FUNCTIONAL CONSTRAINTS ON YOUNG CHILDREN'S OBJECT PROBLEM SOLVING

by

Sarah R. Bidmead

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SUPERVISORY COMMITTEE:

Marissa L. Greif, Ph.D.
Dissertation Advisor

David Bjorklund, Ph.D.

Alan Kersten, Ph.D.

Elan Barenholtz, Ph.D.

Amy Needham, Ph.D.

David Wolgin, Ph.D.
Chair, Department of Psychology

for G. Perry
Gary Perry, Ph.D.
Dean, Charles E. Schmidt College of Science

Barry T. Rosson, Ph.D.
Dean, Graduate College

July 12, 2012
Date

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ABSTRACT

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Although some research has suggested that very young children are “immune” to functional fixedness (FF), other work has shown that young children form robust associations between objects and their prescribed functions. Across two studies, I investigated (a) the developmental trajectory of FF and (b) its relationship with executive function components (inhibitory control and working memory) in 3- to 6-year old children. Both older and younger children experience FF, but older children use familiar tools more flexibly than younger children (3- and 4-year-olds). Furthermore, inhibitory control was related to overcoming FF, indicating that it may be an important cognitive capacity for creative problem-solving. Finally, in a third study, children were instructed to use mental imagery to help them solve the functional fixedness problems. However, these instructions were ineffective at reducing FF compared to a control condition, underscoring the robust nature of object-function relationships in early childhood.

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I. INTRODUCTION

The typical person's environment is filled with countless artifacts, or human-made objects. Artifacts can be used in isolation, but often they are used in conjunction with other objects. Eating soup with a spoon, using a knife to open a cardboard box, and opening a door with a key are just a few examples of tasks that require the coordinated combination of multiple artifacts. Indeed, it is hard to imagine a day in which we do not use multiple objects to achieve ends. Given the central role of object use in day-to-day functioning, an intriguing question for researchers is: When faced with a task, how do adults and children choose which object to use? An obvious consideration should be whether the physical properties of an object meet the demands of the problem. For example, when choosing an object to open a package, it is important that it be slim enough to fit between the flaps of the box, as well as sharp enough to puncture and slice the tape. The facets of a perceived physical relationship between a tool and its environment, termed *affordances,* have been suggested often as an important factor for tool-use decisions (e.g., Gibson, 1979; Osiurak, Jarry, & Le Gall, 2010; van Leeuwen, Smitsman, & van Leewen, 1994; Vingerhoets, Vandamme, & Vercammen, 2009; Wagman & Carello, 2001, 2003). Indeed, according Gibson’s ecological perspective (1979), we do not perceive the individual physical characteristics of tools (e.g., lightweight, sharp, thin) per se. Rather, we perceive the possibilities for action they afford (e.g., effective for slicing).

Although a consideration of an object's affordances may be helpful in some cases, it would not be time-effective to conduct a detailed examination of the physical affordances of many tools each time we must solve a problem. Instead, we likely also rely on our stored knowledge of an object's normal function (Casler & Kelemen, 2007; Creem-Regehr & Lee, 2005; German & Barrett, 2005). In other words, we may tap into existing mental representations of the typical functions of classes of objects. Consider a situation in which you have just received a package in the mail that was taped shut: It would be much too time consuming to examine the physical properties of each implement in at your disposal to find a suitable tool to help you. Instead, being able to quickly match a certain type of object (for example, a box cutter) to a particular task would allow us to achieve our goal in more timely fashion. Indeed, according to Lin and Murphy (2001), functional relationships between objects are one of the ways that people are able to efficiently organize their mental representations.

However, relying on stored representations of function is not without its pitfalls. By associating a particular object with only one, or just a few, uses, we may overlook unconventional ways in which objects could solve problems. For example, in a well-known experiment by Karl Duncker (1945), adult participants were presented with the task of mounting three candles to a door such that they would not drip on the table below. Among other distracter objects, they were provided with three candles and three boxes filled with matches, candles, or thumbtacks. The solution required emptying the boxes and tacking them to the door as platforms for the candles. More than half of the subjects failed to solve this task, presumably because they were “fixated” on the function of the boxes as containers, instead of considering the atypical function of platforms. Thinking about objects in this relatively inflexible way has been termed *functional fixedness,* and has sometimes been considered detrimental to problem solving (e.g., German & Defeyter, 2000; Keane, 1989).

Problems using artifacts that evoke functional fixedness, such as Duncker's candle study, can be classified as a specific type within a broader class of problems, termed *insight problems.* Insight problems are known for having poorly defined problem spaces (mental representations of the problem and possible solutions) and for containing "impasses," or periods of time during which solvers are unsure of how to proceed (Knoblich, Ohlsson, Haider, & Rhenius, 1999). Typically, insight problems cue an initially constrained representation of the problem, resulting in early attempts that are ineffective. According to Knoblich et al. (1999, p. 1535), "[t]he initial representation activates potentially useful knowledge elements (categories, chunks, concepts, constraints, methods, operators, procedures, rules, schemas, etc.). These knowledge elements implicitly define a space of possible solutions." However, the required solution cannot be reached using only the automatically generated knowledge elements. The solution to an insight problem therefore requires the "restructuring" of one's mental representation of the problem (Dominowski & Dallob, 1995). In Duncker's candle problem, the initial, constrained mental representation of the problem involved viewing the boxes only as containers. The insight occurs when a person mentally restructures the problem such that the function of the boxes is expanded to include "platform for candles."

The capacity for humans to be "fixated" on the semantic identity of objects, while ignoring paths of action more appropriate to a given task, may have a neurological explanation. For instance, Hodges, Spatt, and Patterson (2000) have argued that there are two separable brain systems which govern our interactions with objects while problem solving. Specifically, our "semantic" knowledge of objects may be underlain by an inferotemporal brain region that allows us to associate particular objects with certain functions and actions (the "what" pathway). In contrast, our "mechanical" problem-solving ability, which allows us to effectively plan and execute actions based on visual and/or tactile affordances, may be governed by a parietal lobe system (the "how" pathway). In their work, patients with semantic dementia (the progressive deterioration of conceptual knowledge or semantic memory) performed poorly on tests of functional semantic knowledge, in which they had to determine the associated functions of common objects. However, these patients could easily solve a novel tool task, in which they had to choose the most affordant one from a set of novel tools to achieve a goal. Given that these patients could easily manipulate objects to effectively achieve ends, Hodges and colleagues (2000) have argued that there is a dissociation between our conceptual knowledge of objects and a neural system governing mechanical problem-solving ability. Further brain imaging studies have supported the notion of separate neural pathways for conceptual object knowledge and action-perception systems (Canessa et al., 2008; Kellenback, Brett, & Patterson, 2003). Therefore, it may be that for normal populations solving functional fixedness tasks, the (otherwise useful and adaptive) semantic information from the "what" pathway may be interfering with or overriding a more affordance-based, mechanical problem-solving ability.

Functional-fixedness has long fascinated researchers, and with good reason. It highlights our proficiency at automatically associating objects with particular functions, even to the point of hampering tasks in which non-typical usages are necessary. Often used to accomplish means-ends tasks, tools are of particular importance for understanding fixation, because they inherently embody specific semantic identities (Creem-Regehr & Lee, 2005), while in reality they may afford multiple usages. Given the centrality of tools to human survival historically (Kacelnik, 2009) and to adaptive functioning currently, the manner in which young children come to understand tools is of theoretical importance. Some interesting avenues for research by cognitive developmentalists, then, concern young children's tool-to-function associations. How do children come to associate objects with particular functions? Are these relatively strong and fixed from the point at which they are learned, or do they strengthen as children age and get more exposure to objects? What cognitive characteristics are associated with overcoming functional-fixedness? In the next two sections, I will present research findings from two somewhat conflicting lines of thought regarding children's development of object-function concepts.

Functional Fixedness vs. Functional Fluidity in Children

Although the concept of functional fixedness has been well-documented in adults, there has been little research on the phenomenon in children. This is somewhat surprising, given the tradition in developmental psychology of tracking the age-related trajectories of children's problem-solving skills (e.g., Bates, Carlson-Luden, & Bretherton, 1980; Bauer, Schwarde, Wewerka, & Delaney, 1999; Brown, Kane, & Echols, 1986; Chen & Siegler, 2000; DeLoache, 1995; Klahr & Robinson, 1981; Piaget, 1952; Welsh, 1991). It is clear from previous research that adults have difficulty mentally dissociating objects from their typical functions, especially when those typical functions are first made salient. Are young children inherently "functionally fixed"? Or, on the other hand, are younger children *less* constrained with regard to typical functions than are older children? It seems possible that younger children, who presumably have had fewer experiences using objects, would be less likely to think automatically about the functions of everyday tools and objects.

One line of work, by German and Defeyter (Defeyter & German, 2003; German & Defeyter, 2000), has attempted to answer these questions. German and Defeyter (2000) tested children on problem-solving tasks designed to tap functional fixedness. In one experiment, 5-, 6-, and 7-year-olds were given a problem analogous to Duncker's candle problem. Here, children were told a story in which a small model bear needed to reach a high shelf in a toy house. Children were shown several objects, including a box, which they could stack to make a platform tall enough for the bear to reach its goal. Without the box, the other objects would not reach the necessary height, so the solution required turning over the box and stacking the other objects on top of it. In the *preutilization* condition, the objects were presented inside the box, while in the *no-preutilization* condition the objects were presented next to the box. In the no-preutilization condition, the oldest children solved the problem much more quickly than the 5- and 6-year-olds. However, somewhat surprisingly, in the preutilization condition, 6- and 7-year-olds actually performed the most poorly, taking more than *twice* as long as the youngest group to solve the task. Apparently, priming the typical function of the box during the preutilization condition caused older, but not younger, children to become "fixed" on the box's function as a container, failing to consider the alternate usage of "platform."

Why would younger children be less functionally fixed than older children? Defeyter and German (2003) outlined two hypotheses. One is that younger children think more *fluidly* about object function than older children: While they can associate tools with their typical functions, these mental associations are more flexible than older children's, and this is a result of having less experience with them. An alternative hypothesis, however, is that younger children simply have relatively deficient knowledge about the typical functions of objects. When presented with the "preused" box during the stacking task, younger children may have been able to conceive of using it as a platform, because they had no other pre-existing usage already associated with "boxes." The authors ultimately rejected the latter hypothesis, citing evidence that even very young children associate objects with specific functions.

