A Tale of Two Flexibilities: Preschoolers' Developing Consecutive and Concurrent Cognitive Flexibility Skills

by

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A thesis submitted to the Faculty of Graduate and Postdoctoral Affairs in partial fulfillment of the requirements for the degree of

Doctor of Philosophy

in

Psychology

Carleton University
Ottawa, Ontario

Abstract

Cognitive flexibility is the ability to think of something in more than one way. Research examining cognitive flexibility in 3- to 5-year-olds typically focuses on consecutive cognitive flexibility—the ability to consider several dimensions of a single stimulus one after another (e.g., sorting cards depicting blue boats and red rabbits by colour and then by shape). However, relatively little research examines preschoolers' *concurrent* cognitive flexibility skills—their ability to coordinate several dimensions of a single stimulus simultaneously (e.g., understanding that a blue boat can be both blue *and* a boat at the same time). The current work focuses on emerging concurrent cognitive flexibility skills in preschoolers. In Study 1, though a structural differentiation between consecutive and concurrent cognitive flexibility was not supported, an exploration of the data suggested that these skills are affected differently by abstraction demands—whether children had to induce the relevant dimensions on their own or were told which dimensions to consider. In this study, 121 preschoolers (*Mage* = 48.12 months; *SD* = 5.37) received 6 different cognitive flexibility tasks. Consistent with Jacques and Zelazo's (2005) review, children found deductive tasks—tasks in which the experimenter provides all the information to the participants—easier than inductive tasks—tasks that required children to identify the relevant dimensions themselves—in the context of consecutive cognitive flexibility. In contrast, these children found inductive *concurrent* cognitive flexibility tasks easier than deductive concurrent cognitive flexibility tasks, indicating that abstraction demands affect children's performance on these two cognitive flexibility skills differently. In Study 2, this finding was partially replicated using an experimental design: under certain conditions, 5-year-olds (*N* = 76) found concurrent

cognitive flexibility easier in its deductive (unlabeled) version, as compared with its inductive (labeled) version. However, this was not the case for 4-year-olds ($N = 84$), or for another task measuring concurrent cognitive flexibility. These findings can be interpreted using the Attentional Inertia Account (e.g., Diamond, 2012; Kirkham, Cruess, & Diamond, 2003), which argues that the critical skill required to succeed in cognitive flexibility tasks is the ability to disengage from a previously relevant dimension.

Acknowledgements

It is remarkable how many people this project involved. I could not begin to thank all of these people, so the following acknowledgements are hardly an exhaustive list.

First and foremost, I would not be at this point without my supervisor, Dr. Deepthi Kamawar. Deepthi has encouraged me to ask questions and challenged me to come up with better answers. She supported me throughout this project and, indeed, the last eight years of my life. She is a mentor and a role model, and showed me more patience than I had reason to hope for. She made me a researcher and a clear thinker and her voice will follow me in every professional endeavour.

I had fantastic committee members with whom I was honoured to work. I want to thank Dr. Stuart Marcovitch and Dr. George Pollard for their thoughtful comments and a fascinating discussion. I am especially indebted to Dr. Jo-Anne Lefevre and Dr. John Logan, who had accompanied this project from inception, always ready to advise, guide, and impart their wisdom. I would also like to thank June Drayton Callender and Etelle Bourassa from the Psychology Department, who helped me navigate the daily life of academia, and to Natalie Pressburger, whose care and attention brought me to Carleton all those years ago.

My lab-mates, Dr. Corrie Vendetti and Dr. Andrea Rahim, have journeyed with me through graduate school and a doctorate program—a bonding experience, no doubt. They made me a better thinker with their questions, and I learned so much from them. I hope we can still bounce ideas off each other from afar. Outside the lab, the lovely Dr.

Deanna Whelan and Master Jessie Gunnell had been my social and emotional support net, and I thank them for always being there for me when I needed a drink.

Katherine Andrews worked with me on most of the data collection. She meticulously documented the answers of dozens of preschoolers, which often do not make sense to us boring grownups. For her dedication and brilliant company, I owe her a debt that could not be repaid with Starbucks gift cards. Many more undergraduate students have been a part of this project, some by helping with task construction, some by helping with data collection, and some by asking questions that made me think about something in a whole new way at our weekly lab meetings. I thank them all for their time and efforts.

This work was enabled by hundreds of people who volunteered their time and their children's time to advance science. Out of the goodness of their hearts, daycare coordinators, school principals, and teachers made time and space for me to play my games with the kids under their care. Their hard work often remains unacknowledged; not today. I am also grateful for the parents who trusted me with their most precious treasures, and to all the children who were willing to play random games with the weird lady who kept asking them the same silly questions.

And last, but in no way least, this work would not have seen the light of day without my family. To my husband and partner, Guy, who is my rock, my better half, and my best friend, and supported me through this incredible journey; to my children, Adam and Naomi, who make my life *much* more interesting; and to my amazing, abundant, and very involved family—I am extremely grateful, today as every day, for all that you are. Thank you.

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Chapter 1: General Introduction

Imagine a child who would like to reach a cookie jar placed on the kitchen counter, out of reach. She looks around for a way to boost herself up. Finally, she stacks up some books by the counter and stands on them to get to the jar. In thinking about the books as more than just reading material, the child has demonstrated *cognitive flexibility*—the ability to think about something in more than one way.[1] This ability emerges during the preschool years (e.g., Cragg & Chevalier, 2012; Doebel & Zelazo, 2013; Garon, Bryson, & Smith, 2008; Perner, Stummer, Sprung, & Doherty, 2002; Podjarny, Kamawar, Vendetti, & Rahim, in preparation), and relates to competencies such as flexible problem-solving (Deák, 2004; Siegler & Svetina, 2002), creativity (Diamond, 2006), and reasoning about others' mental states (i.e., Theory of Mind; Perner, Lang, & Kloo, 2002). Moreover, preschoolers who have better cognitive flexibility skills perform better in school later on (Coldren, 2013; Masten et al., 2012) and exhibit fewer academic problems (e.g., Bull & Scerif, 2001). The focus of the current work is young children's emerging cognitive flexibility.

Cognitive flexibility is often investigated in the context of Executive Functions (EF), a term referring to cognitive processes that enable goal-directed behaviour (e.g., Garon et al., 2008). In addition to cognitive flexibility, researchers typically include under the umbrella of executive functions two other skills: (a) working memory, which is the ability to maintain and manipulate information; and (b) inhibitory control, which is

[1] Several terms have been used to describe the skill of considering multiple aspects of a stimulus, including *representational flexibility* (Kloo, Perner, Aichhorn, & Schmidhuber, 2010), *set-shifting* (Garon et al., 2008), *mental flexibility* (Smidts, Jacobs, & Anderson, 2004), and *attentional flexibility* (Stahl & Pry, 2005). I use the term *cognitive flexibility* in keeping with Jacques and Zelazo's (2005) use of the term.

the ability to refrain from performing an automatic or over-learned response (e.g., Diamond, 2006; Garon et al., 2008; Miyake, Friedman, Emerson, Witzki, Howerter, & Wager, 2000). While this three-processes model has been supported in structural analyses of executive functions in adults and adolescents (e.g., Lee, Bull, & Ho, 2013; Miyake et al., 2000), its application to children, and especially preschoolers, is still under debate (e.g., van der Ven, Kroesbergen, Boom, & Leseman, 2013). Particularly, several structural analyses of executive functions in preschoolers have demonstrated that executive functions could not be separated into latent factors; instead, these investigations found that all executive functions tasks loaded onto a single factor (e.g., Fuhs & Day, 2011; Wiebe, Espy, & Charak, 2008; Wiebe, Sheffield, Nelson, Clark, Cheavlier, & Espy, 2011; see Lee et al., 2013, for a review). On the other hand, other investigations reveal a dual structure in preschoolers, with inhibitory control and cognitive flexibility tasks loading onto the same factor (e.g., Brydges, Fox, Reid, & Anderson, 2014; although see Miller, Giesbrecht, Müller, McInerney, & Kerns, 2012, for a dual structure with cognitive flexibility loading onto the same factor as working memory). Nonetheless, many researchers accept the three-processes model promoted by Miyake and colleagues (Miyake et al., 2000; Miyake & Friedman, 2012; for the three-factor model of executive functions in use see, e.g., Bialystok, 2011; Diamond, 2012; Miller, Chatley, Marcovitch, & McConnell-Rogers, 2014; Miller, Müller, Giesbrecht, Carpendale, & Kerns, 2013; Zelazo & Carlson, 2012).

An important part of the operationalization of cognitive flexibility is for a given individual to show different responses to the same stimulus in different contexts (see, e.g., Deák, 2004; Ionescu, 2012; Jacques & Zelazo, 2005). That is, had we known that the girl who stacked up the books to enhance her height had never used a book in the traditional way (i.e., as something to read), we would be unlikely to credit her with flexible behaviour. The flexibility comes from being able to adjust the way we think about an object depending on the context, or situational demands.

Researchers typically measure this skill using tasks that require children to switch from considering one aspect of a stimulus to considering another aspect of the same stimulus (see, e.g., Cragg & Chevalier, 2012; Deák, 2004; Diamond, 2006; Jacques & Zelazo, 2005; Snyder & Munakata, 2010). For example, the most widely used task to measure cognitive flexibility in preschoolers, the Dimensional Change Card Sort (DCCS; e.g., Zelazo, 2006), requires children to sort bivalent test cards (e.g., blue rabbits and red boats) first according to one dimension (shape or colour) and then according to the other. Children are only able to succeed in this task if they are able to switch between thinking about the test cards first in terms of one dimension (e.g., think about the blue rabbits as *rabbits*) and then in terms of the other dimension (e.g., think about the blue rabbits as *blue ones*; Frye, Zelazo, & Palfai, 1995). However, thinking about an object in two different ways, one after the other, is not the only way to exhibit flexible behaviour. In addition to this sequential way, we are sometimes required to coordinate several aspects of a single stimulus concurrently.

Perner, Stummer, et al. (2002) called attention to the distinction between sequential and concurrent processes in the context of perspective taking (i.e., thinking about an object or event from someone else's point of view). The authors defined *switching perspectives* as alternating between different perspectives at different times (e.g., using 'rabbit' in one situation and 'animal' in another to refer to the same object), and *confronting perspectives* as representing two different perspectives simultaneously (e.g., understanding that the object is *both* a rabbit and an animal at the same time). Both cognitive flexibility and perspective taking rely on the same basic process: children must represent the same object or situation in two (or more) different ways. Whereas perspective taking necessitates another person (that is, the second view is always someone else's; see, e.g., Moll, Meltzoff, Merzsch, & Tomasello, 2013), the same person can think about an object first in one way and then in another. Nevertheless, both skills require the understanding that the same thing (object or situation) can be represented in multiple ways. I therefore have extended Perner, Stummer, et al.'s (2002) distinction to discriminate between two types of cognitive flexibility: *consecutive cognitive flexibility*, which involves shifting between dimensions sequentially (as required by the Dimensional Change Card Sort), and *concurrent cognitive flexibility*, which involves coordinating two or more dimensions of the same object simultaneously (Podjarny et al., in press). Current measures of cognitive flexibility for preschoolers measure consecutive cognitive flexibility, as they involve thinking about different aspects of a stimulus sequentially (e.g., Cragg & Chevalier, 2012; Deák, 2004; Diamond, 2006; Jacques & Zelazo, 2005; Snyder & Munakata, 2010). Thus, we know very little about preschoolers' developing concurrent cognitive flexibility.

Understanding the development of concurrent cognitive flexibility could contribute to furthering our understanding of the development of several social and cognitive skills. For instance, Perner, Stummer, et al. (2002) argued that confronting perspectives, rather than switching perspectives, is the critical skill in children's reasoning about others' mental states. While their task refers to visual perspective taking (i.e., seeing the world from someone else's point of view), their argument applies to cognitive flexibility as well. These authors proposed that in order to understand that other people view the world differently, the child must integrate the two points of view as different perspectives of the same thing. Similarly, in order to understand that an object can be both blue *and* a rabbit, the child must integrate these two characteristics of the object as different representations (or views) of the same object.

In addition to the theoretical implications suggested by Perner, Stummer, et al.'s (2002) work, a clear picture of early concurrent cognitive flexibility development may help researchers predict important developmental outcomes. Specifically, multiple classification and multiple sorting tasks (which are based on Piagetian multiple classification; Inhelder & Piaget, 1964) have been shown to predict academic achievement and intelligence (e.g., Arlin, 1981; Siegler & Svetina, 2002). These tasks require children to coordinate several dimensions simultaneously in order to complete a pattern or sort objects along several dimensions simultaneously. For instance, in the matrix completion task children are asked to simultaneously coordinate several dimensions in order to select an item that completes a 2x2 grid. Performance on multiple classification and sorting tasks is related to nonverbal intelligence (Siegler & Svetina, 2002), reading proficiency (Cartwright, Marshall, Dandy, & Isaac, 2010; Colé, Duncan, & Blaye, 2014), and mathematical skills (e.g., Arlin, 1981) in primary school-aged children. However, no such tasks have been reported for use in preschoolers. Once we are able to measure concurrent cognitive flexibility in preschoolers, we will be able to investigate the role that its early development plays in developmental outcomes such as the ones mentioned.

Another reason to study the development of concurrent cognitive flexibility is that it might help us get a clearer picture of the relations among different executive function skills in young children. As mentioned before, structural investigations of executive functions in children (up until 13 years of age) yielded mixed findings, sometimes showing no distinction between inhibitory control and cognitive flexibility latent factors (see Lee et al., 2013, for a review). This lack of distinction may result from the close link between inhibitory control and consecutive cognitive flexibility: in order to succeed in consecutive cognitive flexibility tasks, the participant must recruit inhibitory control to ignore the previously relevant dimension. Therefore, it may be that researchers' inability to statistically separate the inhibitory control and cognitive flexibility latent factors results from the reliance of consecutive cognitive flexibility tasks on inhibitory control, rather than from a true unity of the two factors. Concurrent cognitive flexibility does not require inhibitory control in the same way. Because all relevant dimensions must be processed simultaneously, using inhibitory control to suppress one dimension may even hinder performance on concurrent cognitive flexibility tasks. Thus, using concurrent cognitive flexibility tasks in addition to consecutive cognitive flexibility tasks in executive functions structural investigations may help us better understand the interrelations among executive functions in children.

In order to investigate how concurrent cognitive flexibility plays a role in children's development, however, we must first have ways to measure concurrent cognitive flexibility in preschoolers. As mentioned before, the tasks reported in the literature to measure preschoolers' cognitive flexibility measure only consecutive cognitive flexibility. In addition, multiple classification and sorting tasks that tap concurrent cognitive flexibility often prove too difficult for preschoolers (e.g., Rittle-Johnson, Saylor, & Swygert, 2008).

There are several possible reasons preschoolers show poor performance on multiple classification and sorting tasks. First, it is possible that the skill of coordinating two dimensions simultaneously only comes online around 7 or 8 years of age. Alternatively, I argue, there may be task-related reasons for preschoolers' poor performance. For one thing, multiple classification tasks often require children to coordinate more than two dimensions. For instance, the matrix completion task (Siegler & Svetina, 2002) required children to coordinate four dimensions—shape, colour, size, and orientation. Another reason preschoolers might find these tasks difficult is that they require inductive reasoning; in other words, they require children to determine (induce) the relative dimensions before solving the problem. In a review of cognitive flexibility tasks, Jacques and Zelazo (2005) demonstrated that inductive tasks pose more difficulties for preschoolers than deductive tasks, which are tasks that include all the information necessary to solve the problem (in this context, a deductive task is one in which the experimenter labels the relevant dimensions in each trial). Thus, the first step in examining preschoolers' emerging concurrent cognitive flexibility is to develop age-appropriate tasks. Moreover, careful task analysis is required in order to ensure that if children fail concurrent cognitive flexibility tasks they do so because they are incapable of coordinating two dimensions simultaneously, rather than because they cannot induce the relevant dimensions or find coordinating more than two dimensions difficult.

My research focuses on understanding the development of concurrent cognitive flexibility vis-à-vis the development of consecutive cognitive flexibility during the preschool years. I examined the development of concurrent cognitive flexibility in the context of other executive functions, as well as other individual differences such as general language ability and nonverbal intelligence. In this work, I shall report two studies I conducted to this end.

In Study 1, I examined children's performance on several consecutive and concurrent cognitive flexibility tasks, in order to investigate the relations among consecutive and concurrent cognitive flexibility and other cognitive skills. I administered three consecutive and three concurrent cognitive flexibility tasks—both inductive and deductive, requiring the coordination of two and three dimensions—as well as tasks measuring inhibitory control, working memory, language, and nonverbal intelligence to 3- and 4-year-old children. The goal was to determine whether I could distinguish consecutive from concurrent cognitive flexibility as two separate latent constructs (using Structural Equation Modeling). Although the structural analysis did not yield the expected results, I used a descriptive analysis to examine the differential developmental trajectories of concurrent and consecutive cognitive flexibility, showing that the two processes, while strongly related, show distinct developmental trajectories. In this analysis I examined how task demands (i.e., whether the task was inductive or deductive) and number of dimensions to be coordinated interacted with the two types of cognitive flexibility (consecutive and concurrent) to affect children's cognitive flexibility performance.

In Study 2 I used an experimental manipulation to investigate the effects of experimenter labels and the way the task is presented on children's performance on two concurrent cognitive flexibility tasks. Thus, if the experimenter labeled the dimensions, the task was deductive, and if she did not the task was inductive. Because I used this experimental manipulation on the same tasks, I was able to more directly compare children's performance on inductive vs. deductive concurrent cognitive flexibility tasks. I found a three-way interaction between age, condition, and task order that I will discuss in terms of several theories.

I begin this document with a review of the literature regarding the development of consecutive and concurrent cognitive flexibility. I will then describe, in Chapter 3, the Methods and Results of Study 1, in which I took a structural analysis approach to differentiating consecutive from concurrent cognitive flexibility skills in preschoolers. As mentioned before, the results did not support a structural differentiation, so, in Chapter 4 I will describe an exploratory analysis I have conducted with the Study 1 data, and discuss how it can shed light on the role that two factors play in children's performance on consecutive cognitive flexibility tasks: (1) whether the task is inductive or deductive; and (2) whether children are asked to coordinate two or more dimensions. In Chapter 5 I shall describe Study 2, which focused on the effects of the deductive/inductive nature of the task (factor 1) on concurrent cognitive flexibility performance. The concluding chapter will be a General Discussion, in which I will discuss how both studies together contribute to our understanding of early cognitive flexibility development.

