous experience with the TOL as part of another study taking place in the same lab. This previous experience might have resulted in some children performing better simply because they had seen the task before.

Future Directions

More consistency is needed in research on executive functions. As described earlier, many different types of tasks exist to capture the same construct, which makes it challenging to form a definitive depiction of how executive functions work together independently and interdependently when findings are often not replicated using identical tasks. Additionally, it appears that striving to utilize the purest measures of executive functions is critical to revealing the true relationships that exist between executive functions, such as planning and inhibitory control. Though Davidson et al. (2006) provide good reasoning for why their version of an inhibitory control task does not place a high demand on working memory, performance on this version of an inhibitory control task has never been correlated with a working memory task. This is a necessary next step to ensuring that the inhibitory control task we used is actually a pure measure of inhibitory control as Davidson and colleagues assert. Thus, correlating performance on this inhibitory control task with several working memory tasks might also be helpful in supporting not only the purity of the task but potentially to the singularity of inhibitory control as an executive process.

Utilizing eye-tracking technology to follow children's eye movements while completing TOL trials could possibly reveal much more information about children's planning. First, it would allow researchers to see what children are looking at prior to making their first move on TOL problems. If children were truly planning their moves, researchers would be able to see this by following their eye movements. Second, it would be easy to track whether children utilize the plans they make to guide their completion of TOL trials. Researchers would be able to follow eye movements prior to the first move and then follow subsequent moves to see if the execution matches the plan. Eye-tracking research of TOL completion would also show how far in advance children plan prior to beginning TOL problems. It may be that children only plan the first move they make and then begin to move balls around until they reach the goal state using trial-and-error methods. However, children may plan the first two moves and then begin to solve the problem, adjusting their moves as they continue to solve.

To summarize, our results indicate that prompting children to plan before beginning a planning task does not result in improved problem solving efficiency. This may be because children at this age still employ multiple problem-solving strategies when solving problems such as the TOL. In addition, it does not appear as though inhibitory control is related to planning as measured by the TOL. Proportion of errors made on the inhibitory control task was not related to TOL performance. This provides support to the claim that executive functions like planning and inhibitory control are unique cognitive processes.

Table 1

Means and Standard Deviations of TOL Performance Measures by Instruction Group

Group	Total Extra Moves	Average Planning Time (ms)	Average Execution Time (ms)
Instruction	12.2 (17.4)	5787 (2126)	35137 (26564)
No-Instruction	9.5 (12.7)	5027 (2605)	26521 (13670)

Note. Numbers in parentheses are standard deviations of the means.

Table 2

Means and Standard Deviations of Inhibitory Control Task Performance by Trial Type

Group	Total Proportion of Errors	Average Response Time (ms)
Inhibition	15.14 (14.72)	910 (515)
Non-Inhibition	1.16 (1.84)	804 (254)

Note. Numbers in parentheses are standard deviations of the means.

Figure 1: Example Trial of the Tower of London

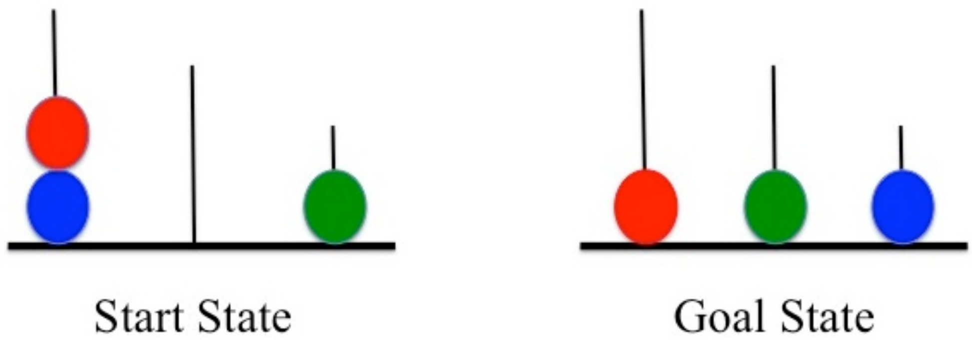

Figure 1. This is an example of a Tower of London trial. The goal of the Tower of London is to rearrange the three colored balls in the start state to match the arrangement of balls in the goal state in a minimum number of moves. For this example, the goal position can be achieved with four ball movements. First, the green ball will need to be moved to the middle peg. Second, the red ball will be moved to the middle peg, on top of the green ball. Third, the blue ball should be moved to the far right peg. Lastly, the red ball will be moved from the second peg to the far left peg.

Figure 2: Inhibitory Control Task

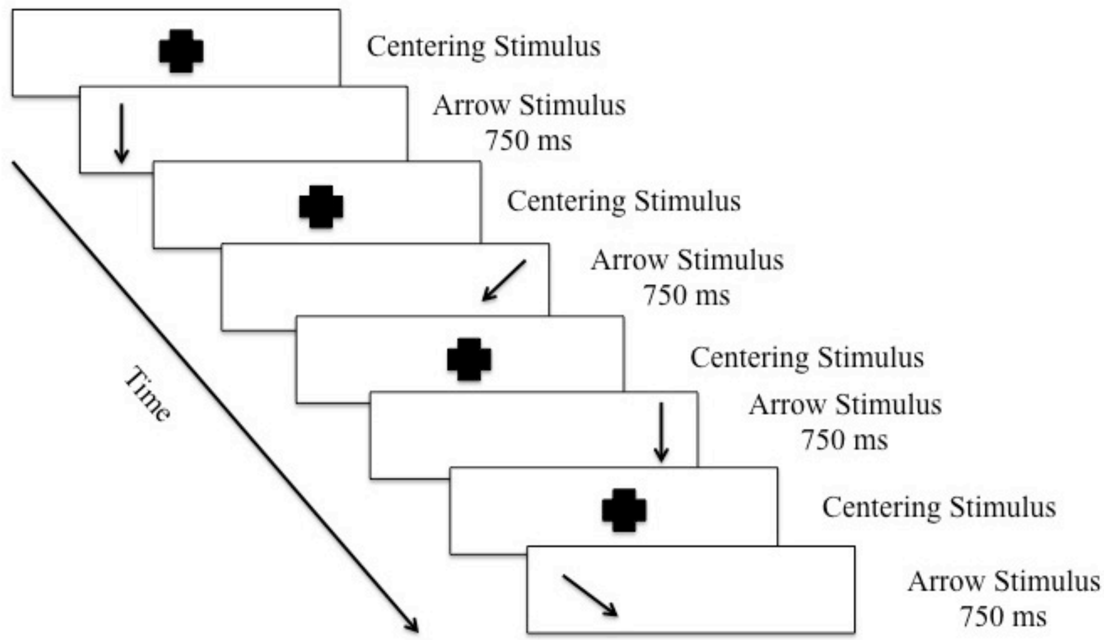

Figure 2: This figure presents the sequence of events for the inhibitory control task. For this task, the goal is to click the side of a computer mouse based on where the arrow points. The centering stimulus appears first followed by an arrow (either a straight (90°) or angled (45°) arrow). The arrows are presented for 750 ms and the centering stimuli is presented for either 500, 1000 or 1500 ms. The time between each arrow (inter-trial interval) is randomized and the presentation of left and right and 90° and 45° arrows are both counterbalanced throughout each block.

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