German and Defeyter (2003) built upon their earlier findings with another set of experiments aimed to investigate children's functional fixedness. In this work, 5-, 6-, and 7-year-old children were told a story about a make-believe character who was going on a voyage. Children were then presented with several items and told the items were the things the character needs for his voyage. In the *function demonstration* condition, the experimenter primed children with the typical function (e.g., by using a pencil to write a word, or using a straw to drink from a cup) of one of the "target" objects that would work to solve the task. After the experimenters' demonstration, children were asked to repeat what the item was used for (e.g., holding the pencil, the experimenter asked "[c]an you tell me what this is for?"). In the baseline condition, children were simply presented with the set of objects, and did not see any functional demonstrations. Then, all children were presented with the problem-solving task of extracting a toy animal from a plexiglass tube, in which only the target tool (either a pencil or a straw) would work to solve this task.

The results of this study again demonstrated a rather counterintuitive finding: 5-year-olds in the function demonstration condition solved the task more quickly than older children in the same condition. Finally, the authors performed a second study to experimentally disentangle whether younger children's advantage was due to greater functional fluidity or to a relative deficit in functional knowledge. Using completely novel stimuli and novel functions (e.g., a plexiglass rod that could be used "to make light" by activating LEDs when it touched a glass holder), children otherwise followed the same procedure as in the first study. Again, 5-year-olds in the function demonstration condition solved the task much more quickly than older children. Because novel tools and functions were used, and both older and younger children readily learned object functions, the authors concluded that the age difference was due to greater functional fluidity (and not deficient function knowledge) in younger children.

The results from the experiments by German and Defeyter seem to suggest that there is a marked shift in the way that young children conceptualize objects. Around five years of age, these studies indicate that children think more fluidly about objects, able to override the accepted usage of a tool and flexibly employ it in the manner that fits task demands. However, older children in these studies were slower to adopt task-relevant functions for tools that had other functions already associated with them. In the following section, I will consider an opposing viewpoint that implies the case may not be quite as simple as the trend described above.

Evidence for Knowledge of Object Function at a Young Age

Although the work of Defeyter and colleagues provides some evidence that children are "immune" to functional fixedness before the age of six, these findings are somewhat at odds with the growing body of literature suggesting that young children, and even infants, are indeed quite sensitive to object function and automatically associate functions with particular objects. For example, Futó, Téglás, Csibra, and Gergely (2010) used a looking-time paradigm to investigate 10-month-old infants' intuitions about objects. They found that, in contrast to perceptual differences, demonstrating two different object functions allowed 10-month-olds to infer the presence of two distinct objects behind an occluder. Furthermore, in a second experiment, the demonstration of two different functions by a single artifact produced the illusion of two objects, suggesting that infants expected only one function to be associated with a given object. These authors concluded that, like adults, infants make use of functional information to guide their object categorization, and make one-to-one inferences between specific functions and single objects.

In the same vein, Hunnius and Bekkering (2010) found evidence that even young infants expected given objects to be associated with particular functions. They showed videos of adults performing actions with everyday objects to 6-, 8-, 12-, 14-, and 16-month-old infants. Half of the infants viewed an object being acted upon in a manner consistent with its typical function (e.g., a phone being brought to the ear). The other half of the infants viewed an object being acted upon in a non-typical manner (e.g., a cup being brought to the ear). Notably, for all age groups, infants made more anticipatory glances to a given target location when an actor brought a functionally-associated object to that location (e.g., a cup to the mouth) than when he used a non-functionally-associated object (e.g., hairbrush to mouth). These results are striking in that they provide evidence that infants as young as six months of age have learned the associated actions, and, presumably, the functions, of certain objects.

Similar to the aforementioned infant studies, recent preschool literature has also seen a trend toward recognizing the importance of functional identity to conceptualizing objects. In a study of 3-year-olds' artifact naming, Diesendruck, Markson, and Bloom (2003) reported that the shape bias – the tendency to extend a novel object's name to unfamiliar objects with the same shape – was eliminated when children were given an explanation about why the objects were perceptually similar, even though they were intended to serve different functions. Here, 3-year-olds were presented with three objects: one target object, one object similar in shape, but different in function, to the target object, and one object similar in function, but not shape, to the target. When children were given no information about the objects' functions, they extended the target object's name according to shape. However, when children were told the functions of all three objects, they used functional similarity to guide their name extension. These results suggest strongly that preschoolers take functional information into account when forming conceptual categories. In a related vein, another study asked 4-year-old children to invent the names for novel objects. These objects were designed to be unfamiliar to children and adults, and their functions were not readily identifiable by sight. In this study, children who were shown the functions of the objects overwhelmingly used function, as opposed to perceptual categories, to name them, such as a "ball launcher" or "circle drawer" (Kemler Nelson, Herron, & Holt, 2003).

Young children's sensitivity to function is further highlighted by their ability to rapidly construct enduring object-function mappings. With regard to learning functions, *mapping* refers to the process by which children (and adults) learn to associate a specific function with a given tool or object (Casler & Keleman, 2005). In their study of object-function mappings, Casler and Kelemen (2005) demonstrated using a novel tool to perform a particular function (launch a toy out of a tube). They then gave 4- and 5-year-olds the choice between the demonstrated tool, and a second, equally functional tool, to perform the same action. Children overwhelmingly chose the demonstrated tool as being the one “for” the launching action. Furthermore, they replicated this result with children as young as 24 months of age, and even after a 24-hour delay (Casler & Kelemen, 2005, 2007). Moreover, another study by Wohlgerlernter, Diesendruck, and Markson (2010), showed that 2- and 3-year-olds believed the intended purpose of a given object was the function they had seen intentionally and consistently demonstrated.

Further evidence that preschoolers expect a given tool to be associated with only one function comes from work by Casler, Terziyan, and Greene (2009). Here, 2- and 3-year-old children were shown a novel tool and its function by an experimenter. Subsequently, the children viewed a puppet use the tool to perform either the demonstrated task or a different task while out of sight of the experimenter. When the puppet used the tool in a different manner than the experimenter, children of both age groups responded normatively, by protesting his actions, attempting to correct him, or “tattling” on him. Clearly, then, even young preschoolers represent cognitively what particular tools are “for.” Taken together, the studies reviewed in this section suggest that children categorize objects according to function, name objects according to function, and learn to associate one function with one object from a very early age.

Collectively, these studies highlight a curious paradox. A good deal of research has shown that preschoolers (and even infants) readily form mental associations between particular objects and specific functions. However, other work (most notably that of German and colleagues) has shown that younger children are actually better than older children at functional fixedness problems, which involve mentally dissociating prescribed functions from objects. Of course, these two lines of thinking are not mutually exclusive: It may be that, although both older and younger children automatically map functions to specific objects, younger children are simply more capable of dissociating objects from their typical functions. This notion implies that 5-year-olds conceptualize object functions in a *qualitatively different* manner than 6- and 7-year-olds, apparently undergoing a shift from more flexible to less flexible object-to-function mappings.

The Role of Executive Functions

Interpretations of these disparate patterns of results usually involve appeals to children's emerging "design stance," an increasingly complex reasoning system in which children learn that objects are designed to fulfill purposes determined by their inventors (e.g., Gelman & Bloom, 2000). A different possibility is that children's ability to regulate associations between typical functions and objects may change with age, and may be underscored by development of executive functions (EFs) which are implicated in goal-directed behavior. Indeed, an examination of the cognitive mechanisms underlying insight problem-solving should shed light on how and why older and younger children may behave differently on such problems. Certain cognitive characteristics, particularly aspects of executive functioning, may be heavily tapped during problem solving, and an understanding of the developmental trajectories of these abilities may help to predict age-related performance on insight problems.

Executive functions have been characterized as goal-directed behaviors that allow individuals to preempt automatic or established behavior or patterns of thought (Garon, Bryson, & Smith, 2008). Underscoring the importance of these capacities, early individual differences in executive functioning are predictive of a wide range of competencies, including mathematics (Bull & Scerif, 2001; Espy et al., 2004), reading (e.g., Blair & Razza, 2007), and general intelligence (e.g., Ardila, Pineda, & Rosselli, 2000). One component of executive function thought to be important to problem solving is inhibitory control. From a cognitive standpoint, *inhibitory control* involves the suppression of pre-existing cognitive patterns or information (Michel & Anderson, 2009) and has been experimentally linked to the development of prefrontal regions of the brain (Durston, Thomas, Yang, Ulug, Zimmerman, & Casey, 2002). Like other facets of executive functioning, inhibitory control shows steady increases during early childhood. In particular, there are marked increases in inhibitory control between the ages of three and six (Kochanska, Murray, Jacques, Koenig, & Vandegeest, 1996). In children, cognitive inhibition is tested with tasks in which children must hold a rule in mind, respond according to the rule, and suppress prepotent responses (Garon, Bryson, & Smith, 2008). For example, in the day-night Stroop task, children must respond to cards picturing a bright sun by saying the word "night" and to cards picturing a moon and stars with the word "day" (Gerstadt, Hong, & Diamond, 1994). In this way, they must suppress a more natural tendency to verbally associate the word "day" with card showing a sun, and instead respond with the word "night".

As discussed in the first section, insight problems necessitate overcoming a prepotent response (such as an expected usage for a particular tool, in the case of functional-fixedness tasks) to solve a problem. Several authors have theoretically connected insight problem-solving with inhibitory control in children (e.g., Diamond & Taylor, 1996; Vlamming, Hare, & Call, 2009). It makes sense that inhibitory control should be related to performance on insight problems: While tests of inhibitory control hinge on one's ability to hold back automatic responses to stimuli, success at insight problems requires overcoming initial, automatically-generated mental representations. For instance, when faced with the candle problem, the ability to suppress the associations between the objects and their prescribed functions might allow one to solve the problem more effectively, because disengaging from typically-associated representations should allow one to focus solely on the physical relationships among the objects at hand. Although some have linked inhibitory control to problem-solving ability, there has yet to be an experimental examination of the relationship between inhibitory control and insight problem solving in children.

A second component of executive functioning that may influence performance on insight problems is *working memory*. Working memory refers to the faculty that allows one to actively hold information in mind in a manner that is stable (i.e., resistant to disruption), yet flexible. Information held in working memory may be acted upon—for example, it can be added to, removed, changed, or judged (Bledowski, Kaiser, & Rahm, 2010). Like inhibitory control, working memory ability increases with age throughout childhood (Dempster, 1981). For example, older children outperform younger children in tasks that require them to remember a series of letters while simultaneously adding digits (Gaillard, Barrouillet, Jarrold, & Camos, 2011). Among preschoolers, working memory is typically tested with tasks that require children to hold information in mind over a delay, or hold information in mind and then manipulate it (e.g., by remembering a string of words and repeating them backward; Garon, Bryson, & Smith, 2008).