Chapter 2: Literature Review

A better understanding of cognitive flexibility development will help researchers to predict individual differences in developmental outcomes such as academic achievement (e.g., Arlin, 1981; Cartwright et al., 2010; Colé et al., 2014) and nonverbal intelligence (e.g., Siegler & Svetina, 2002). As mentioned in Chapter One, we know quite a bit about the development of consecutive cognitive flexibility skills in preschoolers (3- to 5-year-olds); in contrast, we know very little about the emergence of concurrent cognitive flexibility skills during the same developmental period. Knowing more about concurrent cognitive flexibility development would inform our understanding of cognitive flexibility development more generally.

In this chapter, I will review the research examining the development of cognitive flexibility during the preschool years. To help situate cognitive flexibility in the context of Executive Functions, I shall first provide a brief, general overview of Executive Function skills development between the ages 3-5 years. Then, I will review research investigating consecutive cognitive flexibility development in preschoolers, including tasks that are used to measure this skill in preschoolers. I will then discuss some of the theories that have been offered to explain the development of cognitive flexibility during the preschool years. Next, I will review the relatively limited research examining concurrent cognitive flexibility development, including tasks that have been used in previous research. I will then turn to discuss what we know about the relation between concurrent and consecutive cognitive flexibility skills, and how this work will examine the nature of this relation.

Executive Functions

Consecutive cognitive flexibility has traditionally been examined in the context of Executive Functions. Following Miyake et al.'s (2000) work, many researchers adopt a three-factor model of Executive Functions. This model includes inhibitory control, working memory, and (consecutive) cognitive flexibility[2] (see, e.g., Garon et al., 2008; Lee et al., 2013). I shall briefly review research on preschoolers' working memory and inhibitory control development, in order to set the stage for discussing the development of cognitive flexibility during the same time.

We call *working memory* into action when we are required to hold and manipulate information in mind (Baddeley, 1992, 2012). According to Baddeley, working memory consists of a central executive that regulates information arriving via different modalities. Thus, the central executive receives input from the phonological loop (auditory and linguistic input, both from long-term memory and from short-term memory), the visuo-spatial sketch-pad (visual input), and the episodic buffer (episodic input from long-term memory; Baddeley, 2000).[3] In the context of Executive Functions development, the term working memory often refers to the central executive—a regulatory process that monitors input and allows for its processing (see, e.g., Carlson, Moses, & Breton, 2002; Lee et al., 2013). To measure this process in preschoolers, researchers use either dual tasks (tasks in which participants have to simultaneously perform two separate memory tasks), reversed order recall, or self-ordered search tasks (see, e.g., Gathercole, Pickering, Ambridge, &

[2] Most researchers use *cognitive flexibility* to refer to consecutive cognitive flexibility or set-shifting. I insert the term *consecutive* (parenthetically) to indicate that the authors used the term cognitive flexibility, but the research examined consecutive cognitive flexibility specifically.

Wearing, 2004). For example, listening recall is a dual-task in which children hear sentences, and after each sentence they have to state whether the sentence is true or false. After hearing and judging a set of sentences (the number increases across trials), children have to recall the final word of each sentence they heard and judged. Thus, children must perform two tasks: they must process the linguistic information of the sentence (in order to make the true/false judgment) and remember the sentence-final words. An example of a self-ordered search task is the self-ordered pointing task, in which children see an array of pictures that are presented in a different, random spatial order in each trial (thus, spatial information is not informative). In each trial children are asked to point to a different picture ("point to a picture you didn't point to before"). Children must monitor their responses in order to select a correct item in every trial (Cragg & Nation, 2007). Note that the listening recall uses the phonological loop (auditory input, linguistic processing) whereas the self-ordered pointing uses the visuo-spatial sketch-pad (visual input, but not spatial position).[4] Thus, working memory tasks differ in their input modality, type of task (e.g., dual task, self-ordered searching, or reverse order recall), and the nature of the information to be remembered.

In a large cross-sectional study examining the traditional components of working memory (i.e., phonological loop, visuo-spatial sketch-pad, and central executive), Gathercole et al. (2004) found that performance showed a linear improvement in all three

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[3] The episodic buffer was added to the original tripartite model (which included the central executive, phonological loop, and visuo-spatial sketch-pad) fairly recently (Baddeley, 2000, 2012).

[4] If the Self-Ordered Pointing is administered using familiar pictures (e.g., a house, a ball, etc.), children may use labels of the item instead of a visual representation. Some versions of the Self-Ordered Pointing task contain abstract pictures, so as to reduce the use of verbal labels. Nevertheless, in both versions the input for this task is visual rather than auditory.

components between ages 4 and 15. They also showed that the adult tripartite model of working memory held for 6- to 15-year-olds. However, these authors only gave the preschoolers (4- and 5-year-olds) in their sample a single central executive task (the backward digit recall, in which children are required to repeat a string of digits in a reversed order). Therefore, they could not test the tripartite model of working memory for 4- and 5-year-olds. Overall, the study found that children steadily improve on working memory (central executive) tasks. Combined with Garon et al.'s (2008) review on Executive Function between ages 2-5 years, we know that children show consistent improvement in their working memory capacity from the time they are about 2 years of age throughout childhood and adolescence (Garon et al., 2008; Gathercole et al., 2004).

We tap into our *inhibitory control* when we need to suppress a strong, automatic or over-learned response (i.e., *prepotent* response; e.g., Garon et al., 2008). There are two types of inhibitory control: delay and conflict (Carlson & Moses, 2001). *Inhibitory control–delay* is recruited when we must delay or suppress an impulsive response. For instance, in the widely-known 'marshmallow task' (Mischel, Shoda, & Peake, 1988), children are seated in a chair with a single marshmallow placed on the table in front of them. The children are told that if they can refrain from eating the marshmallow, they can have two marshmallows upon the researcher's return (15 minutes later). The dependent variable is the time children are able to delay their impulse to eat the marshmallow, with longer wait times interpreted as demonstrating greater inhibitory control-delay skills. Interestingly, preschoolers' performance on this task is related to a wide range of outcomes, including better social-, cognitive-, and health-related outcomes even into adulthood (see Mischel et al., 2011, for a review).

Another type of inhibitory control, *inhibitory control–conflict* is tapped when we are required to suppress a strong response, and to replace it with a different—and typically conflicting—response. For instance, in the day/night Stroop-like task (Gerstadt, Hong, & Diamond, 1994), children are presented with cards depicting the sun ('day' cards) or the moon ('night' cards), and are asked to respond with "day" to the night cards and "night" to the day cards. To succeed, children must suppress the automatic response of saying "day" when seeing the day card, and then replace it with a conflicting response (saying "night"). The ability to use the appropriate (conflicting) response is taken as an indicator of inhibitory control-conflict skills. Both inhibitory control skills (delay and conflict) emerge fairly early in life, and performance on the tasks described show a marked improvement during preschool years (3-5 years of age; Garon, 2008). Nevertheless, inhibitory control skills continue to develop throughout childhood and adolescence (e.g., Ordaz, Foran, Velanova, & Luna, 2013).

The focus of the current thesis, however, is on cognitive flexibility in particular. So, I will now review consecutive cognitive flexibility research, in considerably more detail than the other Executive Function skills. I shall begin with consecutive cognitive flexibility, as this skill has been studied quite extensively in preschoolers (Cragg & Chavlier, 2012; Ionescu, 2012).

Consecutive Cognitive Flexibility Development During Preschool

Consecutive cognitive flexibility, like working memory and inhibitory control, shows a protracted developmental trajectory (Best & Miller, 2010; Cragg & Chevalier, 2012; De Luca et al., 2003). Like inhibitory control, significant improvement can be seen in children's consecutive cognitive flexibility performance between the ages 3 and 5 years (e.g., Garon et al., 2008).

Researchers employ a number of different tasks to measure preschoolers' emerging cognitive flexibility (see Cragg & Chevalier, 2012, for a review). However, all tasks require children to be able to consider a particular item in more than one way (i.e., attend to particular characteristics as required for a given goal). For example, the Dimensional Change Card Sort (DCCS; Frye et al., 1995; Zelazo, 2006) is a widely-used measure of children's consecutive cognitive flexibility skills (Zelazo, Müller, Frye, & Markovitch, 2003). In this task, children have to first attend to one dimension of a set of test cards (e.g., colour or shape), and sort the cards along that dimension. Children typically have very little difficulty with this part of the task. Then, after doing this for a number of trials (typically 5 to 8), they have to switch their attention to the other dimension (e.g., shape or colour), and sort the cards along the new relevant dimension. Children's post-switch performance is taken as indicative of their cognitive flexibility (i.e., their ability to flexibly attend to whatever dimension is relevant). For example, children can be asked to sort blue rabbits and red boats first according to colour (the 'colour game'), with all of the blue ones into one box (with a blue boat target card affixed to it) and all the red ones into another (with a red rabbit target card). Then a switch is announced, and in the post-switch phase children are required to sort according to a new rule, and attend to the second dimension when playing the 'shape game' (all the rabbits into the box marked with a red rabbit and all the boats into the one marked with a blue boat). Children are only able to succeed on this task if they are able to switch from the pre-switch to the post-switch rule (Frye et al., 1995). More specifically, children succeed on this task only if they are able to regard the same stimulus (a blue rabbit or a red boat) in terms of the first dimension on the pre-switch phase and then in terms of the second dimension on the post-switch phase.

It is generally found that 3-year-old children have difficulty switching between two aspects of the same stimulus, regardless of the order in which they are presented (i.e., colour first or shape first; see, e.g., Zelazo, 2006). By the time they are about 4.5 years old, most children succeed on the Dimensional Change Card Sort, demonstrating the ability to flexibly attend to the relevant aspect of image (e.g., Frye et al., 1995; Kloo et al., 2010; Zelazo, 2006). Preschoolers' performance on this task is related to their ability to reason about someone else's mental states (Theory of Mind; e.g., Perner, Lang, et al., 2002), and predicts later academic achievements (Coldren, 2013).

Though informative, there are several points to consider when using the Dimensional Change Card Sort as a task to measure (consecutive) cognitive flexibility. First, it typically only involves a single switch—from the pre-switch dimension to the post-switch dimension (Zelazo, 2006). While a 'borders version' had been developed, in which children have to sort cards along one dimension if the card has no border and along the second dimension if the card has a border (e.g., Miller et al., 2012; Zelazo, 2006), this task still does not allow for examining children's ability to consider more than two dimensions of a single stimulus.[5]

Another point to consider is that performance on the Dimensional Change Card Sort tends to be bimodal: children either sort all (or almost all) post-switch cards

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[5] A 3D-Dimensional Change Card Sort, which does require children to consider three different dimensions (shape, colour, and size), was developed by Deák (2004). This task is not as popular as the standard Dimensional Change Card Sort, however. I will review this task in more details in Chapter 4.

correctly, or they perseverate on the post-switch phase, sorting all (or almost all) cards along the pre-switch dimension (Carlson, 2003; Kirkham et al., 2003). From data collected using this task, it would appear that some children are able to flexibly consider a certain stimulus, whereas some cannot (see, e.g., Carlson, 2003; Kirkham et al., 2003). One possible explanation for this pattern is that consecutive cognitive flexibility is an 'all-or-none' ability: children either can consider two dimensions consecutively, or they cannot. However, the bimodal pattern of performance may result from the single-switch demand of the task: because it is typically used with only two dimensions between which children are required to switch once (Zelazo, 2006; see Cragg & Chevalier, 2012 for a review), there are some children who are able to switch once between two dimensions, and children who fail to perform that single switch. This task, at least in the way it is currently used, does not provide us with information as to children's ability to perform several switches, only one switch between two dimensions. Although the borders version allows for several switches back and forth, the Dimensional Change Card Sort does not allow for examination children's ability, for instance, to switch from shape to colour once, and then from shape to size (unless one runs the task twice with different stimuli).

Another point to consider with the Dimensional Change Card Sort is that it originally was described as an inhibitory control measure (e.g., Carlson & Moses, 2001). In support of the interpretation of the Dimensional Change Card Sort as an inhibitory control task, Perner and Lang (2002) reported a 'characters' version of the Dimensional Change Card Sort where, instead of target cards, the two boxes were described as belonging to a character (e.g., Donald Duck and Mickey Mouse). In the pre-switch phase, children were told that one character wanted all the red ones and the other character wanted all the blue ones; in the post-switch phase, children were told that one character wanted all the rabbits and the other character wanted all the boats. Both 3- and 4-year-olds found this version significantly easier than the standard version, in which the target cards affixed to the boxes were in conflict with the test cards. The character version was described as reducing the “visual clash” (conflict) between the target cards and the test cards—thus reducing the inhibitory control demands of the task. Note that in this characters version, the cognitive flexibility requirements of the task remained the same: children had to sort the same test cards first by colour and then by shape. Despite this inhibitory control component, the Dimensional Change Card Sort is currently widely used as a measure of cognitive flexibility, including by Zelazo, one of its original developers (e.g., Zelazo, Anderson, Richler, Wallner-Allen, Beaumont, & Weintraub, 2013).

Despite these issues, the Dimensional Change Card Sort is a useful tool to assess preschoolers’ consecutive cognitive flexibility. It is easy to administer and is suitable to administer to even 3-year-olds (Zelazo, 2006). It provides the researchers with a clear pass or fail score, and shows extremely high test-retest reliability (Beck, Schaefer, Pang, & Carlson, 2011). I therefore chose to use it in my Study 1 as one of the measures of consecutive cognitive flexibility (see Chapter 3).

Another task that has been used to measure children’s (consecutive) cognitive flexibility is the Flexible Item Selection Task (Jacques & Zelazo, 2001; Jacques, Zelazo, & Lorenco, 2007, as cited in Marcovitch, Jacques, Boseovski, & Zelazo, 2008). In this task, children are presented with an array of three trivalent items (vary in terms of size, colour, and shape), with one pair matching on one dimension and a different pair matching on another dimension. For instance, children were shown a big blue flower, a big blue shoe, and a small blue shoe (Jacques et al., 2007). The children are asked to select two items that "go together in one way", and then to select two items that "go together in another way". In this case, a correct answer would be either to select both shoes and then both big items or vice versa. Note that the researchers always held the irrelevant dimension (in this case, colour) constant. So, selecting the big blue flower and the small blue shoe would be scored as incorrect (Jacques et al., 2007).

In order to succeed on the Flexible Item Selection Task, children must flexibly consider one item—the *pivot* item, in this case the 'big blue shoe'—first in terms of one dimension (e.g., shape) and then in terms of another dimension (e.g., size). Children are scored on their accuracy on the first selection across trials, and separately for their second selections (Jacques & Zelazo, 2001; Jacques et al., 2007). There are either 12 (Jacques & Zelazo, 2001) or 15 (S. Jacques, personal communication, November 5, 2007) test trials in this task, and in each of these trials the relevant dimensions vary across two of the three possible dimensions. Children are required to perform one switch per test trial (from one relevant dimension to another). Thus, instead of a single switch in the Dimensional Change Card Sort (from pre-switch rules to post-switch rules), there are 12-15 switches (depending on the number of test trials) on the Flexible Item Selection Task. Moreover, because three dimensions are being used in this task, we can vary the dimensions' combination for each switch (e.g., two items that match on colour and two that match on shape, two items that match on size and two that match on colour, and so on). Given these characteristics, the Flexible Item Selection Task potentially allows for more variable performance than does the Dimensional Change Card Sort.

Performance on the Flexible Item Selection Task is related to performance on other flexibility tasks such as the Verbal Fluency Task (in which children have to come up with as many category words—e.g., food items—in a limited time frame; Snyder & Munakata, 2010) and the Pattern Completion Task (in which children have to complete patterns based on one or two dimensions; Bennett & Müller, 2010; see below for a more detailed discussion of this task).

In our lab, we (Podjarny, Kamawar, & Vendetti, & Astle, 2009) made two changes to the Flexible Item Selection Task as reported by Jacques et al. (2007). First, because in the original task the irrelevant dimension was held constant, all three items match on that dimension. Thus, children who selected, for instance, the big blue flower and the small blue shoe were scored as incorrect, despite both these items being blue. We cannot know whether these children chose this pair because they were not able to be cognitively flexible, or because they did not realize that dimension was irrelevant for that trial (colour is a relevant dimension in other trials). In our Modified Flexible Item Selection Task (see Chapter 3 for detailed methodology), the items varied on the irrelevant dimension, instead of being kept constant. Using the example above, in which colour is the irrelevant dimension, this would mean showing the child a big *blue* flower, a big *red* shoe, and a small *yellow* shoe (with the big red shoe as the pivot item – matches the first item in terms of size and the final item in terms of shape). In this way, children who select the wrong pair (in this example, the big blue flower and the small yellow shoe) can be more confidently considered as not matching on any dimension.

Another change that we made had to do with how performance was scored. In previous work, scoring was done independently for each of the two selections and summed across trials (Jacques & Zelazo, 2001; see also Bennett & Müller, 2010). That is, if a child selected an incorrect pair on the first selection (the big blue flower and the small blue shoe), and then selected a correct pair in the second selection, she was scored as correct on the second selection, despite not necessarily being able to consider the pivot item (the big blue shoe) in two different ways. We have modified the scoring, and only gave children credit on a given trial if they were correct for *both* selections. Thus, our contingent scoring would only give credit for children who could flexibly consider the pivot item.

With these modifications, the Modified Flexible Item Selection Task still reflected a similar developmental pattern as the one reported in Jacques and Zelazo (2001). In addition, our contingent score showed significant correlations with the Dimensional Change Card Sort and with other working memory measures than the scores that considered the first and second selections separately (Podjarny et al., 2009). The Modified Flexible Item Selection Task scores in our sample showed more variability than the Dimensional Change Card Sort scores, not following a bi-modal distribution. Therefore, when I used the Modified Flexible Item Selection Task in the current work I used our modified version.