With regard to insight problem solving, one’s ability to hold information in mind while manipulating it should be important. For example, during functional-fixedness tasks using tools, participants must hold in mind the theoretical goal state—that is, the physical configuration of the finished task. While considering the goal state, an individual must also conceive of one (or multiple) potential avenues for solving the problem. Even more specifically, one must consider the grip and physical trajectory necessary for using the tool, while imagining the spatial orientation that the tool’s functional end must take when reaching the goal object. Especially for young children, these mental operations may be taxing. Although some research has suggested that there is not a relationship between insight problem solving and working memory (Lavric, Forstmeier, & Rippon, 2000), other studies have indicated a positive association (e.g., Chein, Weisberg, Streeter, & Kwok, 2010). To date, no studies have experimentally linked performance on functional fixedness problems and working memory in children.

The Current Research

Although even very young children are known to use functional identity to guide their intuitions during problem-solving (e.g., Casler & Kelemen, 2005), other research has suggested that younger children think more flexibly about object function than older children (Defeyter & German, 2003; German & Defeyter, 2000). Therefore, the extant literature regarding children's conceptions of object function lacks a clear answer to the question: When reasoning about objects, are younger children less reliant on functional identity than older children? Although German and Defeyter (2000) have suggested that they are less reliant on object function and even display "immunity" to functional fixedness (p. 707), it is unclear just why younger children would have qualitatively different conceptual mechanisms for object-function mappings than older children. Furthermore, structural and causal features of objects other than functional identity are important for successfully completing tool-use tasks (McCarty, Clifton, & Collard, 1999, 2001). Even young children have been shown to take into account physical features of tools that are relevant for their use such as rigidity, length, size, and shape of the functional end (Brown, 1990; Chen & Siegler, 2000; Cox & Smitsman, 2006; Gardiner, Bjorklund, & Greif, in press; Gredlein & Bjorklund, 2005; Klatzky, Lederman, & Mankinen, 2005; Steenbergen, van der Kamp, Smitsman, & Carson, 1997). The current research investigates the relative importance of physical structure and functional identity for using objects as tools.

The function of an object may be linked to one's representation of that object via a thematic relation. According to Lin and Murphy (2001), *thematic relations* are the links among objects, people, events, and other entities that frequently interact or occur together. Thematic relations can be spatial, functional, causal, or temporal in nature. For instance, while a spatial thematic relation might link *car* and *garage*, a functional relation may link *spoon* and *eating*. Thematic concepts are distinct from taxonomic categories, because their members may bear little, if any, resemblance to each other. Thematic relations have been found to play key roles in the way both children and adults organize concepts (e.g., Borghi & Caramelli, 2003; Lin & Murphy, 2001; Lucariello, Kyratzis, & Nelson, 1992; Markman, 1981; Nguyen & Murphy, 2003; Sachs et al., 2008).

Therefore, the current research will ask the question: When faced with a choice between a categorically-related and a structurally appropriate (though not categorically-related) tool, which will children use to solve a task? The term *categorically-related* was chosen rather than the term *functionally-related* to avoid any confusion that might arise from multiple meanings of the word "functional." Because in the current studies, objects that are "functionally-related" are not actually "functional" to solve the tasks (i.e., they are not physically capable of solving), I have avoided the term *functionally-related*. Instead, I will refer to objects as *categorically-related* or *related by functional category*.

If younger children choose tools based on functional category equally or more often than older children, then the idea that younger children are immune to functional fixedness can be rejected. In contrast, if younger children choose based on functional category less often than older children, the hypothesis that younger children are immune to functional fixedness would be supported. Furthermore, allowing children to choose between a related and unrelated object that are *both* affordant can help elucidate the role that functional relationships play in problem solving. If there are multiple structurally appropriate tools, do children automatically choose the one related to the problem by a functional relationship? Finally, a third avenue for exploration concerns strategies for mitigating the effect of functional fixedness. Specifically, mentally visualizing possible solutions may aid children in overcoming the tendency to choose structurally ill-suited objects based on functional relationships, because they should be able to predict the potential failure or success of the objects by imagining their action paths. If mental imagery helps children to choose structurally appropriate objects based on affordances, this will shed light on the underlying mental processes associated with affordance-based problem solving (e.g., use of visuospatial representations and forward planning). The following three studies will address each of these questions.

EXPERIMENT I

Although functional fixedness during problem solving has been demonstrated often in adults, the extent to which young children display functional fixedness is less clear. While much research indicates that even very young children expect objects to be associated with particular functions, other studies seem to show that younger children are less reliant upon prescribed object functions than older children. If it is the case that older and younger children conceptualize object functions in a qualitatively different way, this is a striking finding. However, it is unclear just *why* younger children would have more flexible object-function mappings than older children. In addition, there is reason to believe that components of executive function should predict performance on functional-fixedness tasks, but these abilities increase with age.

It is also worth noting that certain methodological features of the studies on functional fixedness in children may partially explain their counterintuitive findings. For example, recall that in the experiments by Defeyter and German (2003), experimenters first demonstrated to children the typical functions of the target objects (e.g., by saying “[t]hese are things Sam uses for writing” (p. 140) and then writing a word with a pencil). Afterwards, they showed the target objects to children and asked, “[c]an you tell me what this is for?” Children always answered correctly with the function that had been demonstrated immediately before (e.g. “for writing” and “for drinking”). Although this step was meant to ensure children’s retention of intended functions, it may have actually implied that writing or drinking was the *only* thing those tools were to be used for. Older children, more so than younger children, may have interpreted this as a statement of a rule, because they may have logically assumed that the experimenters asked them these questions *for a reason*, and that the questions were meant to imply that the objects were only to be used for the demonstrated functions. After being told what the tools were used for, and then being asked to repeat their functions, older children may have been responding to the implicit convention of conversation that utterances are purposeful. Indeed, according to Sperber and Wilson (1987, 2004), speech acts are generally interpreted as purposeful, and listeners tend to search for meaning in any given utterance. Therefore, older children (who are presumably better versed in the norms of dyadic communication) may have translated the reinforcement as a rule or instruction from experimenters and thus avoided contradicting the described usage.

In the current research, we will avoid this type of interpretation by presenting children with problems in which the functional identities of the objects are not explicitly stated by experimenters but are made salient by the nature of the problems themselves. Specifically, we will present children with problem-solving tasks in which a tool is functionally related to a task by way of thematic relations. The proposed experiments use an object-choice paradigm, in which participants must select from a set of objects to solve a task. The problem tasks will be designed such that one of the object choices (the "categorically-related" object) is linked to the task by a functional thematic relation. However, this object will be physically ill-suited to solve the task. Therefore, although it will be related by functional category, it will not actually work to solve the task because structural constraints will preclude it from successfully achieving the goal (e.g., its functional end will be too large to fit into the goal apparatus). The tool that will work to solve the task (the "unrelated" object) will be *unrelated* to the task by functional category, but will have suitable physical characteristics for solving it. There will also be a third object choice (the "distracter" object), which will be neither thematically related to the task nor physically capable of solving it. Finally, measures of working memory and inhibitory control will be administered to assess their relationship with insight problem solving.

Given the available objects, children's choices should follow one of two patterns: (1) they will choose the unrelated object first and be able to solve the puzzle quickly, or (2) they will choose the categorically-related (and non-working) object first, and take longer to solve the puzzle, because solving will require switching to the unrelated object, and potentially perseverating with the categorically-related object. Therefore, children will either choose based on affordances alone, or they will choose based on functional category (categorically). Choosing categorically will be indicative of functional fixedness, because children will be basing their choices on functional category and *ignoring* the affordances of an object that, when used in a novel way, would work to solve the problem. If the pattern of results obtained by German and Defeyter (2000; Defeyter and German, 2003) is accurate, and functional fixedness in children increases with age, then older children should be more likely to choose categorically than younger children (and younger children more likely to use affordances alone to guide their choices). Finally, I expect that, controlling for age in months, the measures of working memory and inhibitory control will be associated with more successful problem solving outcomes, such that children within each age group with higher levels of executive function will take less time to solve the tasks and will be more likely to choose the unrelated object than children with lower levels.

Method

Participants. Twenty-three younger children (13 male; *M* age = 4 years, 2 months, range: 36 – 59 months) and 22 older children (12 male; *M* age = 6 years, 1 month, range = 60 – 86 months) participated. Children were recruited by letters sent home to parents at local preschools. Parent-reported ethnicity was 52.7% White, 3.6% Black, 3.6% Asian, 29.7% Mixed, 1.8% "Other," and 9.1% no reply.

In addition, 24 adults (12 male) participated to fulfill a research participation requirement for an Introductory Psychology course at a suburban university.

Measures.

Children. For children, two measures of inhibitory control, one measure of working memory, and one measure of memory span were administered.

Day-Night Stroop. The day-night Stroop (DNS) task was used to measure inhibitory control in children and was replicated from Gerstadt et al. (1994). For this task, the experimenter first presented children with a light blue card picturing a yellow sun and a dark blue card picturing a moon. Children were told that in this game, they were to say *night* when they saw the card picturing a sun and to say *day* when they saw the card picturing the moon. After five warm-up trials, children were presented with 16 cards in a fixed, pseudorandom order. The number of correct responses out of 16 was recorded.

Tapping. The tapping task, used to assess inhibitory control, was adapted from Luria (1966). In this task, children were required to tap one time when the experimenter tapped twice, and to tap two times when the experimenter tapped once. The experimenter first explained the rules of the game, and then gave children two warm-up trials, followed by praise if correct or a restatement of the rule(s) if incorrect on one or both trials. Following the warm-up trials, children were given 16 test trials in which the experimenter tapped once or twice in a fixed, pseudorandom order. The number of correct responses out of 18 was recorded.

Animal flipbook. The animal flipbook task was used to assess working memory and was adapted from Willoughby, Wirth, and Blair (2010). In this task, the first page of a flipbook depicts an animal figure and a colored dot. Both the dot and the animal are situated within an outline of a house. The child is then asked to name both elements (the animal and the color). Next, the page is turned, revealing just the outline of the house from the previous page. The experimenter asks the child to name the animal that was in the house. The child is thus required to retain two pieces of information in mind (the color and the animal) while naming one of them. During a total of seven trials, complexity increases such that there is one flipbook page with one house, three pages with two houses, and three pages with three houses. The total number of correct responses (out of 16) is recorded.

Forward word span. The forward word span task (FWS) was modified from the backward word span task used by Carlson, Moses, and Breton (2002). In this task, the experimenter first demonstrated repeating words by saying two words ("book, cup") and asking her assistant to repeat them back (saying, "book, cup"). Then children were asked to repeat these words as a practice trial. During test trials, experimenters asked children to repeat a string of monosyllabic, non-semantically related words, with the length of the string increasing by one word with each successful trial. The longest string length repeated correctly was recorded (strings consisted of 2 - 6 words). It was decided to use a forward word span task, because pilot testing revealed that very few children were able to correctly answer even the easiest backward word span items.

Adults. Adults completed one working memory measure and one inhibitory control measure.

Memory squares. The measure that assessed working memory in adults was adapted from Bugg, DeLosh, & Clegg (2006). Adult participants completed a computerized task in which they saw a series of large (20 cm by 20 cm) and small (3 by 3 cm) squares. Their task was to keep track of how many large and small squares they saw, respectively. Squares appeared on the screen, one at a time, for 2000 ms each. Each square was followed by a fixation point that appeared for 150 ms. Each of eight test trials included 11-14 small squares and 11-14 large squares. Three of the trials were easy trials, with only 2 - 3 switches from one type of square to another (for example, a trial with two switches might be: 6 large squares followed by 13 small squares followed by 6 large squares). The remaining five trials were difficult trials, in which there were 11 switches from one type of square to the other. Trials were presented in a fixed, pseudorandom order, beginning with an "easy" practice trial. At the conclusion of each trial, participants were prompted to write down how many large and small squares they saw, and the number correct (out of 16) was recorded.

Number Stroop. We assessed inhibitory control in adults with a measure adapted from Windes (1968). Here, participants were instructed to count the number of identical digits they saw on a computer screen and to respond with the number keys on the keyboard. Stimuli were either congruent (i.e., the quantity of digits shown matched the identity of the digit, for example, 333) or incongruent, in which the quantity did not match the number's identity (e.g., 1111). Correctly responding during incongruent trials thus required participants to overcome the automatic processing of the number's identity. During test trials, sets of digits appeared on the screen until participants keyed in a response, and then a new set of digits immediately appeared. They viewed three consecutive test trials (22, 33, 1111) and then were told that the correct answers were 2, 2, and 4. Participants then proceeded to complete 60 test trials, in which 30 were congruent and 30 were incongruent. Number of correct responses on the incongruent trials (out of 30), as well as response latency, were recorded.

Materials. For each of three problem-solving tasks and one practice task, there were three object choices, one goal apparatus, and a small animal figurine. In addition, a wooden folding tray was used on which to place the object choices. The three problem-solving tasks are pictured in figure 1.

Practice task. The goal apparatus consisted of a blue rubber ball and a strip of electrical tape placed on the table perpendicular to the participant's shoulder span. The animal figure was a small plastic turtle. The ball was placed on the side of the tape closest to the participant, and the turtle was placed on the far side of the tape. The problem was to move the ball back over the line to the turtle. The three object choices were: a dark brown shoe horn, a thin wooden rod covered with orange and green electrical tape, and a blue plastic cylinder. These objects were chosen to be relatively unfamiliar to children, and thus to not have prescribed functions associated with them. They were also chosen so that any of them were capable of solving the task.

Test problems. For each test problem, there were three object-choices. One of the object-choices (the categorically-related object) was related to the task by functional category, but not physically capable of solving it. Another of the choices (the unrelated object) was affordant for solving, but not thematically or functionally related. The third choice (the distracter object) was neither thematically related to the task, nor physically capable of solving it.

Leaves problem. For this task, the goal apparatus was a red and white model barn that had realistic-looking leaves immediately within its open doors. The problem task was to get the leaves out of the barn. The animal figurine was a small plastic cat. The categorically-related object was a rake that was too wide to enter the barn doors. The unrelated object was a grey ruler. The distracter object was a large cardboard tube covered with blue and red electrical tape. The solution required inserting the ruler (the only object that would fit) into the barn doors and dragging out the leaves.

Soup problem. For this task, the goal apparatus was a medium-sized saucepan that was half-filled with water (representing soup) and a small white bowl. The problem task was to move some of the soup from the saucepan into the small bowl. The animal figurine was a small plastic gorilla. The categorically-related object was a grey slotted ladle. The unrelated object was a small orange flower pot with an intact bottom. The distracter object was a white plastic funnel. The solution required dunking the flower pot into the saucepan to transport water.

Covering problem. For this task, the goal apparatus was a plastic tupperware container filled with 2 cm wooden spheres representing food. The problem task was to cover the tupperware container. The animal figurine was a small plastic dog. The categorically-related object was a blue tupperware lid that was too small to cover the container. The unrelated object was a clear plastic bowl. The distracter object was a green plastic fruit carton. The solution required overturning the plastic bowl to cover the Tupperware container.

Procedure. Child participants were tested in a quiet room at their preschools. Adult participants were tested in a laboratory room at a university. All participants began by completing the EF measures. For adults, half completed the memory squares task first, and half completed the number Stroop task first. Children completed the EF measures in one of two orders (animal flipbook, tapping, FWS, DNS or DNS, FWS, tapping, animal flipbook), such that half completed an inhibitory control measure first, and half completed a working memory task first.

Following the EF measures, participants were told they were going to play a game about helping animals. They were told that when they played the games, they were only allowed to touch the things that would be on the tray next to them (where the object-choices would be placed), and not the things on the table in front of them (where the goal apparatuses would be placed). The practice problem was always presented first, followed by each of the three test problems.

The test problems were administered such that for all age groups, each problem occurred in every order (first, second, or third) an equal number of times, and each problem followed each other problem an equal number of times. During all problems, the goal apparatus was first placed on the table, and then a story script, which described the problem to be solved, was read (see the Appendix for the scripts). The research assistant then placed the object-choices on the tray to the participant's right. Objects were placed such that the categorically-related, affordant, and distracter objects were each located on the left, right, and center once during each testing session. Furthermore, across all participants, each tool type was placed in each position (left, right, or center) during each problem task (leaves, covering, and soup) an equal number of times. After the objects were placed on the tray, participants were encouraged to use any of them to help them solve the task. Trials ended after participants either solved the task, expressed that they did not wish to keep trying, or 120 seconds elapsed.

Coding. To assess children's performance on the EF and span measures, an undergraduate assistant marked the number correct on each task on site during the experimental session. Adults' performance on the EF measures was recorded by the software used to assess each measure.

To assess performance on the problem-solving tasks, a trained, independent rater who was blind to the purpose of the study watched all videos. For each task, the rater recorded (a) the first object used in an attempt, (b) the amount of time taken to solve the task ("insight time"), and (c) whether the task was successfully solved. In addition, a second rater coded one third of the vidoes. Interrater reliabilities were $\kappa = 1.0$, $\kappa = .87$, and $r(24) = .92$, for the number of tasks solved, the first object used, and insight time, respectively.

Results

EF and Span Measures. Independent-Samples *t*-tests indicated that older children outperformed younger children on all EF and span measures (see table 1 for means; tapping: $t(43) = 4.21$, $p < .001$; DNS: $t(43) = 4.52$, $p < .001$; Flipbook: $t(43) = 4.96$, $p < .001$; FWS: $t(43) = 4.28$, $p < .001$). Next, Pearson correlations revealed that for children, all pairs of measures were correlated at least at the $p < .01$ level. However, after controlling for age in months, FWS was not correlated with any of the EF measures (p's > .05). In contrast, controlling for age in months, the Flipbook task (working memory) was moderately correlated with both measures of inhibitory control (tapping and DNS, both *p*'s < .05). The two measures of inhibitory control were strongly correlated, $r(42) = .63$, $p < .001$. Therefore, they were averaged to yield a composite inhibitory control measure, which will be used for the remaining analyses.

Problem-solving Tasks. An independent coder indicated whether each problem task was successfully solved. Because each participant attempted three problem tasks, summing the number of problem tasks solved resulted in a number that ranged from 0-3. A one-way analysis of variance (ANOVA) revealed a significant effect of age group (younger children, older children, and adults) on number of problem tasks solved, $F(66, 2) = 12.5$, $p < .001$. Younger children ($M = 2.57$, $SD = .590$) solved fewer problem tasks than older children ($M = 3.00$, $SD = .000$; $t(43) = 3.46$, $p = .001$), or adults ($M = 3.00$, $SD = .000$; $t(43) = 3.46$, $p = .001$). There were no differences between older children and adults ($p > .05$), as all older children and adults solved each puzzle.

For each problem, the latency to achieve insight was calculated by summing the seconds from the beginning of each task to the point at which the participant began using the unrelated object in the correct manner to solve the task[1]. Latencies were recorded

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[1] We used this point, rather than the moment at which the end goal was achieved (e.g., all leaves were removed from the barn) because some participants were able to achieve the end goal after arriving at the solution more quickly than others, due to factors such as leaves clinging to the entrance of the barn. Therefore, we considered the problem solved

during each problem task and then summed to yield an overall latency measure ("insight time") for each participant. A one-way ANOVA revealed a significant effect of age group on insight times, $F(66, 2) = 36.2$, $p < .001$. Younger children (M = 86.7 s, SD = 50.1 s) took more time to achieve insight than older children (M = 34.48 s, SD = 13.9 s; t (43) = 4.72, $p < .001$). Both age groups took longer than adults (M = 11.58 s, SD = 3.33 s; older children: $t(44) = 7.91$, $p < .001$; younger children: $t(45) = 7.34$, $p < .001$).

Next, object choice was examined. For each problem, participants were scored with a *1* if they chose the categorically-related object and a *0* if they chose the unrelated object in their first problem-solving attempt[2]. This yielded a "categorical score" that ranged from 0 – 3. Higher values indicated choosing more often based on functional category, and lower values indicated choosing more often based on physical structure alone. A One-Way ANOVA revealed a significant effect of age group on categorical scores, $F(66, 2) = 64.9$, $p < .001$. Independent samples t-tests revealed that younger children (M = 2.30, SD = .780) had higher categorical scores than older children (M = 1.68, SD = .703; $t(43) = 2.815$, $p = .007$), meaning that they were more likely than older

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when: (1) in the leaves task, the participant grasped the ruler and began raking leaves (2) in the soup task, when the participant grasped the pot and began to dunk it in the pan and (3) in the covering task, when the participant overturned the bowl and moved it toward the tupperware container to cover it. If a child failed to solve the problem, he or she was assigned a latency of 120 seconds.