Another task that has been used to measure children's (consecutive) cognitive flexibility is the Object Classification Task for Children (Smidts et al., 2004). This task was design to measure both concept generation—the ability to identify conceptual categories, such as "food" or "animals"—and flexibility in children from 3- to 7-years of age. In this task, children are asked to sort 6 objects that vary along three dimensions (shape, colour, and size), in three different ways. For instance, one of their six-object sets included a big red plane, a big red car, a big yellow car, a small red plane, a small yellow plane, and a small yellow car. Children were asked to sort the objects along each of the three dimensions. The experimenter provided increasing levels of support for the children who needed it. The first step was to ask the children to sort the objects on their own (e.g., “can you make two groups for me? Something has to be the same about the toys in each group”, p. 391) and then to label the dimension along which they sorted (“can you tell me what’s the same about these toys?”; p. 391). If they could not sort on their own, the experimenter sorted the objects for them along one dimension, and asked them to label that dimension (identifying the relevant dimension was considered to measure children’s ability to identify the conceptual category). Children who could not identify (i.e., label) the relevant dimension, were provided with more support: the experimenter later returned to the dimensions the child could not label on her own, and provided the child with explicit labels (“can you put all the red ones on this side and all the yellow ones on that side?”, p. 392) to examine the child’s ability to consider a different dimension from the one(s) already considered in previous sorts.

Smidts et al. (2004) reported that only 40% of the 3-year-olds and 50% of the 4-year-olds in their sample were able to sort 6 objects into two groups (i.e., the first sort, where no cognitive flexibility is required) on their own. For children who could not sort the 6 objects into two groups on the first sort on their own, the authors used a reduced stimuli set with 4 objects that varied along two dimensions. Therefore, at least half of the 3- and 4-year-olds in their sample received a bivalent, rather than a trivalent, stimuli set.

In terms of preschoolers’ (consecutive) cognitive flexibility performance, 70% of the 3-year-olds and all of the 4-year-olds in the sample needed the experimenter to explicitly label the relevant dimension in order to perform a switch (Smidts et al., 2004). That is, after sorting along one dimension (e.g., shape), these children could not switch to sort the same objects on their own along a second dimension (with the exception of one 3-year-old, who "appeared to be unaware that he had sorted the objects correctly"; Smidts et al., 2004, p. 395). It is unclear from the report whether—or how many of—these children actually succeeded in sorting the objects along a second dimension once the experimenter labeled it (e.g., to follow the instructions of "can you put all the red ones on this side and all the yellow ones on that side?", p. 392). Of the 3- and 4-year-olds who were able to sort along the first dimension on their own (and so stayed with a 6-objects stimuli set), none could perform the second switch on their own or to identify the category once the experimenter sorted the objects (along a third dimension) for them.

Five-year-olds in Smidts et al.'s (2004) sample, in contrast, performed better than 3- and 4-year-olds on all accounts. All of them were able to group the 6 objects along the first dimension on their own and thus continued to work with the 6-object stimuli set; 40% of them were able to perform the first switch on their own, and sort along a second dimension; however, less than 10% of them were able to perform the second switch on their own, and about 60% needed the experimenter to explicitly label the third dimension (again, it is unclear from the report whether they then proceeded to sort the objects along the labeled third dimension). Thus, performance on this task is consistent with the developmental trends found when using the Dimensional Change Card Sort and the Flexible Item Selection Task: 3- and 4-year-olds mostly have difficulties with switching from seeing a stimulus in terms of one dimension to seeing it in terms of another dimension, but older children's (in this case, 5- to 7-year-olds) (consecutive) cognitive flexibility skills improve steadily.

The Modified Object Classification Task for Children is useful because it not only allows for more than one "switch", but it also allows for measuring children's ability to consider the stimuli in more than two ways—in this case in three ways. Thus, it expands the measured cognitive flexibility skill further: the Dimensional Change Card Sort measures one switch, the Flexible Item Selection Task measures several switches across three dimensions, but only between two dimensions *per trial* (i.e., each pivot item only had to be considered in two ways), and the Object Classification Task for Children measures three switches, along three dimensions for each stimuli set. However, because Smidts et al.'s (2004) decision to use a reduced set for children who could not sort along a single dimension on their own narrowed the scope of the task from measuring children's ability to consider the stimuli set in up to three ways, to only measuring their ability to consider the stimuli set in two ways. In the context of Smidts et al.'s focus, this decision made perfect sense: their investigation was mainly concerned with conceptual reasoning, and to a lesser extent with (consecutive) cognitive flexibility. However, this procedure prevents the researchers from examining children's ability to consider three dimensions consecutively.

While the finding that many 3- and 4-year-olds are unable to sort a trivalent stimuli set on their own informs us about 3- and 4-year-olds' concept generation abilities, the reported study does not shed light on young preschoolers' ability to consider three dimensions (i.e., shape, colour, and size) of a stimuli set—because these children never got a chance to sort the full 6-objects set along three dimensions.[6] The older children in the study (5- to 7-year-olds), however, found considering the same trivalent stimuli in a third way harder than considering them in the first two ways (note that Smidts et al.'s report does not mention whether children were more likely to sort along a specific dimension—e.g., shape—as compared with other dimensions). This finding supports the notion that even after mastering switching from considering one dimension to considering another, children may still have difficulties with switching to a *third* dimension. The number of dimensions to be coordinated, then, is an important characteristic of a cognitive flexibility task, and should be taken into account when examining cognitive flexibility development. For this reason, I have chose to use the Object Classification Task for Children (modified, details below) in my work.

Children's difficulties with considering a stimuli set in three different ways could be attributed to working memory capacity, as keeping three dimensions in mind (and remembering which ones were already considered) requires more working memory than keeping only two dimensions in mind. In terms of inhibitory control, however, it seems unlikely that disengaging from the second dimension considered should be more difficult than disengaging from the first dimension considered. No study has yet examined the role that working memory and inhibitory control play in children's performance on the Object Classification Task for Children.

There are a few methodological points to consider regarding the Object Classification Task for Children. I shall outline these points and explain how I addressed

[6] While some studies show that children's concept generation abilities precede their (consecutive) cognitive flexibility abilities (e.g., Jaqcues & Zelazo, 2001), (consecutive) cognitive flexibility does not necessarily depends on concept generation. I shall discuss the relationship between these two skills in more details in chapter 4.

them in my version of this task—the Modified Object Classification Task for Children (see full details in Chapter 3). The first point to consider is that Smidts et al. (2004) chose to use toys rather than pictures because these “can be manipulated by the child and are thought to be more appealing to young children than diagrams or graphics” (p. 389). However, precisely because toys can be manipulated, it is possible that they were too distracting for young children, especially 3-year-olds, thereby hindering their performance (i.e., children may have wanted to play with the toys, and not sort them as per the researcher’s request). In the Modified Object Classification Task for Children, I used cards depicting trivalent stimuli (e.g., a picture of a small red circle), to address the concern of toys being too distracting.

Second, there was no demonstration or practice of sorting items that were not identical. The authors used two practice trials in which the child was asked to sort 4 toys (2 identical pairs) into 2 groups. Following the practice trials the experimenter presented children with the test stimuli set and asked them to “do the same with these toys” (Smidts et al., 2004, p. 391). However, the test toys were not identical as were the ones in the practice trials. Therefore, young children may have misunderstood the task requirements because they had not seen a demonstration or had practice with stimuli similar to the test stimuli (i.e., stimuli that were non-identical, but matching on a certain dimension, such as shape, colour or size). In my Modified Object Classification Task for Children, I added a demonstration trial in which the experimenter sorted a set of stimuli similar to the test items (i.e., a set of 6 cards depicting objects that could be sorted by shape, colour, and size). In this way, children were made aware of what was required of them in the test trials.

The third point to consider, which I discussed before, was that children who could not perform the first sort on their own were shown a different, smaller set of stimuli. In particular, the reduced set only allowed for considering two dimensions, which precluded measuring young children's ability to consider three dimensions. In the Modified Object Classification Task for Children I only used a set of 6 cards for a given test trial, and if children could not sort the cards on their own in the first sort they received the same increasing support system as they did in the second and third sort. In this way, all children were tested with the 6 cards set, and I was able to measure their ability to consider the stimuli set in three ways.

The fourth methodological point was that Smidts et al.'s (2004) task included a single test trial, which makes reliability difficult to establish. Moreover, sorting once along a certain dimension can be achieved by chance (as evident from Smidts et al.'s, 2004, report of one 3-year-old who succeeded in sorting the cards on his own but seems to do so accidentally, without truly generating a conceptual category). To address this issue, I used 3 test trials, and children were only considered to succeed if they were able to show consistent performance.

Finally, the scoring system used by Smidts et al. (2004) was not designed to distinguish among different levels of achievement because they summed across the different sorts for the set of items. For example, children received 3 points for sorting toys correctly on their own, and another point if they labeled their own sort correctly. If they could not do this, the experimenter would then sort the toys and ask the children to label the dimension, and they could have received 2 points for that. The points were summed across the sorts, and there were three sorts (one for each dimension, for the set of items). So then, children could receive 8 points, for instance, either by sorting 2 dimensions correctly on their own (3 points for each sort) and then successfully labeling the third dimension in the identification condition (2 points), or by sorting the first dimension and labeling it correctly in the free generation condition (4 points) and then successfully labeling the following two dimensions in the identification condition (2 points for each sort). Children's scores on their task, therefore, could not be easily interpreted to indicate only their (consecutive) cognitive flexibility skills (independent of their ability to provide a verbal label). Fortunately, the authors also provided a frequency analysis, which allows for a glimpse of children's (consecutive) cognitive flexibility performance. In my Modified Object Classification Task for Children I used a separate score for each sort, and the summing score reflected only the children's sorting behaviour, independent of their labeling behaviour (although I collected data on their labeling behaviour as well, this was not a focus of the thesis).

Despite these issues, the original Object Classification Task for Children is useful because, as mentioned before, it provides a fairly straightforward way to measure children's ability to consider the same stimulus in three different ways. Moreover, the increasing support structure is useful to examine how much support children require in order to consider a stimulus in several different ways. Therefore, I chose to use this task (with the modifications indicated above) in my work. I will discuss the effects of this increasing support, as well as the number of dimensions to be coordinated, on children's cognitive flexibility performance in more details in Chapter 4.

The (consecutive) cognitive flexibility tasks outlined above have been used with 3- to 5-year-olds in a number of studies (e.g., Aarnoudse-Moens, Smidts, Oosterlaan, Duivenvoorden, & Weisglas-Kuperus, 2009; Bennett & Müller, 2010; Coldren, 2013; Gillis & Nilsen, 2014; Jacques & Zelazo, 2001; Jacques et al., 2007; Ramscar, Dye, Gustanfson, & Klein, 2013; Snyder & Munakata, 2010). Across them, we can see some consistency in terms of the developmental pattern. For example, most studies find that 3-year-olds fail to consider two dimensions consecutively. Most 3-year-olds are capable of sorting cards along one dimension (as in the Dimensional Change Card Sort pre-switch phase; Zelazo, 2006), or grouping two non-identical items along one dimension (as in the first selection of the Flexible Item Selection Task and the first sort of the Object Classification Task for Children; Jacques & Zelazo, 2001; Smidts et al., 2004). However, on average, 3-year-olds perform quite poorly when they are required to consider the same stimulus in a different way; this consistent finding indicates that 3-year-olds have poor consecutive cognitive flexibility skills. Another consistent finding is that over the next year of life, children's consecutive cognitive flexibility improves rapidly: by the time they are 5 years old, many children are able to consider a stimulus in a second way (e.g., Jacques & Zelazo, 2001; Zelazo, 2006). Nevertheless, they sometimes require some assistance, and they still find it difficult to consider that same stimulus in a third way (Smidts et al., 2004).

Consecutive Cognitive Flexibility Theories

Researchers have developed theories to account for the changes demonstrated by preschoolers on tasks such as the ones reviewed (i.e., consecutive cognitive flexibility tasks). Though designed to account for changes in consecutive cognitive flexibility, they have the potential to be applied to concurrent cognitive flexibility. Therefore, they provide a useful framework with which to interpret findings related to both consecutive and concurrent cognitive flexibility development. I now turn to describing and discussing two main theories that have been offered to explain (consecutive) cognitive flexibility development during the preschool years.

The first theory I will discuss is the *Attentional Inertia Account*. It was developed by Diamond (e.g., Diamond, 2006, 2012; Kirkham et al., 2003), and argues that cognitive flexibility is enabled by working memory and inhibitory control working in synchronization to allow us to adapt to changing situations. On Diamond's (2006, 2012) view, cognitive flexibility is the ability to re-orient the attentional focus, which is a combination of disengaging from the previous focus (inhibitory control) and actively maintaining the current focus (working memory). This claim is consistent with some recent findings that, in children, the latent factor of (consecutive) cognitive flexibility cannot be distinguished structurally from the other two Executive Functions, inhibitory control and working memory (e.g., Brydges et al., 2014; Fuhs & Day, 2011; Lee et al., 2013; Wiebe et al., 2011). Given that, for this account, consecutive cognitive flexibility essentially depends on the other two Executive Functions, it cannot be differentiated from them until children become more skilled at both "pre-requisite" processes. According to this account, the difficulties that 3-year-olds have with tasks such as the Dimensional Change Card Sort stem from their inability to disengage their attention from the first—and now no longer relevant—dimension. Thus, 3-year-olds find it hard to stop attending to the "blueness" of the item, and this prevents them from attending to its "rabbitness" (Kirkham et al., 2003). Hence the name for this theory: *Attentional Inertia Account.*

The Attentional Inertia Account has been supported by several findings, most of them involving manipulations of the features of the Dimensional Change Card Sort (as a representative task). Recall that in this task, children are asked to sort bivalent test cards first along one dimension (e.g., shape), and then along a second dimension (e.g., colour).

In one manipulation that is taken as support for the Attentional Inertia Account, Kirkham et al. (2003) administered the Dimensional Change Card Sort using four different conditions. In addition to the "standard version", they had a label condition, a "face up" condition, and a sleeve condition. In the label condition, instead of labeling the relevant dimension explicitly (e.g., "here's a red one"), the experimenters asked the children on the first post-switch trial "what colour is this one?" (p. 455), and on later post-switch trials "what's this one?" (p. 455) and waited for the children to provide the specific value of the relevant dimension (e.g., "red") for each test card before sorting it. In the "face up" condition, the standard version was used, with cards that are sorted into the trays facing up (they are usually sorted so that the item cannot be seen), so that the previous sorting dimension was more salient (seeing the previous and no-longer-relevant dimension was expected to create increased inhibitory control demands, and thus impede children's performance).[7]

Kirkham et al. (2003) found that three-year-olds (but not 4-year-olds) did better when they named the relevant dimension themselves than when the experimenter labeled the relevant dimension. The authors argued that by naming the relevant dimension on their own, children's attention was directed towards the relevant dimension, helping them disengage their attention from the previously relevant dimension. Four-year-olds were

[7] Note that in the 'sleeve' condition the test card was hidden inside an envelope *after* the child saw it, a manipulation that intended to prevent the child from confronting the irrelevant dimension while she sorted the card. However, this condition is somewhat problematic as the children did see the cards before they were inserted into the envelope (see Vendetti, 2008 for more details), making their performance on this condition difficult to interpret.

adversely affected by the “face up” condition, relative to the standard version of the Dimensional Change Card Sort. The researchers argued that seeing the previously relevant dimension in this condition impeded children’s performance because, at least in part, children’s difficulties on the Dimensional Change Card Sort result from the demand to disengage from the previously relevant dimension.

Note that several studies seem to contradict the Attentional Inertia Account. For instance, Müller, Zelazo, Lurye, and Liebermann (2008) failed to replicate Kirkham et al.’s (2003) labeling condition’s effect on children’s performance. In addition, assuming that one trial is not enough to create a strong response of sorting along the first dimension, we should see improved performance on the post-switch phase after a single-trial pre-switch phase (Kloo & Perner, 2005). However, 3-year-olds fail the Dimensional Change Card Sort even after a single pre-switch trial (Zelazo, Frye, & Rapus, 1996, Experiment 2). This finding was taken to indicate that attentional inertia plays a small role in Dimensional Change Card Sort performance (see, e.g., Kloo & Perner, 2005).

The other main theory put forward to account for (consecutive) cognitive flexibility development is the Cognitive Complexity and Control theory (CCC; Zelazo & Frye, 1998). The Cognitive Complexity and Control theory was originally used to account for similarities in children’s performance on the Dimensional Change Card Sort and tasks measuring false belief understanding (the ability to understand that different people can represent the world differently; see, e.g., Zelazo & Frye, 1998). This theory was later revised (Zelazo et al., 2003), and I will outline the revised version.

According to the Cognitive Complexity and Control Theory (Revised), between 3 and 5 years of age, children’s ability to use embedded rules improves, allowing them to integrate two views of the same object as two different contexts. Thus, while 3-year-olds can follow two different rules (e.g., "if it's a red one, it goes in the red box" and "if it's a blue one, it goes in the blue box"), they are unable to embed these rules into a hierarchical rule structure of if-if-then rules (e.g., "if we are playing the colour game, and if it's a red rabbit, it goes in the red box; but if we are playing the shape game, and if it's a red rabbit, it goes in the rabbit box"). By the time they are 5 years old, however, the number of levels of rule-embedding increases, providing children with the ability to process an if-if-then structure (Zelazo & Frye, 1998).

From the point of view of the Cognitive Complexity and Control Theory (Revised), Kirkham et al.'s (2003) finding that children do better on the Dimensional Change Card Sort when labeling the relevant dimension themselves, as compared to when the experimenter labels the relevant dimension, may have more to do with the child having to actively consider the relevant dimension than with the dimensions being labeled *per se*. For instance, Zelazo et al. (2003) argued that "labeling does, in fact, provide children with a more sophisticated conceptual structure." (p. 114). However, it is unclear whether they refer to a labeled (i.e., deductive), as compared to an unlabeled (i.e., inductive) version of the task, or to the comparison made by Kirkham et al. (2003). The comparison between inductive and deductive cognitive flexibility tasks will be discussed in more details in Chapter 4.