[2] The distracter tool was chosen first on only two occasions, both times by younger preschoolers. In these two cases, children's scores were determined by the object they chose after their unsuccessful attempt with the distracter tool.

children to initially choose the categorically-related object, even though it was not affordant for solving the problem. Adults rarely chose the categorically-related object, as evidenced by a mean categorical score of 0.10. Both groups of children had significantly higher categorical scores than adults (older children: $t(44) = 8.00$, $p < .001$; younger children: $t(45) = 12.21$, $p < .001$)

Relationship between EF and Problem Solving Tasks. Finally, relationships between the EF and span measures and the problem-solving tasks were evaluated. For adults, neither EF measure was correlated with either problem solving DV (insight time or categorical score). For children, the correlations between the EF and span measures and problem solving are displayed in Table 2. Controlling for age in months, inhibitory control was significantly, negatively correlated with both categorical scores and insight time ($r(42) = -.33$, $p = .028$, and $r(42) = -.33$, $p = .027$, respectively)[3]. This indicates that higher levels of inhibitory control was associated with choosing the unrelated object first as well as faster problem solving. However, neither forward word span nor the flipbook measures was significantly related to either of the problem solving outcomes (p's > .05).

Discussion

[3] Because both tapping and DNS were measured out of 16, the scores on each were averaged to yield the composite inhibitory control variable. However, it was also of interest to examine a composite inhibitory control variable computed using *Z-scores* of DNS and tapping. With a composite inhibitory variable using z-scores, the partial correlations of interest remained significant at the $p < .05$ level ($r = -.311$, $p = .040$ for categorical scores and inhibitory control composite; $r = -.302$, $p = .046$ for insight times and inhibitory control composite).

These results have shown that on problems in which working, unrelated objects are pitted against categorically-related (but ineffective) objects, older children were more likely to choose based on physical affordances alone, while younger children chose more often based on functional relation. Furthermore, older children's insight times were considerably lower than those of younger children. This suggests that older children who first chose the categorically-related object may more quickly override the tendency to keep trying with the related object, and to try the unrelated object. Younger children, in contrast, perseverated longer with the categorically-related objects.

These results appear to be in line with a recent series of studies on children’s insight when solving tool-modification problems (Beck, Apperly, Chappell, Guthrie, & Cutting, 2011; Cutting, Apperly and Beck, 2011). In one of these studies, the problem task required 3- to 10-year-old children to manipulate a tool and then use it in a novel fashion. Specifically, children were presented a transparent tube with a toy basket inside of it. They were also presented with a set of objects, including a target tool (a pipe cleaner) that would work to solve the task (retrieving the basket from inside the tube). However, the pipe cleaner required bending into a hook shape in order for it to be capable of retrieving the basket. In these studies, the authors found that younger children fared much *worse* than older children at successfully modifying the pipe cleaners. Specifically, 3- to 5-year-olds rarely solved the task, with success gradually increasing with age for children from 6 to 10 years. These authors concluded that children lacked the ability to think very flexibly about objects when problem solving until the middle childhood years.

While the tasks of Beck and colleagues are not completely analogous to the current functional fixedness problems, there are similarities between the two types of tasks. Both involved solving problems in which there was a considerable problem-solution distance, and both required children to solve a problem with a tool in a manner that may not have been readily apparent. In the experiment by Beck et al. (2011), the authors described children's difficulty with the bending task as a problem with 'mental flexibility'. Younger children, it seemed, had a rigid approach to using objects in these experiments. In this way, the developmental trend revealed in the current study is in accord with recent literature on insight-problem solving among children. The current findings also accord with a good deal of recent literature showing that young children and even infants form immediate and robust object-function mappings (e.g., Casler & Kelemen, 2005; 2007; Futó et al., 2010; Hunnius & Bekkering, 2010).

In line with my hypothesis, inhibitory control was significantly correlated with successful problem solving outcomes. Having a higher level of inhibitory control was associated with initially bypassing the categorically-related object and choosing the unrelated object first. These children may have been more easily able to avoid the urge to simply choose the object related to the task and instead considered the other object choices as well. Furthermore, high inhibitory control was also associated with shorter insight times. One reason for this may have been that, even if a child initially chose the categorically-related object, having a relatively high level of inhibitory control may have allowed him or her to more easily suppress the tendency to perseverate on the tasks with the related (though nonworking) objects. Indeed, this suggestion is supported by previous research that has linked unsuccessful perseveration at tasks with lower levels of executive functioning (e.g., Wiebe, Lukowski, & Bauer, 2010).

Somewhat surprisingly, working memory was not significantly related to either of the problem solving outcomes, although the relationships were in the expected direction. It may be that the cognitive mechanism(s) tapped by the inhibitory control tasks are more closely associated with the skills necessary to solve functional fixedness tasks than is Working memory. It may be that the ability to hold in mind information while acting upon it is not quite as essential an ability during functional fixedness tasks, with the more important aspect of executive function being the ability to override a pre-existing tendency (i.e., the association between the task and the categorically-related object).

This work leaves some open questions. Is it that object-function mappings are actually stronger in early childhood, such that children's conceptions are linked more closely than older children's and adults? If so, this would explain younger children's greater tendency to initially choose the categorically-related object and to use it longer than older children. In contrast, it may be that that older children, like younger children, thought initially in terms of functional categories but were faster to gauge the physical inadequacy of the categorically-related objects. Indeed, a closer examination of the categorically-related objects would show that they are not suitable for the task (for instance, a child may notice that in the barn task, the rake is somewhat too large to fit in the barn doors). As a result, older children may have altered their plans of action, choosing the unrelated object instead.

In Study 2, I modified the problem tasks so that both the categorically-related and unrelated objects were physically capable of solving the tasks. If older children now choose based on functional category as much as younger children, this would support the hypothesis that older children do not have more flexible object-function mappings than younger children, but may have noticed the physical inadequacies (e.g., the slots in the ladle) more readily than young children in study 1. On the other hand, if older children still choose based on functional category less often than younger children, this would support the notion that younger children associate objects and their functions more rigidly than older children do.

EXPERIMENT 2

Study 1 supports the notion that older children may actually be less functionally fixed than younger children, because they were more likely to choose based on affordances alone, and younger children chose more often based on functional category. Furthermore, when older preschoolers did choose the categorically-related object, they took less time to adopt a new strategy and switch to the unrelated object. However, concluding that older children are indeed less susceptible to functionally-fixedness than younger children is problematic. Older preschoolers may have been quite likely to think in terms of functional categories, but they may have gauged more quickly the physical inadequacy of the categorically-related objects. Older preschoolers are known to have more advanced planning abilities than younger preschoolers (e.g., Atance & Jackson, 2009; Klahr and Robinson, 1981). Therefore, it is possible that although older children had initially considered the categorically-related objects, they were able to more efficiently appraise the physical limitations of those objects as they applied to the task.

To further examine the relative flexibility of older and younger preschoolers' object conceptions, a second experiment was conducted in which the object-choices for the problem tasks were varied. In this experiment, children were presented with the same problem tasks and two of the same object-choices: the same unrelated (and working) object, and the same distracter object. However, instead of a categorically-related object that is physically ill-suited to solve the problem, there was a categorically-related object that is physically capable of solving. Therefore, children had the choice between a distracter and *two* physically suitable objects: one related by functional category, and one unrelated to the task.

I hypothesized that both older and younger children would choose the categorically-related object more often than the unrelated object. That is, I expected that both groups of children would choose primarily based on functional relationships. This prediction is based on the notion that both older and younger children hold strong object-function mappings, but that in Study 1, older children were able to more quickly disengage from these mappings due to higher levels of executive function. However, if as in Study 1, older children choose based on physical characteristics alone (i.e., choose the unrelated object) more often than younger children, this would suggest that they do indeed have more fluid or flexible object-function mappings than younger children.

Method

Participants. Thirty-six children participated, comprising an older (9 female, N = 18, M age = 6;1, range: 60 – 85 months) and a younger group (9 female, N = 18, M age = 4;2, range: 39 – 59 months). Parent-reported ethnicity was 69.2% White, 7.7% Black, 7.7% Mixed, and 15.4% no reply. Twenty-four adults participated. Methods of recruitment were the same as in Experiment 1.

Materials. Stimuli for the problem-solving tasks were identical to Experiment 1, except: In the covering task, the small lid was replaced by a larger lid that could cover the container. In the barn task, the doors of the barn were made wider so that the rake could fit inside. In the soup task, the slotted ladle was replaced with a similar ladle with an intact bowl, making it capable of moving water.

Additionally, a third IC task was included for children and replaced the otherwise uninformative WM and FWS measures from Study 1. We used a Simon Says task (20 trials; adapted from Murray and Kochanska, 2002) in which children had to respond to commands only when preceded by the words "Simon Says". Only the 10 trials in which children had to inhibit action were coded. Scores were entered as the number correct (no movement) out of 10.

Procedure. The procedure was identical to study 1, except that for children, the Simon Says task replaced the Flipbook and FWS tasks.

Coding. Videos were coded using the same method as in study 1. Again, a second rater coded one third of the videos. Interrater reliabilities were $\kappa = 1.0$, $\kappa = 1.0$, and $r(30) = .90$, for the number of tasks solved, the first object used, and insight time, respectively

Results

Inhibitory Control Measures. Older children (*M* tapping = 14.6, *SD* = 1.79; *M* DNS = 14.1, *SD* = 1.78; *M* Simon Says = 8.45, *SD* = 1.86) outperformed younger children (*M* tapping = 10.5, *SD* = 3.99; *M* DNS = 12.1, *SD* = 2.84; *M* Simon Says = 5.74, *SD* = 1.64) on all three measures of inhibitory control (tapping: $t(34) = 3.95$, $p < .001$; DNS: $t(34) = 2.58$, $p = .015$; Simon Says: $t(34) = 4.42$, $p = .001$). Next, Pearson correlations revealed that for children, all three pairs of inhibitory control measures were correlated at least at the $p < .01$ level. Partial correlations controlling for age in months showed that all measures were correlated at the $p < .05$ level. Therefore, *Z*-scores were calculated for each measure, and these were averaged to yield a composite measure of inhibitory control.

Problem-solving Tasks. All children and adults were able to successfully solve all 3 problem tasks, with the exception of one 3-year-old who only solved 2 of the tasks. A one-way ANOVA revealed no effect of age group (younger children, older children, and adults) on number of problem tasks solved, $F(2, 57) = 1.174$, $p = .317$, $\eta^2 = .040$.

Next, a one-way analysis of variance (ANOVA) was conducted to investigate whether there was a difference in solving latencies[4] for each age group. Results indicated there were differences between the age groups, $F(2, 57) = 5.496$, $p = .007$, $\eta^2 = .162$. Younger children ($M = 27.4$ s, $SD = 36.8$ s) took more time to solve the tasks than older children ($M = 9.4$ s, $SD = 4.0$ s; $t(34) = 2.06$, $p = .047$) or adults ($M = 7.8$ s, $SD = 2.9$ s; $t(40) = 2.73$, $p = .009$) to solve the tasks. Older children's solving latencies were not significantly longer than adults, $t(40) = 1.50$, $p = 0.14$.