It is important to note that the two accounts are not mutually exclusive. For example, findings from research examining the effects of labels on children's consecutive cognitive flexibility performance suggest that the Attentional Inertia Account may explain 3-year-olds' difficulties with tasks such as the Dimensional Change Card Sort, whereas the Cognitive Complexity and Control Theory (Revised) may be a better explanation for 4-year-olds' difficulties with other tasks measuring (consecutive) cognitive flexibility. For instance, in Kirkham et al.'s (2003) study, when 3-year-olds named the relevant dimension (following the experimenter's prompt), they performed better on the Dimensional Change Card Sort as compared to the standard version (in which the experimenter named the relevant dimension). In contrast, 4-year-olds did not benefit from this manipulation. Jacques and Zelazo (2005) suggest that the effects of labels qualitatively change between the ages 3 and 5 years. They argue that while for 3-year-olds the attention-directing properties of the labels provide support for their (consecutive) cognitive flexibility performance, for 4-year-olds the labels allow for reflection on the hierarchical rule structure of the task. It is possible that 3-year-olds, who have fairly poor inhibitory control skills (e.g., Garon et al., 2008), have difficulties with disengaging from the first dimension (consistent with the Attentional Inertia Account), whereas 4-year-olds, who have more developed inhibitory control skills, find disengaging from the first dimension relatively easy, but still have difficulty in seeing the stimulus in terms of the second dimension (consistent with the Cognitive Complexity and Control Theory—Revised).

Note that both theories—the Attentional Inertia Account and the Cognitive Complexity and Control Theory (Revised)—have been proposed to explain consecutive cognitive flexibility development (and particularly children's performance on the Dimensional Change Card Sort). As I mentioned in Chapter 1, thinking about a stimulus first in one way and then in another is not the only way to exhibit cognitive flexibility. Indeed, several researchers define cognitive flexibility as considering multiple representations of the same stimulus *simultaneously* (based on Jacques & Zelazo, 2005). However, the operationalization of cognitive flexibility in most studies examining this skill in preschoolers involves tasks that require children to think about the different dimensions of the stimulus consecutively (see Cragg & Chevalier, 2012 for a review).

In summary, major changes occur in children's consecutive cognitive flexibility skills between the ages 3 and 5 years of age. The mechanisms by which these changes occur is still under debate, with the two main theories proposing either inhibitory control development as driving (consecutive) cognitive flexibility development or the ability to grasp hierarchical structures as the driving force.

In the next section, I will review what we know about concurrent cognitive flexibility development, and discuss a possible reason as to why concurrent cognitive flexibility has not yet been widely studied in preschoolers. I will also briefly discuss how the two theories may be informed by concurrent cognitive flexibility research.

Concurrent Cognitive Flexibility Development

In this section, I will review the relatively limited research examining concurrent cognitive flexibility development. Much of the work that can be considered as examining children's concurrent cognitive flexibility stemmed from Piaget's work on multiple classification tasks — tasks that required sorting items along several dimensions simultaneously (e.g., Inhelder & Piaget, 1964). These tasks have not been framed as measuring concurrent cognitive flexibility, but they provide a fairly direct way to measure it.

Most of the work using multiple classification tasks was done with primary-school-age children (about 6-11 years), and the limited work that has been done with preschoolers found that they are unable to succeed on these tasks. While some researchers (e.g., Halford, 1980) argued that preschoolers simply lack the capacity to coordinate two dimensions simultaneously, Perner, Strummer et al., (2002) argue that "the ability to confront different perspectives emerges around 4 years" (p. 1466) and that the early emergence can be detected once extraneous task demands are removed from the more classical tasks (see also Light & Nix, 1983). I will therefore first review some tasks that have been used to measure children's ability to coordinate two dimensions simultaneously, with a focus on task features that may hinder younger children's performance.

Concurrent cognitive flexibility—measured in 7- to 9-year-olds—relates to flexible problem-solving (Sielger & Svetina, 2002), reading comprehensions (Cartwright et al., 2010), and academic achievements (Arlin, 1980). It may be that preschoolers' emerging concurrent cognitive flexibility skills could also predict these outcomes—but previous studies did not find enough variability on this skill measured in young children. Understanding the early emergence of concurrent cognitive flexibility skills (as measured in preschoolers; Podjarny et al., in preparation) will further our understanding of the development of cognitive flexibility more generally, and may enable us to predict these developmental outcomes from an earlier age. Following the tasks review, I shall turn to discussing how the examination of concurrent cognitive flexibility in preschoolers can inform theories of cognitive flexibility development in general.

The first task I shall review is the Pattern Completion Task (Rittle-Johnson et al., 2008). This task requires children to simultaneously consider two dimensions (shape and colour) to complete a bi-dimensional pattern by selecting the correct item from an array of 9 choices.[8] For example, children must complete an ABCAB[C] pattern, where A is a red spider, B is a red dragonfly, and C is a blue dragonfly (Rittle-Johnson et al., 2008). Note that because the items vary along two dimensions (colour and shape), the child must consider both dimensions in order to select the correct item. The authors gave the 4- and 5-year-olds in their sample one point for each correct dimension in their solution. The children scored an average of 0.8 out of 2, indicating that they tended to focus on one dimension only.

Bennett and Müller (2010) also used a Pattern Completion Task. In their study, however, the focus was on relational processing. These authors included 'easy items' in which the correct answer was identical to the fifth item (e.g., AABBC[C], where A is a red square, B is a blue triangle, and C is a green circle) and 'hard items'—similar to the example taken from Rittle-Johnson et al. (2008). According to Bennett and Müller (2010), in order to solve these items, children "had to recognize similarities among the first and second halves of the sequence, abstract the relation that holds between the first three elements in the sequence, and infer the features of the missing element" (p. 458). It is clear from this description of the task that the Pattern Completion Task involves more than just concurrent cognitive flexibility skills. The preschoolers (3- to 5-year-olds) in their sample performed better on the 'easy items' (solving on average 3.78 trials correctly out of 6) than on the 'hard items' (solving on average 1.57 trials correctly out of 7). Nonetheless, performance on this task was correlated with performance on the Flexible

[8] The authors do not specify which options were on the array, as the focus of their work was not cognitive flexibility but children's explanations of their choices.

Item Selection Task, a finding that was interpreted to indicate that the Pattern Completion Task does require some cognitive flexibility skills (see Bennett & Müller, 2010).

Another task that has been used to measure children's (concurrent) cognitive flexibility is the matrix sort task (Bigler & Liben, 1992; Cartwright et al., 2010). In this task, children (typically 7- to 9-year-olds) are asked to sort 12 cards that vary along two dimensions onto a 2x2 grid. For instance, Cartwright et al. (2010) examined children's (concurrent) cognitive flexibility in relation to reading comprehension. In their study, children were given a set of cards: an orange car, an orange bus, and orange ambulance, a purple truck, a purple car, a purple limousine, an orange canoe, an orange tugboat, an orange rowboat, a purple sailboat, a purple yacht, and a purple speedboat.[9] The children were asked to sort the cards into a 2x2 grid according to "what colour they are and what kind of thing they are" (Cartwright et al., 2010, p. 68). To complete the task correctly, children had to consider both the colour and category of the items; thus, this task taps their concurrent cognitive flexibility skills. The children were then asked to label each value of the 2x2 grid (in this case: orange, purple, road-vehicles and water-vehicles). In this study, children received, per trial, 1 point for a correct sort (i.e., sorting all 12 cards in the set correctly) with an incorrect label, 2 points for an incorrect sort with correct labels, and 3 points for a correct sort accompanied by correct labels. Note that children only had to label the value of the attribute, such as purple or orange, rather than identifying the dimensions themselves (e.g., "colour").

[9] Children also saw a 'graphophonological-semantic' cognitive flexibility task, which had the same structure but required children to sort cards with written words (e.g., bear, bread, cat, and cake) according to category (animals and foods) and initial sound (/b/ and /c/). This task, however, cannot be used with pre-reading preschoolers, and thus is not considered here.

There were 4 test trials (i.e., 4 different sets of 12 cards each), so children could earn up to 12 accuracy points.[10] While the authors report fairly high accuracy for the 6- to 9-year-olds in their sample, their score confounded correct sorting with explicitly identifying the value of the attributes. Thus, there is no way of knowing how children performed on the task independently of their verbal labels, and it is therefore not possible to compare the scores to chance levels. Moreover, it is not possible to isolate children's cognitive flexibility behavioural response—the sorting—from their ability to identify or induce dimensions. That said, the authors do report a developmental improvement (i.e., second-graders performed significantly better than first-graders) on their task.

A third study examining children's concurrent cognitive flexibility employed a matrix completion task (based on Inhelder & Piaget, 1964). In this type of task, children are required to coordinate several dimensions in order to complete a 2x2 relational matrix. Siegler and Svetina (2002) characterise the task as "[measuring] in a particularly direct way the ability to focus on multiple dimensions rather than on just a single one." (p. 794). Children see, for instance, a matrix containing a large gray mouse facing right in the top left-hand corner, a large grey bird facing right in the top right-hand corner, and a small grey mouse facing left in the bottom left-hand corner with a small grey bird facing left (see Figure 2.1). Children are presented with an array of 6 choices and are asked to select the one that would complete the matrix (in this case, the small, grey bird facing left).

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[10] Children were also scored on their sorting speed, but I focus here on the accuracy scores.

In order to succeed on matrix completion tasks such as the one used by Siegler and Svetina (2002), children must first determine the relevant dimensions, and then coordinate these dimensions to select the correct item. Siegler and Svetina's (2002) youngest participants, 6-year-olds, solved an average of 20% of the trials correct, essentially performing at chance levels (the choice array included 6 items, so the probability of selecting the correct answer by chance is 1/6 = .17).

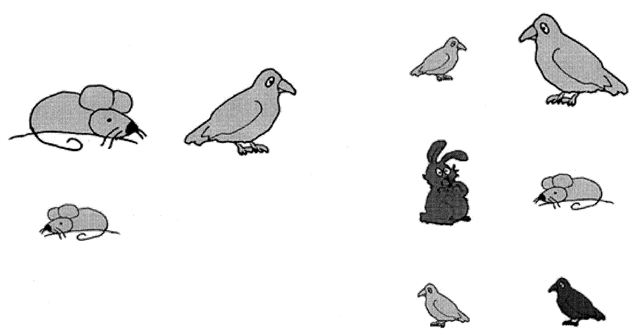


Figure 2.1 A sample trial from a Piagetian matrix completion task. Figure taken from Siegler and Svetina (2002, p. 794). The figure shows a matrix board on the left-hand side and choice array on the right-hand side. Reprinted with permission.

There are several points to consider if one would like to use Sielger and Svetina's (2002) matrix completion task with younger children (e.g., preschoolers; see also Podjarny et al., in preparation). Because this task is a fairly direct measure of concurrent cognitive flexibility, I made some modifications to it, creating the Preschool Matrix Completion Task, which makes it more suitable for use with young children (see Methods section in Chapter 3 for a detailed description of the task).

The first point to consider in Siegler and Svetina's (2002) matrix completion task is that children had to identify the relevant dimensions themselves before they could coordinate them (i.e., children must *induce* the dimensions). Thus, we have no way of knowing whether the children in Siegler and Svetina's (2002) study failed this task because they could not identify the relevant dimensions, because they could not coordinate those dimensions simultaneously, or both. This feature of the task is an advantage if one is examining conceptual processing, defined by Smidts et al. (2004) as encompassing "the capacity to perceive an abstract concept, or set of concepts, and then shift flexibly between competing concepts or dimensions." (p. 386). However, it does not allow one to examine the early emergence of concurrent cognitive flexibility independently of abstraction skills, which is the focus of this work. In my Preschool Matrix Completion Task (my modified version of their task), the experimenter explicitly labels the relevant dimensions, thus eliminating the requirement to identify them and focusing on measuring children's ability to coordinate both dimensions simultaneously (and making this a deductive task; see discussion in Chapter 4).

Second, in Sielger and Svetina's (2002) matrix completion task children were required to coordinate four dimensions simultaneously. For instance, in the example above, the answer choices included a small black bird facing left, a choice that differed from the correct answer only in terms of colour. Therefore, the child had to consider colour in order to make the correct choice, despite colour being an "irrelevant dimension" (i.e., it was held constant in all items on the matrix board) in this example. Thus, children's failure may not stem entirely from an inability to simultaneously consider multiple dimensions, but an inability to consider four of them at once. Therefore, this task may mask early concurrent flexibility ability. In my Preschool Matrix Completion Task I only used two relevant dimensions in each trial, thus examining children's nascent concurrent cognitive flexibility skills.

Finally, their task was presented using introduction trials that only varied on one dimension, potentially training children to use a matching strategy. For instance, a practice problem included "a large green fish facing left in each of the two squares on the left and a small green fish facing left in the top right square" (Siegler & Svetina, 2002, p. 797). Children were asked to complete the matrix in a similar fashion as the test trials, but note that in these practice trials, selecting the item that is identical to the one in the top right square (i.e., a small green fish facing left) is the correct answer. When children were then tasked with the actual test trials, some may have continued to look for a matching item, as they may have inferred was their goal from the training task. In my modified task, I used a practice trial that was structurally similar to the test trials and in which the items varied on two dimensions (see Chapter 3 for details).

The studies mentioned before (Cartwright et al., 2010; Rittle-Johnson et al., 2008; Siegler & Svetina, 2002), as well as previous work (e.g., Arlin, 1981; Inhelder & Piaget, 1964), seem to suggest that before the age of 6 or 7 years, children tend to focus only on one dimension and are not able to consider two or more dimensions simultaneously. However, before turning to my alternative explanation as to why younger children fail this tasks, I will first review another line of investigation that has led researchers to conclude that preschoolers are incapable of considering two dimensions of a single stimulus simultaneously.

This line of investigation focused on attempting to train preschoolers to succeed on multiple classification tasks. For example, Halford (1980) gave 3- to 6-year-old children multiple classification tasks in which a 3x3 matrix had items that varied along either one (colour or shape) or two dimensions (colour and shape). An example of a bi-dimensional problem is presented in Figure 2.2. Children were asked to fill each of the empty cells and were given 3 choices to select from for each cell. The choices were designed to require children to consider both dimensions, so in addition to the correct answer (e.g., a red circle), one choice matched the shape dimension (e.g., a green circle) and the other choice matched the colour dimension (e.g., a red triangle). The experimenter gave feedback to the children on each cell: incorrect choices were rejected (i.e., "try again"), and once the correct item was selected the experimenter referred to either the shape or the colour (see Halford, 1980). Children saw up to 16 trials, or until they were able to correctly solve a matrix (i.e., fill all the cells correctly on their first attempt).

While all children in Halford's (1980) study learned to solve the uni-dimensional problems, 3-year-olds needed significantly more trials than any of the older age-groups in order to solve the task. More telling, the 3-year-olds in this sample could not solve the bi-dimensional problems, even after 16 trials with feedback; 4- to 6-year-olds, however, were able to learn from the feedback and succeeded in solving the task correctly after about 5 trials. Note, however, that it is unclear from the report whether the experimenter gave feedback that referred to a single dimension or to both dimensions on the bi-dimensional problems. If only a single dimension was referred to in the feedback, this could have prevented the 3-year-olds from benefiting from the feedback, perhaps even making the task more difficult as the feedback would suggest that only one dimension mattered. Halford (1980) also measured the children's IQ, and the 3-year-olds' mental age was 4.4; he concluded that before the age of 5 years, children not only are incapable of spontaneously considering two dimensions simultaneously, they are also incapable of learning how to do so.

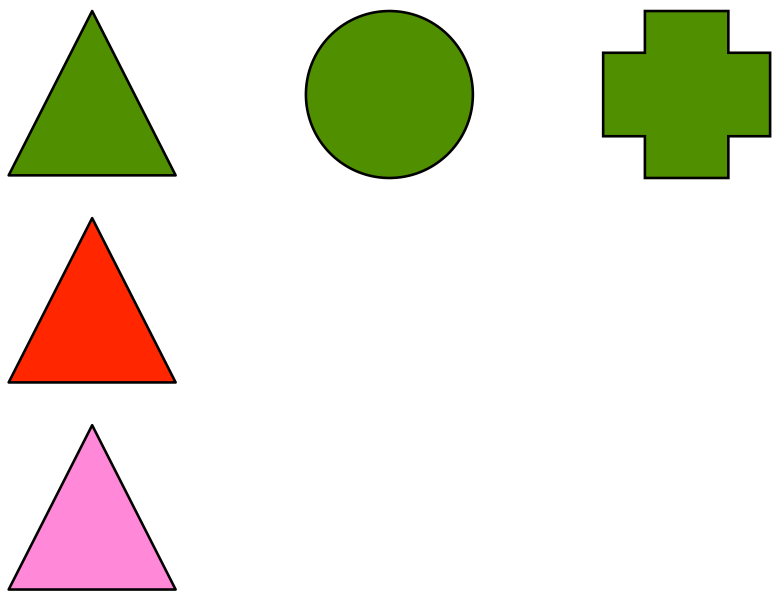


Figure 2.2 A 3x3 matrix completion sample trial. A reconstruction of a Matrix Completion Trial based on Halford (1980; Table 1). Children had to fill all missing items one by one.

Halford's (1980) findings are consistent with previous findings showing that 5.5- to 7.5-year-olds who received training did better than children without training on a 3x3 multiple classification task (Parker, Sperr, & Rieff, 1972). However, none of the children in Halford's (1980) sample, including the 6-year-olds, were able to solve a multiple classification problem on the first trial, indicating that the age in which children are able to solve this task on their own may be higher. Similarly, the children in Parker et al.'s

(1972) study who did not receive training did fairly poorly until they were about 7.5 years of age. These findings also drove researchers to conclude that children's concurrent cognitive flexibility skills do not emerge until their 7th year.

One point to consider regarding these training studies is that both used only a 3x3 classification matrix. It has been proposed that younger children use a different strategy to solve matrices that involve more than 4 items (i.e., with a grid that's larger than 2x2). Inhelder and Piaget (1964) gave children 4- to 9-year-olds matrices with either two attributes (e.g., varying only shape and colour on a 2x2 grid) or three attributes (e.g., varying shape, colour, and orientation using a six-object matrix). The 4-year-olds in their sample (N = 14) performed better on the 3x3 matrices than 6- and 7-year-olds (N = 16). The authors concluded that the two groups must be using different strategies to solve the task, and argued that the younger children solve them on the basis of graphic symmetry as opposed to the older children, who were attempting to induce the logical structure of the task. They reasoned that "the symmetry in the arrangement is stronger when there are 3 attributes" (Inhelder & Piaget, 1964, p. 156), and, therefore, the larger matrices facilitate a perceptual-based solution. The older children, on this account, "begin to think in terms of the objects as such" (p. 156), and because they attempt to use the object's attributes they have more difficulties coordinating three attributes than they have coordinating 2. The 3x3 matrices, then, may not be the optimal measure of young children's concurrent cognitive flexibility, as this task may elicit an alternative strategy, especially in preschoolers.[11]

[11] Note that Inhelder and Piaget (1964) argued that any matrix test is prone this perceptual symmetry (see p. 153), but the 4-year-olds in their sample did not show evidence of using perceptual-based strategy when solving a two-attributes matrix.