Categorical scores (the number of tasks during which the participant first chose the object related by functional category) for younger children ($M = 2.83$, $SD = .514$), older children ($M = 2.89$, $SD = .323$), and adults ($M = 2.67$, $SD = .637$) did not differ, $F(2, 57) = 1.045$, $p = .358$, $\eta^2 = .035$.

Relationship between Inhibitory Control and Problem Solving. Partial correlations, controlling for age in months, revealed that there was no significant

[4] These were calculated in the same manner as "insight times" in Study 1 (i.e., time from beginning the task to starting to use an object in a manner that would solve the task. However, it is here referred to as "solving latency" because given the straight-forward nature of the problem tasks in Study 2, they could not be properly considered "insight problems".

relationships between the composite inhibitory control measure and either categorical scores or solving latency (*p*'s > .05).

Discussion

In study 2, both groups of children as well as adults tended to choose physically-appropriate and categorically-related objects over equally physically appropriate but unrelated objects. This result is significant for several reasons. First, it supports the notion that individuals rely heavily on object-function relationships, finding this result among three fairly diverse age groups. Indeed, adults, five-to-six-year-olds, and three-to-four-year-olds all tended to choose a functionally-related object despite an equally useful alternative. In this way, the current findings are in line with recent work findings that at various ages during childhood, children tend to use objects (and expect them to be used) in a manner consistent with their typical or prescribed function (e.g., Casler & Kelemen, 2005; 2007; Futó et al., 2010; Hunnius & Bekkering, 2010). Second, the current finding supports the idea that older children do not actually have more flexible or fluid object-function mappings than younger children. If older children did map objects and functions more flexibly, then one would expect older children to use the unrelated objects more than younger children.

Thus, it is not necessarily the case that older children have more flexible object-function mappings than younger children. Rather, they may better evaluate causal properties of objects and override a potent tendency to rely on typical function. Indeed, when pitted against a working but unrelated object, even older children and adults chose a working, categorically-associated object to solve a problem. Therefore, it is possible that while both older and younger children are susceptible to functional fixedness, older children's more sophisticated cognitive processing capacities (including inhibitory control) allow them to more easily override object-function associations.

EXPERIMENT 3

Given young children's difficulty at solving tasks in which they must use an object in a novel way, an important avenue of research concerns strategies for mitigating the effect of functional fixedness. Specifically, mentally visualizing possible solutions may aid children in overcoming the tendency to choose structurally ill-suited objects based on functional relationships because they should be able to predict the potential failure or success of the objects by imagining their action paths. If mental imagery helps children to choose structurally appropriate objects based on affordances, this will shed light on the underlying mental processes associated with affordance-based problem solving (e.g., use of visuospatial representations and forward planning).

Although in Study 1, adults quickly and easily identified the only unrelated object to solve the functional fixedness problems, children (especially younger ones) often chose the nonworking, categorically-related object. Presumably, adults were able to use physical cues from the objects (such as the slots in the slotted ladle) to alert them that the tool would not work to solve the task, while children often appeared to rely on the categorical relationship between the task and related object. Clearly, children’s relative deficiency in considering the physical relationships between the tool and task were detrimental to problem solving.

One technique that appears to improve problem-solving outcomes is mental imagery (e.g., Driskell, Copper, & Moran, 1994; Vieilledent, Kosslyn, Berthoz, & Giraudo, 2003). Imagery should be particularly helpful because it allows individuals to mentally test different solution paths before investing energy in a path that may not be effective. Recently, Joh, Jaswal, and Keen (2011) found that mental imagery significantly improved preschoolers' proficiency at solving an otherwise difficult spatial problem. These authors presented 3-year-olds with the "tubes task," known to elicit a gravity bias in young children. In this task, a ball is dropped into one of three intertwined, curved tubes that each have an opening through which a ball can pass. Young children usually expect to find the ball in the cup directly underneath the point where it was dropped (where it would fall as a result only of gravity, if not enclosed by a tube). In reality, the ball is always found in a *different* location than directly under its dropping point because its path is enclosed by a curved tube. In their study, Joh et al. (2011) tested 3-year-olds (*M* age = 39 months) in one of three conditions. In the imagine condition, before the ball was dropped, children were instructed to imagine the ball as it rolled down the tube. In the wait condition, children were first asked a question about the tube and then invited to manually explore it (a prompt designed to take the same about of time as the imagination prompt). Finally, in a control condition, children were simply asked for their predictions without any additional instructions.

The results showed that when 3-year-olds were invited to mentally visualize the path of the ball, they were correct on about twice as many trials as children in either the wait or control conditions. Furthermore, while more than half of the children in the imagine condition performed at above chance levels (9/16), only 1 in 4 of the children in both the wait and the control conditions did so. Apparently, an explicit cue from an adult to use mental imagery facilitated children's ability on this spatial problem solving task. It seems that very young children do not use mental imagery spontaneously, but doing so is a useful strategy for problem solving.

As discussed previously, children in Study 1 often chose an object based on functional relationship to the task, overlooking the physical characteristics that precluded its solving potential. In a third study, children were presented with the same tasks as in Study 1, with the addition of an imagination condition and a wait condition. Mental imagery may help children to avoid the tendency to choose based on functional category. For example, in the soup task, children who imagine the slotted ladle moving water may be able to visualize the difficulty presented by the slots. Investigating strategies, such as mental imagery, that may help children overcome functional fixedness has a clear relevance to young children's education, particularly in the realms of problem solving and engineering.

Imagery instructions may also influence children of differing EF levels. Consider the mental processes necessary to imagine the outcomes of using the object-choices to solve the problem tasks: Children must not only inhibit the urge to touch the objects and begin solving the problem before imagining, but they must keep in mind the goal while visualizing the trajectory of the object solving the problem (for example, they must remember that the rain must be kept out of Scruffy's food, while picturing (1) turning over the plastic bowl and (2) placing it over the food). Children who possess higher levels of executive control may benefit more from the imagination phase than children with less advanced executive abilities, because they may be more capable of successfully managing multiple representations simultaneously, while inhibiting those that are not relevant to the problem solution.

In Study 3, I expected that children in the imagination condition would have lower categorical scores than children in the wait condition. In the imagination condition, children were prompted to form visual representations of the actions paths of the tools, which may cue information about the potential failure of the categorically-related object (or information about the potential success of the unrelated object). As such, children in the imagination condition should also solve the tasks more quickly than children in the wait condition. In addition, it is possible that within the imagine condition, children with higher levels of executive control would be better problem solvers (i.e. lower categorical scores and lower solving latencies) than children with lower levels of executive control, because they would be more proficient at executing the imagine instruction.

Finally, Study 3 will allow an additional test of the findings from Study 1 with a new sample of children. Because participants will be given problem tasks almost identical to those used in Study 1, it will be possible to re-test: (a) the developmental trajectory in which younger children are more likely to choose an object based only on functional associations, and older children are more likely to take physical properties of the task-tool relationship into account and (b) the relationship between inhibitory control and functional fixedness, in which higher levels of inhibitory control are associated with bypassing the categorically-related tool and choosing based on physical properties. Given the results of study 1, I expected that both of these findings would be confirmed.

Method

Participants. Seventy-two children participated, comprising an older (12 female, *N* = 37, *M* age = 5;10, range: 60 – 88 months) and a younger group (16 female, *N* = 35, *M* age = 4;4, range: 44 – 59 months). Parent-reported ethnicity was 51.4% White, 19.4% Black, 9.7% Mixed, 6.9% Asian, 1.4% American Indian, 1.4% Other, and 9.7% no reply. Methods of recruitment were the same as in Experiments 1 and 2.

Materials. Stimuli for the problem-solving tasks were identical to Experiment 1, except that for each task, there were only two object choices: the categorically-related, but non-working object and the unrelated but working object. For example, in the Soup task, the choices were the flower pot and the slotted ladle, but not the funnel. Given that the task of imagining three objects before attempting the task may be cognitively taxing for preschoolers, it was decided to use only the two objects of interest as object choices.

Procedure. The procedure was identical to study 1, except for the following changes. First, of the EF and span tasks, only the measures of inhibitory control (Tapping and DNS) were used. One half of the participants completed the DNS task first and the other half completed the Tapping task first. The inhibitory control measures preceded the problem-solving tasks.

Second, after presenting children with the story scenarios and reading the problem scripts, the object choices were presented one at a time. In the Imagine condition, children were shown one of the objects (either the categorically-related or unrelated object) and told, “here is one of the things you might be able to use. But first, try to use your imagination and see how this one might be able to help you get the soup in the bowl/keep the rain out of the food/get the leaves out of the barn”. In the Wait condition, children were told, “here is one of the things you might be able to use. But remember, your job is going to be to get the soup in the bowl/keep the rain out of the food/get the leaves out of the barn.” In both conditions, the experimenter then paused for a period of approximately 5 seconds while looking in the direction of the problem set-up, in order to allow children time to use mental imagery (in the Imagine condition) or to ensure that the experimental procedure was identical except for the instructions (in the Wait condition). Following the pause, the first object choice was again placed out of sight, and the second object choice was presented, along with the same statement as above and a 5-second pause. Finally, both object choices were placed to the right of the child, who was then allowed to begin the task. The temporal order of presentation of the object choices (categorically-related or unrelated first) was counter-balanced across participants within each condition.

Coding. Videos were coded in the same manner as in Study 1. However, due to camera error for two videos, insight time was not available, although categorical scores and scores for tapping and DNS were recorded onsite. One-quarter of the videos were coded by a second coder. Interrater reliabilities were $\kappa = .92$, $\kappa = .85$, and $r(18) = .93$, for the number of tasks solved, first object used, and insight time, respectively.

Results

Inhibitory control. As in the previous two experiments, the scores from each inhibitory control measure were averaged to yield a composite inhibitory control variable. Older children ($M = 13.4$, $SD = 4.81$) outperformed younger children ($M = 10.4$, $SD = 7.34$) on the composite measure of inhibitory control, $t(70) = 4.03$, $p < 001$).

Problem-solving Tasks. Means and standard deviations for each age group and condition are found in Table 3. First, the effects of condition and age group on children's problem-solving outcomes were investigated. Separate 2 (condition: imagine or wait) x 2 (age group: younger or older) analyses of variance (ANOVAs) failed to yield a significant main effect of condition on number of puzzles solved, $F(1, 68) = .970$, $p = .328$, categorical scores, $F(1, 68) = 1.137$, $p = .290$, or insight times $F(1, 68) = .224$, $p = .637$.