Findings from these studies were taken to indicate that preschoolers are unable to coordinate two dimensions simultaneously (see, e.g., Halford, Wilson, & Phillips, 1998; Rittle-Johnson et al., 2008). Several explanations have been put forward to explain preschoolers' poor performance on these tasks. The first explanation has been offered by Halford (e.g., 1980; Halford et al., 1998). According to his Relational Complexity theory, working memory capacity limitations prevent children from processing several dimensions simultaneously. Thus, children become able to coordinate two dimensions simultaneously (Halford, 1980) when they are about 5 years old and are simply unable to do so before.

As I noted before, there are other possible explanations for preschoolers' poor performance on tasks measuring concurrent cognitive flexibility or multiple classification (see, e.g., Nix & Light, 1983; Perner, Strummer, et al., 2002). I mentioned that in the matrix completion task as reported by Siegler and Svetina (2002) several features of the task may obscure younger children's emerging concurrent cognitive flexibility skills. Similarly, the items on the Pattern Completion Task that include more than a single dimension require several skills in addition to concurrent cognitive flexibility, including abstracting the relations between items (Bennett & Müller, 2010). The matrix sort task (the way it was used by Cartwright et al., 2010) prevents the distinction between children's cognitive flexibility and their ability to identify the relevant dimensions, and it may be that children find the explicit identification of dimensions more difficult than the coordination of two dimensions simultaneously. Finally, because the 3x3 matrix completion task may recruit alternative strategies (Inhelder & Piaget, 1964), it may not be the best tool to measure concurrent cognitive flexibility skills. Thus, it is possible that preschoolers perform poorly on the first three tasks because of these features of the tasks, rather than because of the inability to consider two dimensions of a single stimulus simultaneously.

There is some evidence that indeed, when extraneous demands are removed, preschoolers demonstrate some success on concurrent cognitive flexibility tasks. As I mentioned before, I developed the Preschool Matrix Completion Task to make Siegler and Svetina's (2002) matrix completion task more suitable for preschoolers. In my version of the task, 48% of the 4- and 5-year-olds demonstrated the ability coordinate two dimensions simultaneously (Podjarny et al., in preparation; Podjarny, Kamawar, Vendetti, & Astle, 2013). Note that the task still required children to coordinate two dimensions simultaneously, because in order to select the correct item from an array of choices (from the 'answer board') they had to coordinate both relevant dimensions (e.g., colour and shape; see Methods section in Chapter 3, p. 76). All of our answer boards included items that matched the adjacent cells; children focusing on one dimension only were likely to have been selected these items. Nevertheless, in our sample (*N* = 68) over 45% of 4- and 5-year-olds performed above chance on the Preschool Matrix Completion Task. These findings provide support for the claim that previous studies may have underestimated young children's emerging concurrent cognitive flexibility skills. This study, however, only used one concurrent cognitive flexibility task, so replication and extension are necessary.

In summary, previous research may have underestimated preschoolers' emerging concurrent cognitive flexibility skills. We know very little of concurrent cognitive flexibility development in preschoolers, and as mentioned, understanding nascent concurrent cognitive flexibility skills may inform our understanding of the development of cognitive flexibility in general.

One example of how examining early concurrent cognitive flexibility skills may inform our understanding of cognitive flexibility development is by looking at the relation between concurrent and consecutive cognitive flexibility development. At first glance, the picture of cognitive flexibility development emerging from the literature is that consecutive cognitive flexibility develops during the preschool years, and only once children have mastered the ability to switch between two conflicting aspects of a single stimulus—around the time they finish first grade—can they coordinate these two aspects simultaneously. However, as I mentioned, the reason for children's apparent later development of concurrent cognitive flexibility skills may be methodological (i.e., due to task difficulty and extraneous demands) rather than developmental (i.e., due to an inability to consider multiple dimensions simultaneously). I proposed that concurrent cognitive flexibility is not an extension of consecutive cognitive flexibility, but a distinct skill that emerges around the same time as consecutive cognitive flexibility.

As I mentioned in Chapter 1, one difference between consecutive and concurrent cognitive flexibility is that consecutive cognitive flexibility requires inhibitory control—the ability to suppress a strong, prepotent response. When children are required to consider a stimulus—say, a red rabbit—in terms of a second dimension (e.g., colour) after first considering it in terms of the first dimension (e.g., shape), they must inhibit their attention to the previously relevant dimension. In contrast, when tasked with considering two dimensions simultaneously as in concurrent cognitive flexibility tasks, children must attend to *both* dimensions, and inhibiting either one of them would, in fact, impair performance. It is possible that concurrent cognitive flexibility may rely more on working memory, as children have to coordinate two dimensions. However, little is known about the early development of concurrent cognitive flexibility skills, and so we have no empirical evidence to this theoretical separation.

Turning back to the theories proposed to explain consecutive cognitive flexibility development, recall that I reviewed two main theories: the Attentional Inertia Account proposed by Kirkham et al. (2003) and the Cognitive Complexity and Control Theory (Revised) proposed by Zelazo et al., (2003). As mentioned, both theories were developed to account for children's consecutive cognitive flexibility (and particularly their performance on the Dimensional Change Card Sort), and they currently do not apply to concurrent cognitive flexibility development. If we accept concurrent cognitive flexibility as a skill that is distinct from (if related to) consecutive cognitive flexibility, we will need to re-examine both the Attentional Inertia Account and the Cognitive Complexity and Control Theory (Revised) to extend them to account for concurrent cognitive flexibility development in addition to (consecutive) cognitive flexibility development.

The Attentional Inertia Account argues that cognitive flexibility is a combination of inhibitory control and working memory, because it involves *changing* one's focus (on an object or a situation; see Diamond, 2012, p. 15). If in order to solve concurrent cognitive flexibility tasks children have to coordinate two dimensions simultaneously (i.e., seeing the object as both red and a rabbit, instead of changing from seeing it as a red one to seeing it as a rabbit), and if we accept that this skill is a variant of cognitive flexibility more generally, then the broader concept of cognitive flexibility cannot be described as changing one's focus. While consecutive cognitive flexibility can still be described thus, the Attentional Inertia Account would have to be extended in order to conceptualize concurrent cognitive flexibility as well.

In terms of the Cognitive Complexity and Control Theory (Revised), describing cognitive flexibility as involving a hierarchy of if-if-then rules can be extended to include concurrent cognitive flexibility. Recall that Zelazo et al. (2003) described the structure of the Dimensional Change Card Sort thus: if we are playing the shape game, and if it is a red rabbit, it goes in the rabbit box, but if we are playing the colour game, and if it is a red rabbit, it goes in the red box. Concurrent cognitive flexibility can be similarly described: if I'm looking for a red one, and if I'm looking for a rabbit, then the red rabbit is the correct choice. However, a more straightforward way to describe concurrent cognitive flexibility task structure would be using a logical AND condition: I'm looking for a card that shows something that's (red) AND (a rabbit). Understanding the relation between concurrent and consecutive cognitive flexibility development in children would inform theories of cognitive flexibility development; however, as I mentioned, we know very little about the development of concurrent cognitive flexibility in preschoolers.

The goal of this work was to examine the development of concurrent cognitive flexibility development during the preschool years. In the context of Executive Functions, I proposed a model that tested whether consecutive and concurrent cognitive flexibility were two distinct, although related, skills. Because very little research was done to examine concurrent cognitive flexibility development during this age-range, my first goal was to provide empirical support for the hypothesis that the two processes—consecutive and concurrent cognitive flexibility—are distinct.

An approach that has been useful in examining the structure of Executive Function (and psychological constructs more generally; see, e.g., Hoyle, 2012; Muthén, 2002) is the Structural Equation Modeling approach. According to Miyake et al. (2000), Executive Function research especially can benefit from structural analyses such as Structural Equation Modeling because they operate on other cognitive processes. Structural analyses extract common variance among several tasks, thus enabling researchers to examine the latent structure that drives performance on these tasks (see Chapter 3 for a more detailed discussion). I therefore took a structural analysis approach to the problem of teasing apart consecutive and concurrent cognitive flexibility skills in preschoolers.

In Chapter 3 I will first explain in more details the rationale behind choosing a structural analysis approach to examine the relation between consecutive and concurrent cognitive flexibility. I will then describe the methods and results of this structural analysis, followed by a discussion of these results. As I mentioned before, however, the results of the structural analysis did not support a statistical distinction between consecutive and concurrent cognitive flexibility. However, by conducting an exploratory analysis examining different factors that affect children's performance on consecutive and concurrent cognitive flexibility, I was able to examine different aspects of consecutive and concurrent cognitive flexibility performance, as well as provide an account of preschoolers' emerging concurrent cognitive flexibility. In Chapter 4 I will review the exploratory analysis I conducted, and discuss my findings. Then, in Chapter 5, I turn to describe Study 2, which examined the effects of labels on children's concurrent cognitive flexibility performance. Finally, in Chapter 6 I will discuss the findings of both studies and how this work opens the door to examining the development of concurrent cognitive flexibility in preschoolers.

Chapter 3: Structural Differentiation Between Consecutive And Concurrent Cognitive Flexibility

The goal of this study was to examine the development of concurrent cognitive flexibility development during the preschool years. In the context of executive functions, I proposed a model that treated consecutive and concurrent cognitive flexibility as two distinct, but related, skills. Because very little research was done to examine concurrent cognitive flexibility development during this age range, my first goal was to provide empirical support for the hypothesis that the two processes—consecutive and concurrent cognitive flexibility—could be statistically separated. To this end, I decided to use a Structural Equation Modeling approach.

One challenge when investigating executive functions is that the variance on an executive function task results from individual differences in (at least) two skills: the input processing, and the executive function that regulates the input processing. For example, both the backwards digit span task (in which participants are required to repeat a string of digits in a reversed order; e.g., Davis & Pratt, 1995) and the Self-Ordered Pointing task (in which participants are asked to point to each picture in a set once and only once, while the pictures' locations change after each point; e.g., Cragg & Nation, 2007) have been described as working memory measures — specifically, as measures of the central executive (see, e.g., Cragg & Nation, 2007; Gathercole et al., 2004).[12] However, both tasks also tap additional cognitive processes: the backwards digit span

[12] Arguably, both the backwards digit span task and the Self-Ordered Pointing Task also require inhibitory control (the former in order to inhibit saying the digits in the correct order and the latter in order to inhibit pointing to the same picture). However, both of these tasks are thought to measure primarily working memory (see, e.g., Cragg & Nation, 2007; Gathercole et al., 2004).

task taps the phonological loop and the Self-Ordered Pointing task taps the visuospatial sketch-pad.[13] Thus, neither of the two tasks can assess the central executive in a pure form. This problem has been referred to as the *task impurity problem* (Miyake et al., 2000).

Structural analysis approaches such as Factor Analysis and Structural Equation Modeling extract common variance among different indicators (e.g., behavioural tasks). The common variance is thought to represent a latent structure that underlies performance on all indicators (Hoyle, 2012). In the example above, the shared variance between the backwards digit span and the Self-Ordered Pointing task would be attributed to the common regulatory process—the central executive (see, e.g., Miyake, 2000). Structural Equation Modeling specifically allows for testing a structural model, and comparing two hypothesized models. In my case, because I wanted to compare the model emerging from previous works (i.e., concurrent cognitive flexibility is an extension of consecutive cognitive flexibility, and therefore indistinguishable from it) with my model (i.e., consecutive and concurrent cognitive flexibility skills as distinct, related skills), Structural Equation Modeling was particularly appealing. This approach would allow me to compare the two models and determine which one better describes the structure of cognitive flexibility in preschoolers.

[13] Even if the task is run without spatial information, it still uses visual—rather than auditory—input.

Study 1 was designed to examine the relations between consecutive and concurrent cognitive flexibility in the context of Executive Functions using a Structural Equation Modeling approach. To do so, I used 6 cognitive flexibility tasks, 3 measuring consecutive cognitive flexibility and 3 measuring concurrent cognitive flexibility, along with several control tasks (measuring inhibitory control, working memory, receptive vocabulary, and nonverbal IQ). I tested two models (see Appendix A for details): one specified all 6 cognitive flexibility tasks (both consecutive and concurrent) as loading onto a single factor; the other specified two latent factors, consecutive and concurrent cognitive flexibility, with 3 tasks loading onto each. I compared the two models first without the control tasks, and then with the control tasks loading onto a covariate latent factor (e.g., Muthén, 2002).

Recall that I argued that consecutive and concurrent cognitive flexibility should be distinct, although related, constructs (see Miyake et al., 2000, for a similar theoretical structure). Based on this argument, I hypothesized that the second model—the one in which consecutive and concurrent cognitive flexibility are separate—would be a better fit for the data.

In this chapter, I will describe the methods and results of this structural analysis, followed by a discussion of these results. As I mentioned before, however, the results of the structural analysis did not support a statistical distinction between consecutive and concurrent cognitive flexibility.

Despite the lack of support for the structural separability of consecutive and concurrent cognitive flexibility, I was able to use the data to provide an (exploratory) account of preschoolers' emerging concurrent cognitive flexibility. Though the study was not specifically designed to test their contribution, I examined two factors of cognitive flexibility: (1) whether the task was inductive or deductive (in deductive tasks, the experimenter explicitly identifies the relevant dimensions whereas inductive tasks require children to abstract these dimensions on their own); and (2) the number of dimensions the children were required to coordinate (in the current work, 2 and 3 dimensions, both consecutively and concurrently). I examined how these factors affect children's cognitive flexibility performance, and how they interact with the type of cognitive flexibility (i.e., consecutive or concurrent). In Chapter 4, I will review these factors, describe the results of the exploratory analysis I conducted using the Study 1 data, and discuss their implications.

Methods

Participants

I recruited a total of 133 children from local daycares, as well as from our lab database of parents who have indicated previously that they are willing to be contacted regarding future research (for on-campus testing). Parents signed an informed consent form, and no child was tested without first giving a verbal assent. A trained undergraduate student and myself administered all of the testing. Children recruited from daycares were tested in a quiet space at the daycare, and children from the database were tested in a room in the Children's Representational Development Lab at Carleton University. I excluded data from 12 3-year-olds because they: a) did not pass the screener (see below; N = 6; 1 female); b) refused to participate (2 males); or c) were non-compliant or inattentive to the tasks (N = 4; 1 female). The final sample included 121 children (see Results section for details).

Procedure

We tested each child individually in a quiet space. We saw children in the daycares three times, each session running 25-30 minutes. Sessions were approximately a week apart (*M* = 6.86; *SD* = 5.13 days between session one and two and *M* = 6.7; *SD* = 5.01 days between session two and three). The time-lapse between sessions one and three was typically 2-3 weeks (*M* = 13.55; *SD* = 6.79; max = 33 days). We tested two children at the lab; they were seen once, for a session of about 90 minutes, with a break or two (depending on the child) during the testing. At the end of each session the child received either stickers (in the daycares) or a small book or toy (in the lab), as a token of thanks. Children tested in the lab also received a snack and juice during the break (with parent's approval).

Six tasks were selected to measure consecutive and concurrent cognitive flexibility. I used the Dimensional Change Card Sort (DCCS; Zelazo, 2006), and modified versions of the Flexible Item Selection Task (FIST; based on Jacques & Zelazo, 2001) and the Object Classification Task for Children (Smidts et al., 2004) to measure consecutive cognitive flexibility. I used the Preschool Matrix Completion Task (Podjarny et al., in preparation), a modified version of the Matrix Sort Task (based on Cartwright et al., 2010), as well as a novel task designed for this study, the Multidimensional Card Selection Task, to measure concurrent cognitive flexibility. Because I was interested in the nature of the relation between consecutive and concurrent cognitive flexibility in the context of Executive Functions and other cognitive skills, I also measured children's working memory (Self-Ordered Pointing; Petrides & Milner, 1982) and inhibitory control (Black/White Stroop-Like Task; Simpson & Riggs, 2005).

Moreover, to control for more general cognitive processes, I measured children's receptive language (Peabody Picture Vocabulary Test; PPVT-III; Dunn & Dunn, 1997), and non-verbal IQ (Primary Test of Nonverbal IQ; PTONI; Ehrler & McGhee, 2008).

The tasks were administered in a fixed order, which is preferable when examining inter-task relations and individual differences (e.g., Carlson & Moses, 2001). A fixed order ensures that effects such as fatigue and transfer are consistent across participants, by task (Wiebe, Sheffield, & Espy, 2012). In session 1, the order was: screener (to check that children could identify the various shapes, colours, and sizes used in the study), Modified Flexible Item Selection Task, Primary Test of Nonverbal Intelligence, and the Matrix Sort Task. In session 2, the order was: Multidimensional Card Selection Task, Self-Ordered Pointing; and the Modified Object Classification Task for Children. Finally, in session 3, the order was: Preschool Matrix Completion Task, Black/White Stroop, Dimensional Change Card Sort, and the Peabody Picture Vocabulary Test. Note that in each session, children saw one consecutive and one concurrent cognitive flexibility task, and these tasks were never contiguous. In session 1 the consecutive task was first, whereas in sessions 2 and 3 the concurrent cognitive flexibility task was first.

I piloted the novel and modified cognitive flexibility tasks with 36 preschoolers (*age range*: 38-70 months; M = 51.50 months; SD = 9.54; 19 girls) who did not participate in the main study. I will first describe the results of the pilot study as they pertain to the performance characteristics on these new and modified tasks. Then I will detail the procedure for the screener, describe the procedure and materials for consecutive and concurrent cognitive flexibility, followed by the remaining tasks. For various reasons (e.g., a testing binder for one of the tasks was accidentally left at the lab), 11 children did not receive the tasks in the pre-specified order. These children did not differ from the rest of the sample in their performance on any of the 10 tasks I administered, nor in their age (in months), all *ps* > .03.[14] I therefore included these 11 children in the analyses.

The novel and modified tasks were deemed suitable for preschoolers, as demonstrated by a reasonable success rate in the sample. For example, the majority of the children (86%) in the pilot study were able to coordinate three dimensions concurrently on the Multidimensional Card Selection Task. Similarly, in the Modified Object Classification Task for Children all children in the sample but one were able to sort the 6 cards along the first dimension (Sort1), indicating that children understood the task, and more than half (58%) were able to sort along a second dimension (Sort2) on their own (i.e., in the Category Generation support level; see below for details), and 33% were able to sort along a third dimension (Sort3) on their own. Thus, as performance was not at ceiling, the tasks exhibited sufficient variability for the age range in question.

In addition to examining success rate and variability, I was interested in the stability of children's performance across test trials for a given measure. In order to examine whether the children are performing at some level of consistency (i.e., not randomly), I used a stable performance criterion of requiring the same level of performance on 2 test trials, and ran up to 4 test trials in the pilot study to try to achieve this. Children's performance was fairly consistent across trials: in the Multidimensional Card Selection Task, 64% of the children needed only two test trials to arrive at the stable performance criterion, and 94% of them arrived at the criterion by the third test trial.

[14] A Bonferroni alpha level was used (.05/10 = .005).

Similarly, in the Modified Object Classification Task for Children, 80% of the children arrived at the stable performance criterion within two trials, and none of the children needed a fourth trial to arrive at the criterion. Thus, the tasks were deemed to show reasonable stability.[15] Moreover, this criterion helped me determine how many test trials to use in each task. As almost all children arrived at consistent performance after 3 test trials, I decided to use three test trials for both the Multidimensional Card Selection Task and the Modified Object Classification Task for Children based on the pilot study results. The pilot study also served to arrive at a final version of the cognitive flexibility tasks that required modifications or development. Note that I will revisit additional results from the pilot study as they pertain to each task in the following sections.

Tasks

I had two sets of scores for all cognitive flexibility tasks, except the Dimensional Change Card Sort. The first set was a more continuous cognitive flexibility score, and either included the number of trials solved correctly (for the tasks that only required children to consider two dimensions, i.e., the Modified Flexible Item Selection Task, the Preschool Matrix Completion Task, and the Matrix Sort Task), or else reflected the number of dimensions the child was able to coordinate reliably (i.e., above chance, for the Multidimensional Card Selection Task and the Modified Object Classification Task for Children). This first set of scores was used in the Structural Equation Modeling.

The other set of scores was a pass/fail score for each task, and two pass/fail scores for the tasks that included stimuli that varied on three dimensions—one pass/fail score for considering two dimensions, and one pass/fail score for considering 3 dimensions (for

[15] See Results section for consistency coefficients for all tasks.

each the Multidimensional Card Selection Task and the Modified Object Classification Task for Children). Each pass/fail score took into account the task chance levels. Because chance levels were different for each task, this pass/fail score enabled comparison among the tasks in Chapter 4. For the Dimensional Change Card Sort I used the pass/fail score in the Structural Equation Modeling as well, as the distribution is typically binomial on this task (see, e.g., Carlson, 2003; Doebel & Zelazo, 2013).

I used the first set of scores for the Structural Equation Modeling because when investigating correlations the absolute performance is of little consequence. In contrast, in the exploratory analysis I was interested in group comparisons of absolute performances (e.g., 4-year-olds perform better than 3-year-olds), and so it was important to take the chance levels for each task into account. As I describe the tasks below, I will note the chance levels and the pass/fail criteria.

Screener. In order to check that children were able to identify the items (shapes, colours, and sizes) that are used in the study, participants were first presented with an item identification task. The first screener sheet contained all the shapes that appear in the study (across tasks): a star, a heart, a triangle, a circle, a book, a pair of mittens, a cup, a balloon, a shoe, and a car (all sized to be approximately 3 cm in height, with differing widths depending on the shape). The second sheet contained the sizes used in the study: a big (7 cm wide), medium (4.5 cm wide), and small (2 cm wide) book. The third sheet contained the colours used in the study: green (RGB: 0, 201, 21), red (RGB: 241, 5, 17), yellow (RGB: 252, 255, 34), and blue (RGB: 30, 0, 251). Children were asked to point to the items named by the experimenter (e.g., “can you show me the shoe?”; “can you point to the big one?”; “can you show me blue?”). If a child could not identify an item, the experimenter pointed to the item (e.g., “look, that’s the shoe”). After going over all the items on the sheet once (in a fixed order), the experimenter asked children again to show her the items that they could not identify in the first round (if there were any). Of the 121 children in the final sample, 40 children did not need to be asked for any items more than once, 71 children (41 three-year-olds) needed to be asked a second time (only for 1-4 items, $M = .89$; $SD = .98$), and only 10 of them (5 three-year-olds) needed to be asked a third time, with all ten missing one item only. Of these, 4 (1 three-year-old) were able to identify the missed item on the third trial. As mentioned before, 6 children (4 three-year-olds) were unable to identify an item after three repetitions and were therefore excluded from the study.

Consecutive cognitive flexibility tasks.

Dimensional Change Card Sort (DCCS; Zelazo, 2006). The DCCS is a deductive task measuring consecutive cognitive flexibility. This task was outlined in detail in Chapter 2 (p. 15), and the protocol sheet can be found in Appendix B. The administration of the DCCS was modeled fairly closely after Zelazo’s (2006) protocols. Children were asked to sort 8 test cards for the pre-switch phase (colour), and then another 8 test cards for the post-switch phase (shape; see Appendix B for the protocol). Note that in the standard version (Zelazo, 2006), only 6 test cards are used for each of the phases. However, in our lab we use 8 cards because sorting 7 out of 8 cards correctly, with a chance level of 50%, is significantly different from chance ($p = .03$ on binomial distribution), whereas sorting 5 out of 6 cards with the same chance level is not. All children sorted at least 7 out of 8 of the pre-switch cards correctly. The number of cards sorted correctly on the post-switch phase was summed and used to calculate a pass/fail score. This was done because the Dimensional Change Card Sort typically follows a binomial distribution with most children either clearly failing (0 or 1 out of 8) or passing (7 or 8 out of 8; see, e.g., Carlson, 2003), so a pass/fail score is more appropriate than using raw scores. The pass/fail score was therefore used in all analyses (both Structural Equation Modeling and exploratory analysis).

Modified Flexible Item Selection Task (MFIST). The Flexible Item Selection Task was designed to measure cognitive flexibility in preschoolers (Jacques & Zelazo, 2001, 2005). This is an inductive task measuring consecutive cognitive flexibility (see Chapter 2, p. 18 for a more detailed description). As discussed before, we (Podjarny et al., 2009) made several modifications to the task as reported by Jacques et al. (2007; as cited in Marcovitch et al., 2008; this most recent method changed slightly from the original Jacques & Zelazo, 2001). Other than the modifications outlined below, we followed the reported procedure carefully. The full protocol can be found in Appendix C.

Consistent with the original Flexible Item Selection Task procedure, after our participants demonstrated that they can 'pick two' items out of a set of three (using non-test items, e.g., a house, a tree, and a flower), the children watched as the experimenter correctly selected two pairs on a demonstration trial. The demonstration trial consisted of a medium red teapot, a big blue flower, and a medium yellow flower. The experimenter selected first one pair (e.g., the two flowers), saying, "I'm going to point to this picture here [point to one item] and to this picture here [point to the second item], because these two pictures [pointing to both items alternately] go together in one way.", and then selected a second pair (e.g., the two medium items), saying "I'm going to point to this picture here [point to one item] and to this picture here [point to the second item], because these two pictures [pointing to both items alternately] go together in another way". The order of the pairs was alternated across children in a quasi-random fashion. The ways in which the items 'went together' was never labeled.

Children then received two practice trials (with feedback) followed by 8 test trials (with no feedback). The practice and test trials were similar in structure and included three items. For instance, a trial might include a small red shoe, a big yellow teapot, and a big red flower. Children were asked to select two items that "go together in one way" and, after they did, they were asked to select two items that "go together in another way". I used all three dimensions (shape, colour, and size) across trials, but for each trial only two dimensions were relevant. The irrelevant dimension was varied across items (in the example above, shape was the irrelevant dimension) so that no two items matched on the irrelevant dimension.

Note that the most recent Flexible Item Selection Task has 15 test trials (S. Jacques, personal communication, November 2007). However, in a previous study (unpublished; $N = 35$; 18 girls; Mage = 58.6; $SD = 6.73$) the correlation between children's score on the first 8 test trials and entire battery of 15 test trials was highly significant, $r = .96$, $p < .001$. Therefore, and because of the long testing time for Study 1, I shortened the task to include only those first 8 test trials.

Children were given a point for each trial in which they were correct on *both* selections. In other words, in order to receive a point for a given trial, children had to flexibly consider the pivot item of a given trial in one way prior to seeing it in another way (note that this is different than what was done by Jacques & Zelazo, 2001, who considered the first and second selections separately). The sum of the scores (out of 8) was used in the Structural Equation Modeling analysis.

The chance level of selecting the first correct pair is 2 out of 3 and selecting the second correct pair is 1 out of 3, and the contingent score gave credit for selecting both correctly. Therefore, the probability of receiving credit for a given trial by chance is 2 out of 9 (0.22). Based on the binomial distribution, solving 5 or more trials correctly would be considered significantly better than chance (p = .02). Thus, children were scored as passing if they solved 5 or more trials correctly (out of 8). The pass/fail score was used in the exploratory analysis (see Chapter 4).

The Modified Object Classification Task for Children (M-OCTC). This task was based on the Object Classification Task for Children (OCTC), developed by Smidts et al., (2004) (see Chapter 2, p. 21 for more details), and measured children's ability to switch between sorting trivalent cards along one dimension, to sorting them along a second, and then a third, dimension. I made several modifications to this task in order to address some points I raised previously. Recall that these modifications included: a) using cards instead of the toys; b) adding a demonstration trial to model for children the three ways the cards could be sorted; c) using the full set of 6 cards in all sorts; d) including 3 test trials rather than one; and e) using a separate score for each sort instead of one score incorporating all performance (see Chapter 2, p. 25 for a detailed discussion of the issues and modifications).

My pilot study found that using cards instead of toys and adding a demonstration trial (the two modifications that happened before children were required to sort the cards for the first time) had improved children's performance on the first sort. Smidts et al.

(2004) reported that less than half of the 3- and 4-year-olds in their sample were able to sort along even the first dimension. In contrast, 89% of the 3- and 4-year-olds in my pilot study were able to sort the 6 test cards in the first sort on their own (i.e., they were able to sort along at least one dimension). This was considered as a positive change for my purposes. Recall that Smidts et al. (2004) wanted to examine both abstraction and (consecutive) cognitive flexibility skills. My focus, on the other hand, was on consecutive cognitive flexibility skills only. The higher rate of success indicates that the children understood the task and confirms that their difficulties with later sorts (which did require consecutive cognitive flexibility skills) did not stem from an inability to group together 3 non-identical items along one dimension.

Task overview. All children saw three test trials, with three sorts in each trial. From here on I refer to the sorts as Sort1, Sort2, and Sort3 to denote the first, second, and third sorts within a trial. Each sort contained up to three levels of support, depending on the child's performance. I examined both the level of support each child required in order to sort the test cards for Sort1, Sort2, and Sort3, as well as the number of dimensions children were able to consider on their own. Each of these scores was summed across trials (e.g., Sort1 scores were summed across trials 1, 2, and 3; see below for a discussion of the scoring). The full protocol of the task can be found in Appendix D. I shall now turn to a detailed description of the Modified Object Classification Task for Children procedure.

Introduction trial. Children first saw an introduction trial, in which they were asked to sort two sets of cards with identical pictures (e.g., two bananas and two rabbits) into two groups. This trial was included to ensure children were able to sort sets of cards into two groups, and was modeled exactly after the original task (except that it was done with cards rather than with toys; see Smidts et al., 2004). Children received feedback on this trial, and if the child was unable to complete the sort in the first trial, the trial was repeated with different stimuli (e.g., two pairs of glasses and two lambs). Children who failed to match two identical pictures together on both trials were excluded from the task. Of the 121 children in the final sample, 7 children needed the second introduction trial, and only one did not pass both introduction trials; her data was excluded from the task (but not the entire study).

Demonstration trial. Following the introduction trial, a demonstration trial was presented. In this trial, the experimenter showed the child a set of six cards (e.g., a big blue triangle, a small blue triangle, a small blue circle, a big yellow circle, a big yellow triangle, and a small yellow circle). The experimenter then showed the child that the cards could be sorted into two groups along each of three dimensions (i.e., size, colour, and shape) in a pseudo-random order (a Kruskal-Wallis test confirmed that the order of the dimensions did not affect any of the children's scores on the task, all *ps* > .29).

Test trials. Following the introduction and demonstration trials, children received 3 test trials, each using a different set of stimuli. Each set had the same structure as the one described above, containing six cards that could be sorted into two groups along three dimensions (shape, colour, and size), but the specific colour/shape combinations differed across trials (so children could not simply replicate what they had seen, or done, before). Figure 3.1 (below) illustrates the flow of one sort in one test trial.

I only used common shapes and colours (e.g., stars, circles, triangles, and hearts for shapes; blue, yellow, green, and red for colors; all highly familiar to preschoolers), and two sizes: 'big' (shapes were 5.4 by 5.4 cm) and 'small' (2 by 2 cm). The cards were placed according to a pre-determined placement on the table (the "home position"), in a grid of two columns by three rows. Each test trial included sorting along three dimensions (Sort1, Sort2, and Sort3, according to shape, colour, and size, in whatever order each child selected) and up to three levels of inductive support, depending on the child's performance.

Support levels. For each sort (Sort1, Sort2, and Sort3), per trial, up to three levels of support were available. The support levels were designed to go from least to most. The lowest support level was *category generation*, followed by *category identification*, and then by *instructed sort*. This way, children received support when they required it, and continued to the next sort (or trial) if they did not.

The first level, *category generation*, offered the lowest level of support. In this level, the child saw six cards on the table, arranged in fixed semi-random order (the home position). The experimenter then asked the child to sort the cards into two groups, saying, "Can you make two groups for me? And something has to be the same about the pictures in each group.". All children began with this level of support, for each sort in each of the three trials in this task. If the child sorted the cards in any way at all, she was asked to indicate the commonality across each the group ("can you tell me what is the same about these pictures? And what is the same about the other pictures?"; this data was collected to be used in future work, and children's labels did not affect the administration of the rest of the task). Any child unable to sort the cards with this minimal level of support was given additional support. In this middle level of support, *category identification*, the experimenter sorted the cards along one of the dimensions, which varied across trials (the dimension that was used first in one trial was never used as the first dimension in the next trial). The child was then asked to label the two groups ("can you tell me what is the same about these pictures? And what is the same about the other pictures?"). If the child was unable to label the two groups, the cards were put back to the home position, and the highest level of support, *instructed sort*, was administered. In this level, the child was asked to sort the cards along one of the possible dimensions (e.g., "can you put all the blue ones here and all the red ones there?"). The dimension for the instructed sort level was the same dimension as the category identification level, so the child had already seen the two groups a few moments before. However, the location of the groups was switched. So, if in the category identification level the experimenter sorted according to colour, placing all the red items on the right side and all the blue items on the left side, in the instructed sort level the child was asked to put all the red items on the left side and all the blue items on the right side. This was done to prevent success by direct duplication of the experimenter's sort.

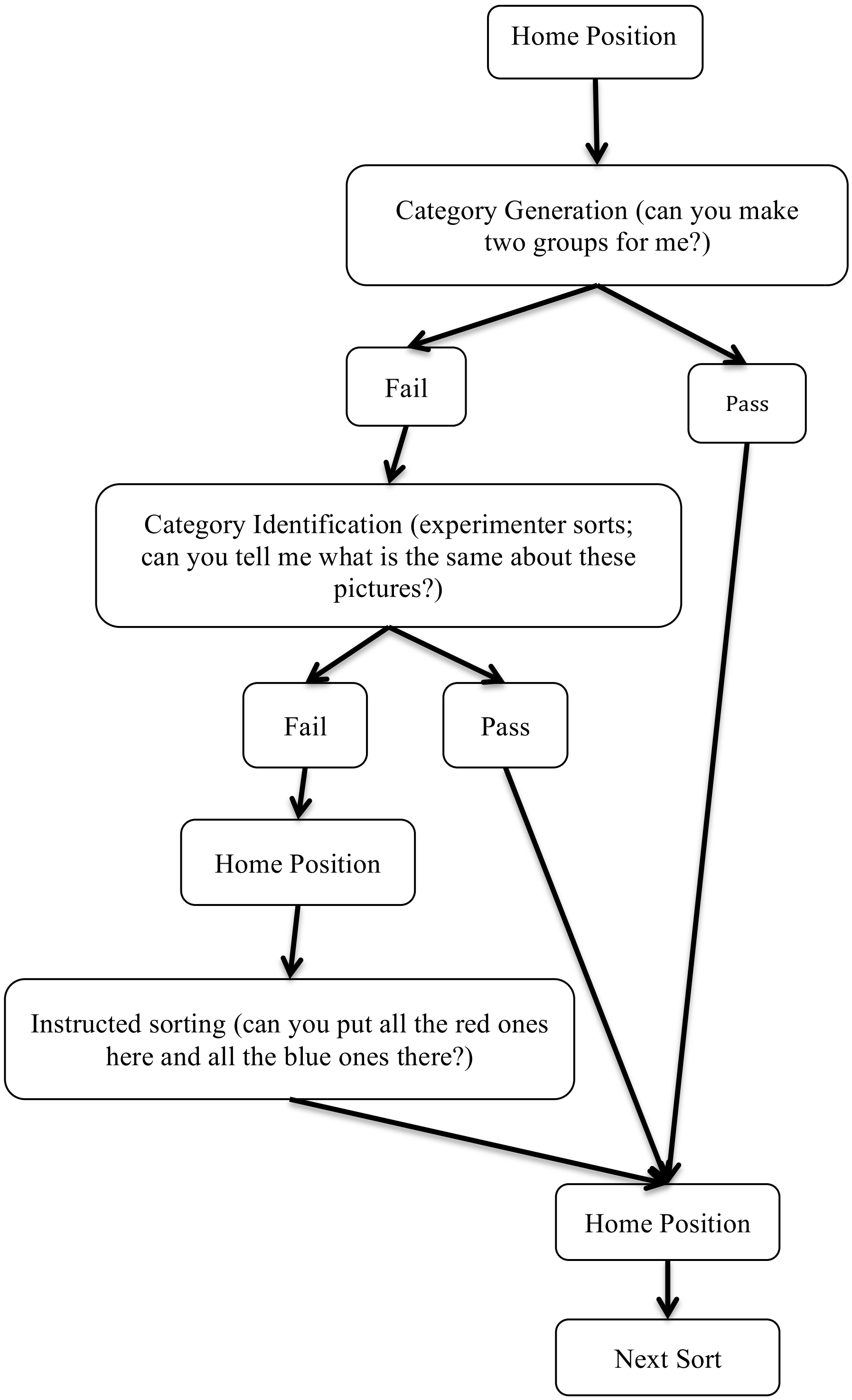


Figure 3.1 Flow Chart of One Sort in One Trial of the Modified Object Classification Task For Children.