However, significant main effects of age group were found for the categorical scores, $F(1, 68) = 11.814$, $p = .001$, and insight time, $F(1, 68) = 14.289$, $p < .001$, but not on number of puzzles solved, $F(1, 68) = 1.091$, $p = .300$. Further analyses showed that insight times for older children ($M = 23.3$ s, $SD = 28.6$ s) were lower than for younger children ($M = 60.7$ s, $SD = 50.5$ s), $t(68) = 3.81$, $p < .001$. In addition, older children (M categorical score = 1.49, $SD = .822$) chose the categorically-related tool first significantly less often than younger children (M categorical score = 2.17, $SD = .870$), $t(70) = 3.43$, $p = .001$.

There were no significant two-way interactions between condition and age group for number of puzzles solved, $F(1, 68) = .001$, $p = .976$, categorical scores $F(1, 68) = .015$, $p = .04$, or insight times, $F(1, 68) = .175$, $p = .677$.

Relationship between Inhibitory control and Problem Tasks. Partial correlations between inhibitory control and problem solving are displayed in table 4. Controlling for age in months, inhibitory control was significantly, negatively correlated with insight time, *r*(67) = -.40, *p* = .001, and marginally, negatively correlated[5] with categorical scores, *r*(69) = -.22, *p* = .064, again showing that higher inhibitory control was associated with choosing based on physical properties alone.

Discussion

In Study 3, the hypothesis that children who were given instructions to use mental imagery would be more successful at overcoming functional fixedness was not confirmed: None of the problem-solving outcomes measured differed significantly between children in the Imagine condition and children in the Wait condition. Therefore, in some ways the current findings are not in line with some previous literature that has shown that preschool-aged children are able to solve spatial problems more effectively when using mental imagery (Joh et al., 2011).

There are several potential reasons for this discrepancy. First, in the experiment by Joh and colleagues (2011), the task for which children were asked to "imagine" necessitated fewer physical steps. Recall that children were being asked to predict the spot a ball would fall when dropped from a particular location. It may be that imagining the trajectory of the ball required fewer cognitive resources than the current tasks, which were more open-ended. In the gravity task, the ball's trajectory was fairly constrained by

[5] As in Study 1, the DNS and tapping scores were averaged to calculate the composite inhibitory control variable. However, when computed using Z-scores of DNS and tapping, the composite inhibitory control variable remains correlated with the problem-solving outcomes at approximately the same levels of significance (*r* = -.216, *p* = .075 for categorical scores and inhibitory control composite; *r* = -.417, *p* < .001 for insight times and inhibitory control composite).

the tube which enclosed it. On the other hand, in the current functional fixedness tasks, the way that children might imagine using each object had fewer physical constraints. Spatially, they could move with the object in any direction, and they could manipulate it in a number of ways. Furthermore, although children were asked to “imagine” using the object to solve the problem, it was not possible to ensure that children were truly using mental imagery to visualize a goal-directed action. Anecdotally, after hearing the instruction to “imagine” how to solve the task, one child responded by describing the actions of non-present characters (“dinosaurs”) coming in and helping with the task. Although this child was certainly using his “imagination,” there was no way to ensure that children’s connotation of the word “imagine” was the same as the experimenters’. It may be that certain children, rather than using imagery to visualize only the objects at hand and how she herself could use them, were imagining non-present entities that they associated with using their imagination.

In some ways, the null findings of the Imagine instructions may point to the robustness of young children’s object-function relationships. Although children were given time to imagine using each object individually, they were still quite likely to choose the categorically-related object, with younger children doing so on about 2/3 of the tasks and older children doing so on about half of the tasks. It may be that children’s strong object-function associations often precluded them from considering using the unrelated objects in a novel way, despite the instructions to visualize using them. In the same way, robust associations may have led them to immediately decide on using the categorically-related objects, without taking the time to thoroughly visualize the outcome, because of an implicit assumption that it was the “correct” object to use for the task.

These findings are in line with several recent lines of research. For instance, Casler et al. (2009) found that even young preschoolers hold strong associations between certain objects and their prescribe usages – in their study, 2- and 3-year-old children protested or “tattled” on a puppet character who would use a tool in an unconventional way.

Finally, Study 3 allowed a second test of the findings from Study 1, which were replicated. With a new sample of children, 3- and 4-year-olds were again more likely than 5- and 6-year-olds to choose the categorically-related object, despite the availability of a more physically-appropriate alternative. In addition, younger children took longer than older ones to begin using the unrelated tool in an unconventional manner. Furthermore, the overall trend found in Study 1, in which controlling for age in months, children with higher levels of inhibitory control were both faster at the tasks and more likely to initially choose the unrelated object, was confirmed. Taken together, these findings provide further support for the suggestion that younger children are equally likely as older ones to experience functional fixedness, although their generally lower levels of executive functions (such as inhibitory control; Kochanska et al., 1996) may be one factor making it appear, in the current work, that they are “more” functionally-fixed.

GENERAL DISCUSSION

The current work investigated children's object-function associations using novel functional fixedness tasks. In Study 1, I sought to answer the question of whether younger children are more or less likely than older ones to use functional identity to guide their object choices when problem solving. Results from Study 1 suggested that with the current tasks, younger children were both less likely to initially choose an object unrelated to the task as well as slower to use an unrelated object in a novel manner. Results also showed that higher levels of inhibitory control was associated with greater success on functional fixedness problems. Study 2 showed that when participants were given the choice between a working, related object and a working, unrelated object, both groups of children as well as and adults tended to choose the related object over the unrelated one. Finally, Study 3 attempted to investigate using mental imagery as a strategy for overcoming functional fixedness when problem solving. Although instructions to use mental imagery did not result in outcomes significantly different from wait instructions, Study 3 did succeed in replicating the findings from Study 1 in terms of the relationship between inhibitory control and overcoming functional fixedness.

At first glance, it appears that Study 1 has shown that younger children may hold more rigid object-function mappings than older children. This result corresponds to some degree with work by Casler and Kelemen (2005, 2007) who have shown that children as young as two years of age readily associate particular objects with specific functions and avoid using them for unconventional purposes. Study 2 provided evidence that younger children do not necessarily have more rigid object-function mappings than older children. When given the choice between two working tools, both groups of children were equally likely to choose the one related by functional category. However, if older children actually had more fluid mental associations between objects and functions, then one might expect them to choose the unrelated object more than younger children. Therefore, I would argue that another interpretation of the developmental pattern found in Study 1 lies in the relationship between functional fixedness and inhibitory control. As seen in Studies 1 and 3, children's ability to overcome functional fixedness was related to their level of inhibitory control. Given that EFs generally increase with age during the preschool years, it may be that older children's ability to more readily bypass the related object in Study 1 is underlain by their generally higher level of inhibitory control, rather than more flexible or fluid object-function mappings.

The findings of the current experiments seem to be at odds with the work of German and Defeyter (2000; 2003), who have found that young children use objects in an unconventional manner *more* readily than older children. As discussed previously, this discrepancy may be due partially to instructions given to children before solving German and Defeyter's tasks (that target tools were "for" specific actions). German and Defeyter (2000, 2003) have interpreted their results as evidence for the emergence of the design stance during the early school age years. According to this view, older children and adults tend to conceptualize objects in terms of the particular purpose for which they were originally designed (e.g., German & Johnson, 2002; Kelemen, 1999; Matan & Carey, 2001). In contrast, children under the age of about six, who have not yet developed strong representations of intended design, tend to consider object function more flexibly. According to German and Defeyter (2003), before children begin to organize their conceptions of objects around the core property of "design," they are more easily able to view objects simply in terms of their mechanical structures and the immediate goals of the users.

However, an alternative possibility is that the ability to use objects unconventionally when problem-solving is not necessarily constrained by an understanding of designer's function per se. Rather, it may be that even young children form an understanding of the *conventional* use of objects, which guides their object concepts from an early age. For example, Siegel and Callanan (2007) asked 5-year-olds, 7-year-olds, and adults the functions of objects that were being used in a novel way by either one person or many people. They found that when an object was used in an unconventional manner by *many* people, participants in each age group did not strictly adhere to reporting that the objects were "really for" the originally intended function. Therefore, older children and adults do not only conceptualize objects in terms of original design. Other work has also shown that 3- and 4-year-old children show understanding of intended design (Asher & Kemler Nelson, 2008), providing evidence that such intuitions are present at an age younger than typically predicted by the design stance paradigm. Furthermore, Casler and Kelemen (2005) found that showing 2-year-olds an action performed with a novel object was sufficient for them to determine that it was "for" that action. Importantly, they later avoided using the demonstrated object for a separate function for which it was physically-well suited, suggesting that preschoolers do not view objects as fluid, multi-purpose entities. Rather, the authors argued that young children can rapidly form object concepts, including information about function, after viewing only a single intentional use.

Given potentially automatic, early developing, and enduring artifact concepts based on conventional use, a relevant question concerns their structure. According to Lin and Murphy (2001) individuals often categorize conceptual knowledge in terms of thematic relations, which can link entities that tend to co-occur or are used together often. For example, the entities *chalk* and *chalkboard* may be linked by a functional thematic relation. Although they do not share perceptual similarities (as do taxonomic relations), they are often used together. Indeed, young children are known to use thematic relationships often to guide their categorization (Nguyen & Murphy, 2003; Perraudin & Mounoud, 2009; Smiley & Brown, 1979). However, it is not only object concepts that can be linked to each other by thematic relationships. Other information, such as associated actions and functions, can be linked with object concepts. For instance, Tyler et al. (2003) found that objects and actions associated with using them activated the same neural regions (the superior and middle temporal cortex as well as the left fusiform gyrus). In addition, work by Grabowski, Damasio, and Damsio (1998) showed that there is a common area of activation when retrieving words representing objects and words denoting their associated actions. According to Sachs et al. (2008), neuroimaging findings such as these suggest that "categories are held together not just by the internal correlations between their features, but also by the external functional relationship between an object and its environment" (p. 410).

Sachs et al. (2008) recently investigated the automatic nature of thematic relationships. Here, adult participants completed lexical decision tasks that involved four types of word pairs: taxonomically related (*car-bus*); thematically related (*car-garage*); unrelated (*car-spoon*); non-word trials (*car-derf*). Reaction times were fastest for the thematically related pairs, indicating a greater priming effect for thematic than taxonomic relations. Furthermore, neuroimaging results suggested that thematic associations required less cerebral processing demands than taxonomic relations, supporting the notion that processing thematically-related entities is more automatic and takes relatively little effort.