Regardless of the level of support the child needed to sort a given dimension, the subsequent sort (within the same trial) always started with the first level of support (category generation). At the beginning of Sort2 and Sort3, the experimenter verbally reminded the child of the dimensions already used by them to sort (e.g., "remember, you already put all the blue ones together and all the red ones together"). This was done to reduce the likelihood that when children sorted along a previously used dimension, it was not because they did not remember the dimensions they already used (i.e., a memory error), but rather because they were unable to switch between the dimensions (a cognitive flexibility error). Once a child completed Sort1, Sort2, and Sort3 for a given trial, they moved on to the next trial (using a different set of cards), until all three trials were done.

<u>Scoring.</u> Each child was scored on several aspects of their performance. First, they were scored on how much support they needed for each sort, across trials. These *support scores* took into account the chance levels for each sort (i.e., Sort1, Sort2, and Sort3) as well as the chance levels for each support level (i.e., category generation, category identification, and instructed sort). I will describe the coding for each of the sorts. I have included a discussion of the chance levels for Sort1 for each support score. For the following sorts (Sort2 and Sort3), I only included a discussion of chance levels if these were different from Sort1.

For Sort1, the support score reflects children's *abstraction level*, as at this point the children have to determine a relevant dimension, but they have not yet been required to show cognitive flexibility skills, since they have not been required to switch from one dimension to another. There were 10 ways to sort each set of 6 test cards into two groups, and only three of them are correct (i.e., sorting by shape, colour, and size).

Therefore, the likelihood of children sorting on their own along any one of these dimensions—which is the performance expected in Sort1—is 0.3. Based on binomial distribution only succeeding on all three test trials is significantly better than chance (p = .03). Therefore, children received credit for category generation if they could perform Sort1 on their own in all three trials.

If a child could not sort the 6 cards into 2 groups on her own, the experimenter sorted the cards for her, and she was asked to identify the dimension along which the experimenter sorted the cards (category identification). The child had to refer to the relevant dimension in her answer; she was given credit even if she labeled the wrong value of the relevant dimension (e.g., if she called the yellow circles orange). Because the response range is quite open for this level, the likelihood of a child stumbling on a correct answer was low. Therefore, a cut-off of 2 correct trials was deemed sufficient to constitute better-than-chance performance.

If the child could not identify the relevant dimension chosen by the experimenter, she was given explicit instruction to sort (the experimenter labeled the relevant dimension). Children were scored on their ability to follow the experimenter's instructions. There was only one correct way to sort the cards (out of 10 possible ways to sort 6 cards into two groups) and, therefore, the cut-off of two correct trials was used here as well (p = .03). Thus, children received credit for instructed sort if they could follow the experimenter's instructions on two of the three trials.

For Sort2, the support score reflected the level of support the child required in order to consider a second dimension. Similarly to Sort1, for this Sort children received credit for category generation if they could perform the sort on their own in all three trials.[16] If they could not, they needed to perform 2 of the 3 test trials correctly to receive credit for category identification. If they needed the experimenter to label the dimensions for them, they had to perform 2 of the 3 test trials correctly to receive credit for instructed sort.

For Sort3, the support score reflected the level of support required to consider a third dimension. At this point, there was only one correct way to sort the 6 cards into 2 groups—along the dimension that has not yet been used (i.e., if the child or the experimenter sorted the cards along size and shape, only sorting along colour would be considered a correct answer). Therefore, the chance levels for this sort are 0.1, and succeeding on two or three test trials is performance that is significantly better than chance ($p = .03$). To receive credit for category generation, then, children only needed to succeed on two trials for Sort3. The category identification and instructed sort remained at the same number of correct trials (2 out of 3). Though complicated, calculating performance relative to chance allows for a reasonable way to compare across scores, and to be fairly confident that children who received credit for a certain level did not succeed by guessing.

For each support score (for Sort1, Sort2, and Sort3) children received a score of 3 if they performed at a category generation level, a score of 2 if they performed at a category identification level, a score of 1 if they performed at the instructed sort level, or a score of 0 if they could not perform at the instructed sort level. Thus, the support scores for each sort (Sort1, Sort2, and Sort3) ranged from 3 to 0, with higher scores reflecting

[16] While at this point there are 2 correct ways (out of 10 possible ways) to sort the 6 cards into 2 groups (i.e., sorting along the already-used dimension was considered incorrect), the number of trials required to perform above chance was unchanged.

better performance (i.e., a need for less support to flexibly sort the cards). Recall that children automatically received credit for any level lower than the level of which they were successful. So, for example, if they performed at the category generation for a given sort on a given trial, they received credit for category identification and instructed sorting for that sort on that trial. This was done following Smidts et al.'s (2004) procedure, and under the assumption that deductive tasks are easier than inductive tasks, so that if a child is able to solve an inductive task she is also able to solve the same task in its deductive version.

In addition to the support scores, a *flexibility score* was calculated. This score reflected the number of dimensions the child was able to sort along without any support (i.e., at a category generation level). In order to receive credit for being able to sort along 2 or 3 dimensions without support, a child needed to sort along the second or third dimension without support in all three test trials for Sort2, or in two or three test trials for Sort3, respectively (see below for a discussion of chance levels). The cognitive flexibility score was used in the Structural Equation Modeling analyses, but for the descriptive analyses described in Chapter 4 I used the support scores, as they provide more information about individual performance. That is, the flexibility score tells us how many dimensions the child is able to consider inductively (i.e., to abstract the dimension as well as to consider it flexibly). In contrast, the support scores tell us, for considering two and three dimensions separately, how much support the child requires in order to achieve flexible performance. Table 3.1 shows some examples of children's performance, by Sort and trial, and the scores they received in each of the four variables associated with the Modified Object Classification Task for Children.

Table 3.1

Modified Object Classification Task for Children Scoring Examples

	Test Trial 1			Test Trial 2			Test Trial 3			Total Support Score			
	Sort			Sort			Sort			Sort			
Participant ID (age in months)	1	2	3	1	2	3	1	2	3	1	2	3	Flexibility Score
3 (44)	CG	CI	IS	CG	CG	IS	CG	IS	CI	3	2	1	1
39 (47)	CG	CG	CI	CG	CG	CI	CG	CG	CI	3	3	2	2
117 (45)	CG	CI	IS	CG	CI	CG	CG	CI	CG	3	2	3	3
108 (58)	CG	CG	CG	CG	CG	CG	CG	CG	CI	3	3	3	3

Note. CG = Category Generation (3 points); CI = Category Identification (2 points); IS = Instructed Sort (1 point). Support scores reflect the level of support required for each sort. Flexibility score reflects the maximal number of dimensions the child was able to consider on her own.

Concurrent Cognitive Flexibility Tasks

Preschool Matrix Completion Task. This task was based on Siegler and Svetina's (2002) task, with several modifications (see Podjarny et al., in preparation; see Chapter 2, p. 40 for details). As mentioned, this task is a deductive measure of concurrent cognitive flexibility in which children have to consider two dimensions simultaneously.

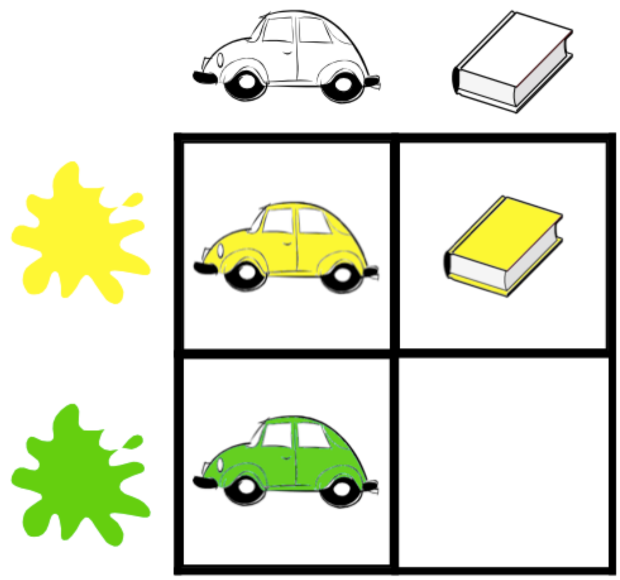
Children saw a 2x2 grid with 3 of the cells filled with an image, such that the items in the top row were related to each other on one dimension (e.g., a yellow car and a yellow book), and the items in the left-hand column were related to each other on another dimension (e.g., a yellow car and a green car; see Figure 3.2). Children were presented with 6 answer options and asked to choose an image to place in the empty cell. Although I used three dimensions across trials (shape, colour, and size), only two dimensions were varied within each trial, and these were counterbalanced in a fixed order across trials. Thus, for instance, the first test trial involved colour and shape, the second test trial used colour and size, and so on.

In each trial a 2x2 grid was presented as the "game board". The grid was labeled with the relevant dimensions, so the children did not need to identify them. The labels were colour swatches (to label colours), a colourless line drawing (to label shape), or the words "BIG" and "small" in a 50- and 12-point font, respectively (to label size without requiring the child to actually be able to read; see also Figure 5.1, p. 180). The children also saw in each trial an array with 6 choices (cards) to select from, for their answers. This array was typically placed to the side of the 2x2 game board. The cards included a duplicate of all the cards that were already on the grid, the correct answer (in this case, a green book), and two distractors. Each distractor matched one relevant dimension (relative to the trial) and was mismatched on the other[17]. For instance, in the example above, the distractors were a blue book (correct shape, wrong colour) and a green balloon (correct colour, wrong shape; see Figure 3.2, panel b). All the answer cards were fastened to the answer board using Velcro buttons, which allowed the children to take them out and place them on the board easily. The locations of each answer type (i.e., the correct answer, distractors, etc.) were varied across the trials.

In the introductory trial, children watched as the experimenter placed three cards into the first three quadrants of an empty grid (Quadrants I, II, and III), labeling each card, and drawing the child's attention to the labels (see Appendix E for task protocol). For example, the experimenter said: "see, here I have a yellow car. It belongs here (placing the card in the first quadrant) because it's car (pointing to the car label on top of the left-hand column) and it's yellow (pointing to the yellow label beside the top row)." The experimenter continued to place the following two items (quadrant II and quadrant III) and labeled them on both dimensions in the same manner. This was done to encourage children to attend to the relevant dimensions of each image, and how the item matched the column and row attributes.

[17] I chose not to introduce medium-sized items into trials in which size was a relevant dimension because these were less distinguishable from the small- and big-sized items than say, a blue item was from a red item.

a)



b)

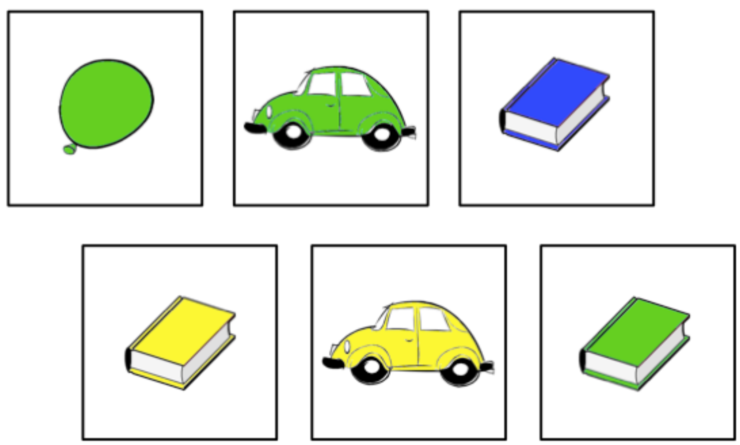


Figure 3.2 Preschool Matrix Completion Task sample trial. The figure shows a problem board (panel a) and choice-array (panel b).

The experimenter then presented the answer choice array and said, “Can you tell me which one of these pictures (gesturing to the answer board) belongs here (pointing to the empty cell)?” Children received feedback on the introductory trial: if the child chose the right answer the experimenter said, “That’s right! The green book belongs here, because it's a book (pointing to the book label on top of the right-hand column) and it's green (pointing to the green label beside the bottom row)". Conversely, if the child chose the wrong answer the experimenter said, "Good try, but the green book belongs here, because it's a book (pointing to the book label on top of the right-hand column) and it's green (pointing to the green label beside the bottom row)". Children were then encouraged to place the correct answer on the matrix board. Because the experimenter provided children with explicit verbal as well as pictorial labels, this task was considered a deductive measure of children's concurrent cognitive flexibility.

Following the introductory trial, 5 test trials were administered, in which the matrix boards already had 3 cells filled, with the fourth quadrant empty. Children saw a choice array (structurally the same as the one described above) and were asked to select a card to place in the empty quadrant. No feedback was given for the test trials, and children's final answer was recorded (i.e., children were allowed to self-correct). Children received one point for each correct answer, and the total number of correct answers (out of five) was used in the Structural Equation Modeling. For the exploratory analysis (see Chapter 4), children's scores were converted to pass/fail scores, with a 'pass' for better than chance performance (i.e., correct on 3 or more trials, with chance = 0.17 for each trial; $p = .04$ on a binomial distribution).

Matrix Sort Task. This task was designed to measure children's ability to coordinate two dimensions concurrently. This task was inductive, as children had to abstract the dimensions themselves on the test trials. It was based on Cartwright et al.'s (2010) matrix sort task in structure (see p. 38 for details), except that only the three basic dimensions (shape, colour, and size), with highly familiar items, were used. Further, children only had to sort 4 cards into the 2x2 empty grid (rather than 12 cards as in the original task). Instead of filling in the one empty cell as in the Preschool Matrix Completion Task, children had to sort all the cards into an empty, unmarked grid (i.e., no labels on the columns or rows). As in the Preschool Matrix Completion Task, though the task employed all three dimensions (shape, colour, and size), only two dimensions varied in each trial. For instance, a trial might include a green book, a blue book, a green car, and a blue car (all medium-sized).

The experimenter first demonstrated a correct sort (see Appendix F for a full protocol). She showed the child 4 cards (a big book, a small book, a big book, and a small balloon, all green), and said "I'm going to put these cards on the game board". The experimenter then proceeded to place each card in the correct cell (in a fixed order). Then she labeled each dimension (saying, "see, all the books are on this side, and all the balloons are on that side. And look at it this way, all the small ones are on the top, and all the big ones are on the bottom").

Three test trials followed, in which the experimenter reminded the child what was required without labeling the relevant dimensions (saying, "Can you put these cards on the game board for me? Remember, the cards on this side [pointing to first column] have to go together, and the cards on this side [pointing to second column] have to go together too. But also, the cards on the top [pointing to first row] have to go together, and the cards on the bottom [pointing to second row] have to go together.").

After placing all four cards on the grid in each trial, children were asked to label the dimensions on each axis (e.g., "can you tell me what is the same about these cards [experimenter motioning along rows]? And what is the same about the other cards [motioning along columns]?"; these responses were collected for future work and are not considered in this document). Children received one point for sorting the cards correctly on each trial. The total number of trials solved correctly was used in the Structural Equation Modeling.

There were 8 ways to sort the four cards correctly, out of 24 possible ways to place four cards into four cells (therefore, chance = 0.33). For instance, children's responses were considered correct if they placed the blue items on the top row and green items on the bottom row as long as both cars were on the same column, and they were considered correct if they placed the cars on the top row and the books on the bottom row, as long as both blue items were on the same column. Children had to solve all 3 trials correctly to perform significantly above chance (p = .03 based on binomial distribution). The pass/fail score was used in the exploratory analysis (see Chapter 4).

Multidimensional Card Selection. This task was developed in order to measure the number of dimensions children are able to coordinate simultaneously, up to three dimensions.[18] This was a deductive task, which included an introduction trial, a memory baseline, and 3 test trials (see Appendix G for full task protocol).

<u>Introduction Trial.</u> Given that the test trials require children to answer the question "are there any more cards?", it was necessary to first establish that they are able, and willing, to answer this question both in the affirmative and in the negative. So, during the introduction trial, children saw an array of 8 cards with pictures on them. The pictures were: two shoes (one red and one blue), three flowers (red, blue, and yellow), and three teapots (red, blue, and yellow). All items were of a similar size. Children were

[18] The task was structured in a way that would allow for more dimensions to be introduced in future work.

asked to give the experimenter "all the flowers". After each flower was given to the experimenter, the child was asked, "Are there any more flowers?" Feedback was given after every answer (see Appendix G for the full protocol). Six children (4 3-year-olds, 1 boy; 2 4-year-olds, 1 boy) were unable to answer the question "are there any more?" in the negative, and their score for this task was excluded (but their data was retained for the other tasks).

Memory Baseline. Following the introduction trial was a memory baseline trial. The purpose of this trial was to ensure that children could hold in mind three values (of the same dimension) when considering 8 cards. In other words, I wanted to examine whether children were able to simultaneously keep in mind three values of a given dimension (e.g., three shapes), before charging them with the more complex task of combining three values across three different dimensions (e.g., a shape, a colour, and a size). The memory trial did not require cognitive flexibility (as the three values pertained to the same dimension), but it did require children to hold in mind three different values. If the participants were generally able to hold three values, later failure in coordinating three different values from different dimensions would be more suggestive of cognitive flexibility limitations rather than simple memory ones (children generally did well on this task; see Results section for details on how children performed on this trial).