Taken together, it is possible that functionally-associated entities (such as *rake* and *leaves*) as well as functions and actions (such as *raking*) are linked at a conceptual and neural level for children at an early age. As such, young children should form easily-accessible relations between entities, actions, and functions that help guide their object knowledge and use. It may be these potentially automatic, engrained associations that lead to functional fixedness in both older *and* younger children, because tools and objects themselves are linked to and may even prime particular actions and functions (e.g., De Stefani, Innocenti, Bernardi, Campione, & Gentilucci, 2012). Therefore, rather than explaining functional fixedness in childhood using relatively complicated reasoning about designer's intention, it may be more easily conceived of as a result of automatic mental associations between objects, functions, and actions that preclude the immediate consideration of novel usages.

Although preliminary, the results from studies 1 and 3 are significant in that they suggest that inhibition may be an important cognitive capacity for creative or insight-based problem solving. During functional fixedness problems specifically, inhibitory control may allow individuals to suppress representations of typical functional associations in order to consider other less conventional uses of objects. Alternatively, it may involve regulatory processes that allow problem-solvers to weigh important structural components of the objects against physical properties of the task and then predict various solution outcomes prior to acting on the problem. Finally, inhibitory control may be important for allaying the tendency to continue perseverative attempts at solving tasks. In the current work, many children continued to attempt the tasks with the categorically-related items (such as the slotted ladle), although they were not resulting in successful outcomes. Although the number of perseverative attempts was not measured here, it may be that children with higher levels of inhibitory control were better able to stop perseverating with the non-working, related object.

In interpreting these intriguing results, it is important to consider limitations, particularly with regard to Study 3. Here, children in the imagine and wait conditions performed similarly on the problem-solving outcomes. As discussed previously, one reason may lie in the open-ended nature of "imagining" using an object on these tasks. Second, it may be that the current instructions to imagine did not effectively lead children to systematically considering the actual physical properties and outcomes of future action paths. Instead, they may have simply "imagined" an action scenario consistent with their mental representations (such as concepts of associated actions and functions) of a ladle, rake, or lid, without taking the present physical limitations into consideration. Perhaps future research on mental imagery can use instructions which more effectively guide children to consider the actual physical dimensions of the problem at hand.

Another limitation is that in the current work, adults did not show functional fixedness, choosing the unrelated tool almost exclusively in Study 1. With only three object choices, adults were likely able to quickly determine the physical outcome of attempting to use each of the objects on the task. Furthermore, adults, more so than children, may have been looking out for a "catch," given that they knew they were participating in a psychology experiment. Therefore, they may have realized that the solution always involved choosing the unrelated item. In short, the current tasks were not challenging enough to evoke functional fixedness in adults. However, one interesting avenue for future research will be to investigate whether the relationship between inhibitory control and overcoming functional fixedness found in children is present in adults as well. This could be investigated using more challenging tests of functional fixedness in adults.

There are several directions for research raised by the current work. First, though the current experiments only tested working memory, word span, and inhibitory control, another facet of executive function that may be relevant to overcoming functional fixedness is set shifting. Set shifting is the ability to switch between tasks or mental sets, such as switching to a new rule on a task that is contradictory to the initial rule learned (Miyake et al., 2000). Given that perseverating by using a tool in a manner consistent with its typical function can be counterproductive to solving functional fixedness tasks, being able to easily shift to a new "mental set" may be a beneficial ability to solving functional fixedness problems specifically, and even insight problems more generally. For example, in Zelazo’s Dimensional Change Card Sort task, children are required to first sort cards by an initial dimension (e.g., color) and then are asked to begin sorting them by a different dimension. This task, as well as a slightly more difficult version, have been shown effective at measuring executive function in children as young as three years of age to as old as seven years of age (Zelazo, 2006), and may help to shed light on exactly which aspects of executive function may be related to overcoming functional fixedness.

Second, the relationship between inhibitory control and functional fixedness in adults should be explored further using more complex functional fixedness tasks, such as the candle problem, that would be more challenging for adults. In the current problems, adults likely were able to quickly grasp the "catch" (that the object capable of solving the task was always the one that was not typically associated with it). On the other hand, the candle study has been shown to be difficult for many adult subjects (Duncker, 1945), who may need to rely on their ability to inhibit concepts associated with the box (such as containment) in order to consider the novel action path required to use it as a platform for the candle. Future research using the candle study, and perhaps other functional fixedness tasks, such as the two-string problem (Maier, 1931) may serve to determine whether this relationship exists in adults. Furthermore, a similar relationship between inhibitory control and other types of fixation, such as design fixation, could be investigated.

In sum, the current work has shown that both younger children (3- and 4-year-olds) and older children (5- and 6-year-olds) think automatically in terms of conventional object functions and are susceptible to functional fixedness. However, it seems that older children could more easily override automatic object-function associations when problem solving. Furthermore, inhibitory control was found to be associated with better problem-solving outcomes across two studies, suggesting that it may play a key role in creative problem solving. Future studies investigating functional fixedness and insight problem solving will allow us to further untangle the basic cognitive processes underlying the way young children and adults think about objects when problem solving. Specifically, future work may help to shed light on how different aspects of executive function are related to functional and other types of fixedness as well as the way that neural organization can help (or sometimes hinder) thinking flexibly about objects and materials.

APPENDIX

Problem scripts.

Practice problem. "This is Terry the turtle. Terry was outside playing with his ball when he accidentally kicked it over this line. Terry is not allowed to cross the line. Can you help to get the ball back over the line to Terry? Remember, you can use any of these to help you."

Leaves task. “This is Sammy the cat. Sammy lives in this barn, but today, the wind has blown some leaves inside. Can you help to get the leaves out of the barn for Sammy? Remember, you can use any of these to help you.”

Soup task. “This is Gabby the gorilla. Gabby wants to eat some soup, but the soup is still in the pan. Can you help to get some of the soup into the small bowl for Gabby? Remember, you can use any of these to help you.”

Covering task. “This is Scruffy the dog, and this is Scruffy’s food. Scruffy’s owner keeps his food outside, but today it is starting to rain. Scruffy doesn’t want the rain to get into his food. Can you help to keep the rain out of Scruffy’s food? Remember, you can use any of these to help you.”

Table 1

Means and Standard Deviations for Span and EF Measures in Study 1

	FWS	WM	DNS	Tapping
Older Children	4.41 (.734)	12.1 (2.22)	14.9 (1.44)	14.1 (2.51)
Younger Children	3.30 (.974)	8.1 (3.10)	11.1 (3.70)	8.91 (5.22)

Note. FWS=Forward Word Span, WM = Working Memory (Flipbook), DNS = Day-Night Stroop. Entries are means with standard deviations in parentheses. Older children: *N* = 22; younger children: *N* = 23.

Table 2

Correlations, controlling for age in months, between Executive Function measures, Forward Word Span, Categorical Scores, and Insight Time in Experiment 1

	IC	WM	FWS	Cat Score	Insight Time
IC	--	.35*	.17	-.33*	-.33*
WM	.35*	--	.10	-.11	-.23
FWS	.17	.10	--	-.05	-.09
Cat Score	-.33*	-.11	-.05	--	.39**
Insight Time	-.33*	-.23	-.09	.39**	--

Note. IC=Inhibitory Control, WM = Working Memory (Flipbook), FWS=Forward Word Span, CatScore = Categorical Score

*p < .05.

**p < .01.

Table 3

Problem-Solving Outcomes for each Age Group by Condition cell in Experiment 3

	Imagine	Wait
Number Solved		
Older children	2.94 (.236)	3.00 (.000)
Younger children	2.89 (.323)	2.94 (.243)
Latency		
Older children	23.1 (33.0)	23.6 (24.6)
Younger children	56.4 (60.8)	65.3 (38.1)
Cat Score		
Older children	1.39 (.850)	1.58 (.901)
Younger children	2.06 (.938)	2.30 (.686)

Note. Entries are mean values with standard deviations in parentheses. Latencies are in seconds.

Table 4

Correlations, controlling for age in months, between Inhibitory Control, Categorical Scores, and Insight Time in Experiment 3

	IC	Cat Score	Insight Time
IC	--	-.22†	-.39**
Cat Score	-.22†	--	.43***
Insight Time	-.39**	.43***	--

Note. IC=Inhibitory control, Cat Score = Categorical Score

† $p = .06$

**$p < .01$.

***$p < .001$.

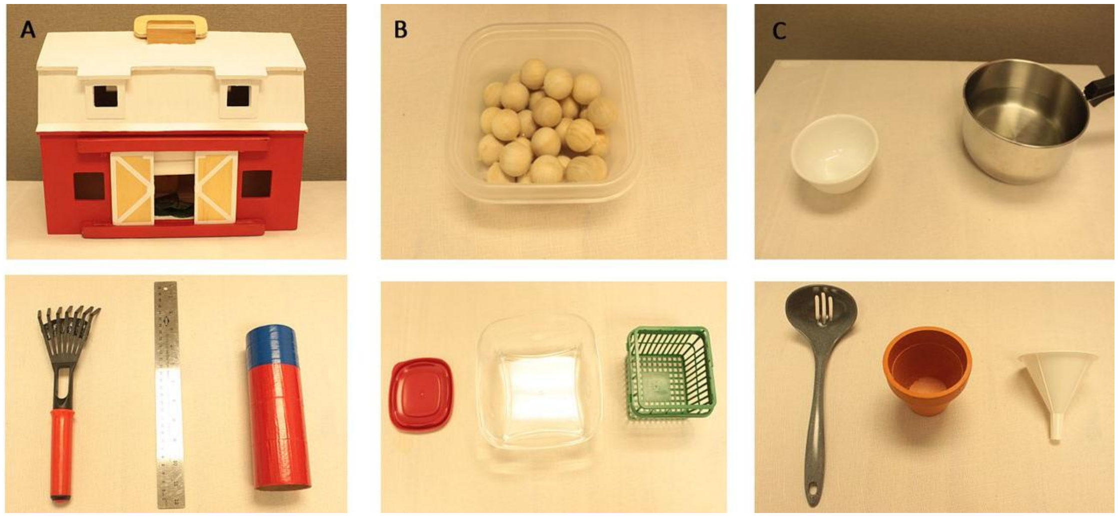

Figure 1. Task set-ups (top) and object choices (bottom) for (A) the barn task, (B) the covering task, and (C) the soup task. For each task, the categorically-related object is pictured on the left, the unrelated object is pictured in the center, and the distracter object is pictured on the right.

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