The memory trial was similar to the test trials, but the descriptions of the requested cards were uni-dimensional and additive. Children saw the following array: a big blue triangle, a small red heart, a small red circle, a small yellow star, a big green circle, a big green heart, a small yellow triangle, and a big blue star. They were introduced to three characters (Plan Toy dolls, see Appendix H), and the experimenter described each character's preference (e.g., "Grace likes hearts") and asked the child to give the character his or her preferred items ("can you give Grace all the hearts?"). The first character's preference only indicated one value (e.g., hearts), the second character asked for two (e.g., hearts and stars), and the third character asked for three (hearts, stars, and circles). Children received 1 point for being able to give the experimenter exactly all the hearts (2/8 cards), 2 points for being able to give the experimenter exactly all the hearts and stars (4/8 cards), and 3 points for being able to give the experimenter exactly all the hearts, stars, and circles (6/8 cards). Most children ($N = 87$; 72%) were able to provide the experimenter with all 6 target cards and only them. Another 18% ($N = 22$) were able to provide only the dual descriptor (hearts and stars), but not the triple. Children did significantly better on the memory trial than on the cognitive flexibility trials, *Wilcoxon's* $Z = 3.85$, $p < .001$.

Test Trials. For each of the 3 test trials, children were presented with an array of 8 cards that depicted different coloured and sized shapes. For example, one array included a big blue heart, a small yellow heart, a small yellow triangle, a big yellow triangle, a big green triangle, a big red circle, and two small red circles (see Figure 3.3). The children were asked to select cards that matched a description consisting of one, then two, then three dimensions. I will refer to these as phases 1-3, where phase 1 required children to consider a single dimension, phase 2 required children to consider 2 dimensions, and phase 3 required children to consider 3 dimensions.[19] For example, they were first asked to select all of the hearts (phase 1; single dimension to consider). Then, they had to select all of the yellow triangles (phase 2; two dimensions had to be considered simultaneously), and finally, they had to select the small, red circles (phase 3; three dimensions had to be considered simultaneously).

Children were asked to give each of the three characters all of, and only, their preferred cards (see Appendix G for a full task protocol). Each array of cards included 2 target cards that met the requirements each phase, with at least one distractor card for the phases 2 and 3. The distractor cards were those that matched at least one of the required dimensions, without matching all of them. For instance, for the trial described above, the big green triangle is the distractor for phase 2 (in which the target was yellow triangles), and the big red circle is the distractor for phase 3 (in which the target was small red circles). Target cards for a given phase were never used as distractors for another phase. Each child received 3 test trials, each with a different array of 8 cards, and each with three phases. The order in which the experimenter asked for the different dimensions is detailed in Table 3.2.

A *flexibility score* was calculated to reflect the number of dimensions the child was able to coordinate, assuming better-than-chance performance (see below). For instance, if a child received credit for the second phase, her flexibility score would be 2. The flexibility score ranged from 0 to 3, with 0 reflecting either being unable to solve any of the phases correctly in at least two trials (n = 5 boys; 3 four-year-olds), or inconsistent performance (e.g., receiving credit for the third phase but not for the first two phases; n = 3 boys; 2 three-year-olds). The other scores (1 to 3) reflected the number of dimensions

[19] I chose to use the term "phases" here because children continue to the next phase regardless of their performance. In contrast, in the Modified Object Classification Task for Children, children continue to the next *level* only if they failed the previous level.

the child received credit for. The flexibility score was used in the Structural Equation Modeling.

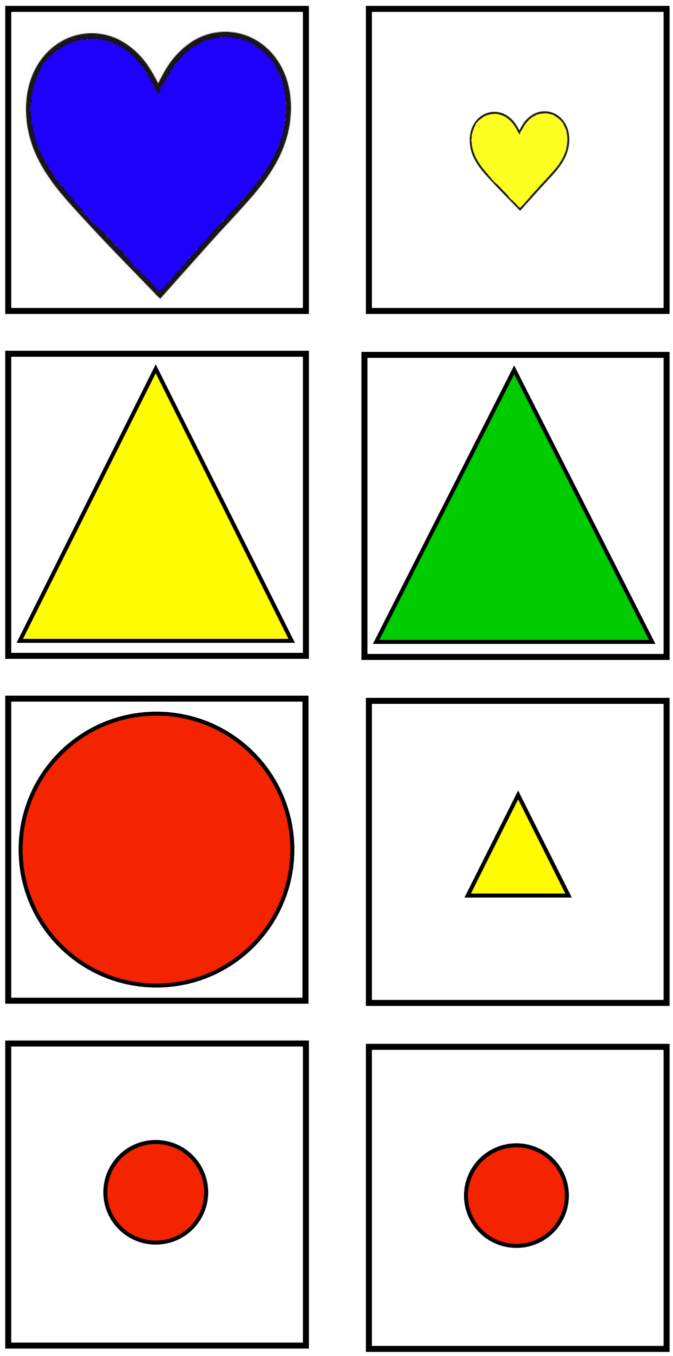


Figure 3.3 Multidimensional Card Selection Task sample test trial.

For each phase, children received credit for being able to coordinate a given number of dimensions if they successfully gave the character all—and only—the correct cards on at least two out of the three test trials of a given phase (summed across trials; this is referred to as the *phase score*). For instance, if a child were able to consider two dimensions in two trials and three dimensions in the third, she would receive credit only for coordinating two dimensions (i.e., a flexibility score of 2). This scoring was used because chance levels were 0.11, (the probability of selecting 2 specific cards out of 8 while not selecting the other 6), and so succeeding on two out of three trials was significantly better than chance ($p = .03$ based on binomial distribution). The pass/fail scores for phases 2 and 3 were used in the exploratory analysis (see Chapter 4).

Table 3.2

Multidimensional Card Selection Task Dimensions

Trial	Phase	Dimension	Value
1	1	Colour	Blue shapes
	2	Size	Small green shapes
	3	Shape	Big yellow triangles
2	1	Shape	Hearts
	2	Colour	Yellow triangles
	3	Size	Small red circles
3	1	Size	Big shapes
	2	Shape	Small stars
	3	Colour	Big blue hearts

Other Cognitive Measures

Recall that I wanted to examine the nature of the relation between consecutive and concurrent cognitive flexibility in the context of other cognitive processes. In order to do so, and following recommendations from Muthén (2002), these measures were all added into a 'covariate' latent factor and that factor was included in the model (see below for outline of the model, and Appendix A for details). For all of the following tasks, no pass/fail score was calculated, and the continuous score as indicated for each task was used in all analyses.

Self-Ordered Pointing. This task measured visual, non-spatial working memory skills (see Cragg & Nation, 2007, for a review of the task in a developmental context), and was found to provide sufficient variability, even with 3-year-old children (Hongwanishkul, Happaney, Lee, & Zelazo, 2005). In this task, children had to point to images in an array, one at a time, without pointing to the same image twice. They could not use the spatial location of the images, as they were shown a different arrangement of the images after each point. Thus, to succeed on this task, they had to be able to remember which images they had, and had not, pointed to before. This task contains visual input and was chosen because many of the cognitive flexibility tasks were visual in nature. A working memory task that relied on visual input was therefore deemed preferable to one that relied on phonological/verbal information (e.g., backward digit span).

Children were presented with sets of images (of objects familiar to children of this age group) printed on card-stock and placed into clear sleeves in a binder (see Figure 3.4 for a sample trial). The sets increased in size from two-picture arrays up to a maximum of eight-picture arrays, and children completed two trials per set size (each using a different array of items).

Children began with two two-picture arrays as practice trials (see Appendix I for full task protocol). The experimenter said “point to one picture on this page”, and waited for the child to comply. Then, after turning to the second page (on which the same two pictures were shown in different spatial locations), the experimenter said, “good job! Now point to the picture you didn’t point to before”, and provided feedback (i.e., “good job” if correct, and “oh, good try, but you already pointed to this picture before”). Following two practice trials, the children proceeded to see 2 trials of each set-size until they made two errors on a given set-size.

After the practice trials, the experimenter instructed the children: “every time I turn the page I want you to point to one picture you didn’t point to before”. The images were placed semi-randomly across the page (rather than on a grid). On each page, the arrangement of the pictures changed, so that it was not possible to succeed on this task by relying on spatial information; instead, children had to track which items they had already selected, either by remembering the images or the names of the images (see Figure 3.4 for a sample trial). In order to be correct for a given trial, children had to point to each image once, and only once, but any order was fine. Children received one point for each correct trial. There were 12 test trials (the last two sets included 8 items each). The total number of correct trials was used in all analyses.

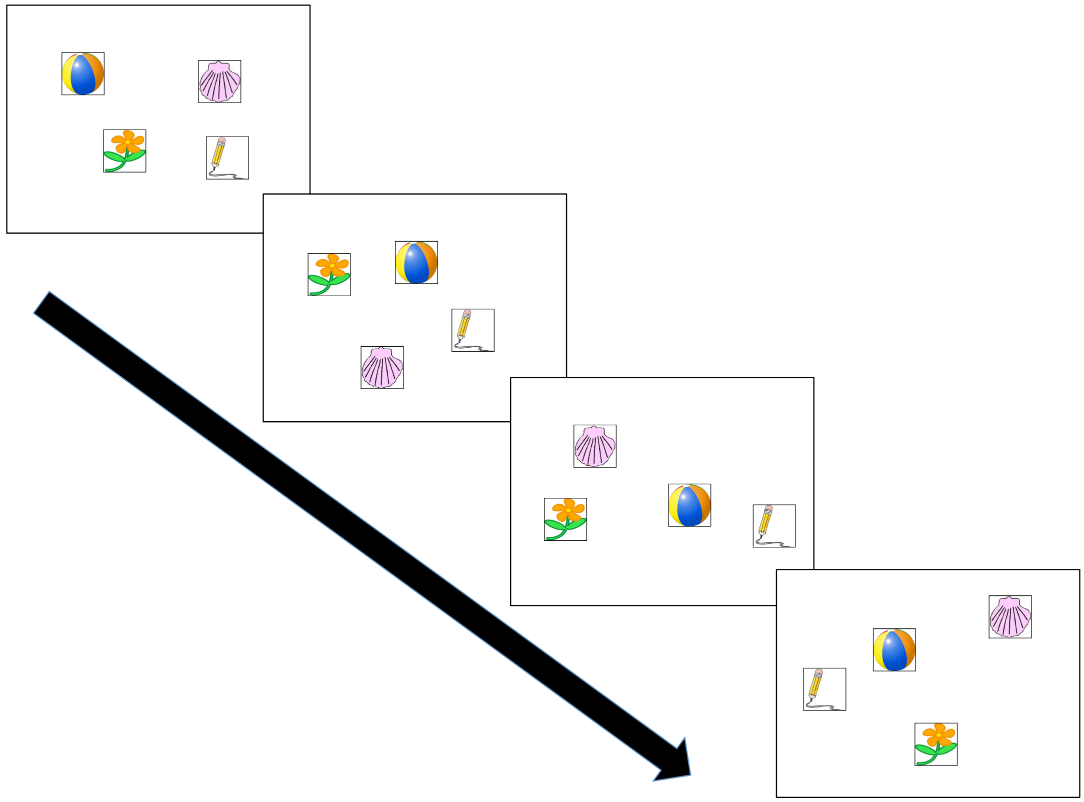


Figure 3.4 Sample trial for Self-Ordered Pointing Task.

Black/White Stroop. This task, based on the Day/Night Stroop task (Gerstadt et al., 1994), was used to measure children's inhibitory control skills. In the Day/Night Stroop task, children were asked to respond with the word "night" to a card with a picture of the sun, and with the word "day" to a card with a picture of the moon and three stars. However, some concerns have been raised regarding the additional inference step that children must perform (i.e., translate "sun" into "day" and "moon" into "night"; e.g., Simpson & Riggs, 2005; Vendetti, Kamawar, Podjarny, & Astle, 2015). Therefore, the Black/White Stroop was used. In this task, children saw black cards and white cards (solid colour) and had to respond in the opposite manner than their natural tendency. In other words, when a child saw a black card she was to respond with "white" and when she saw a white card, she was to respond with "black" (see Appendix J for full task protocol). There were up to 3 practice trials (with feedback) followed by 21 test trials (without feedback) for a total score out of 21 (accuracy). This score was used in all analyses.

Peabody Picture Vocabulary Test – Third Edition (PPVT-III; Dunn & Dunn, 1997). Language skills have been repeatedly found to significantly correlate with Executive Functions measures, and particularly with cognitive flexibility tasks (e.g, Jacques & Zelazo, 2005). Moreover, receptive language skills can often be taken as an indicator of general verbal intelligence (Liebermann, Giesbrecht, & Müller, 2007). Therefore, when examining the relations among different executive functions structures and especially when investigating individual differences in young children, it is important to control for general language ability.

Children's receptive language was assessed using the PPVT-III, which is a standardized measure of receptive vocabulary (Dunn & Dunn, 1997). In this task, children were presented with arrays of four images. The child's job was to indicate which image matched the word named by the experimenter (by pointing to one of the pictures). The vocabulary required became increasingly more difficult with each array. The task was arranged in blocks of 12 words, and once the child committed more than 8 errors in a block, the task was stopped (as per PPVT instructions). The standardized score, calculated according to the manual, was used in all analyses (note that this score is normalized, resulting in a population mean of 100 and standard deviation of 15).

Primary Test of Nonverbal Intelligence (PTONI; Ehrler & McGhee, 2008). Nonverbal intelligence has been shown to correlate to tasks that tap into concurrent cognitive flexibility in primary school aged children (e.g., Siegler & Svetina, 2002). Because of this correlation, it was also important to control for nonverbal intelligence, in addition to verbal intelligence. The Primary Test of Nonverbal Intelligence is a standardized test of nonverbal intelligence. Children were presented with a series of 3-5 pictures per page, in which one picture is different from the others, either visually or conceptually. First, basal has to be established (this is done with a set of 7 consecutive items correct). Children received credit for all items below their basal point. A ceiling is reached when the child answered 5 out of 7 consecutive items incorrectly. The raw score is calculated as the total of correct answers, and then standardized scores were calculated (according to the manual) and used in all analyses. As in the Peabody Picture Vocabulary Test, the standardized scores were normalized by age and have a population mean of 100 and a standard deviation of 15.

Results

The final sample included 121 preschoolers (59 3-year-olds and 62 4-year-olds; 64 girls). Descriptive statistics are provided in Table 3.3. To facilitate comparison, proportion scores (out of the total number of trials) are also reported for the cognitive flexibility tasks. Note that the scores provided here do not take chance levels into account; the percentages of children performing above chance are detailed in Table 4.4 (p. 136). I will first describe the data preparation (i.e., missing data analysis, screening for normality and outliers) and preliminary analyses (i.e., descriptive analysis—including consistency measures—of the cognitive flexibility tasks), before turning to the main analysis (the Structural Equation Modeling).

Table 3.3

Study 1 Descriptive Statistics

Task (sample score range)	Mean	SE	Mean Proportion Score	SE Proportion Score
		Full Sample		
Age in months (37-59)	48.12	.49	-	-
MFIST (0-8)	5.00	.19	.62	.02
DCCS (0-8)	6.02	.28	.75	.03
MOCTC Flexibility Score (0-3)	1.26	.05	.42	.02
Matrix Completion (0-5)	1.20	.11	.24	.02
Matrix Sort (0-3)	2.27	.08	.75	.03
MCS Score (0-3)	2.23	.09	.74	.03
Self-Ordered Pointing (0-9)	3.88	.23	.32	.02
Black/White (0-21)	12.72	.63	.61	.03
PPVT Standardized score (79-138)	110.53	1.23	-	-
PTONI Standardized score (62-150)	108.56	1.72	-	-

(continued)

Task (sample score range)	Mean	SE	Mean Proportion Score	SE Proportion Score
		3-Year-Olds		
Task (sample score range)	Mean	SE	Mean Proportion Score	SE Proportion Score
Age in months (37-47)	43.51	.31	-	-
MFIST (0-8)	4.88	.30	.61	.04
DCCS (0-8)	5.69	.43	.71	.05
MOCTC Flexibility Score (0-3)	1.12	.06	.37	.02
Matrix Completion (0-5)	0.90	.14	.18	.03
Matrix Sort (0-3)	1.98	.12	.66	.04
MCS Score (0-3)	2.04	.14	.68	.05
Self-Ordered Pointing (0-9)	3.83	.31	.32	.03
Black/White (0-21)	11.53	.97	.55	.05
PPVT Standardized score (79-138)	110.90	1.80	-	-
PTONI Standardized score (69-147)	108.53	2.56	-	-

(continued)

Task (sample score range)	Mean	SE	Mean Proportion Score	SE Proportion Score
		4-Year-Olds		
Task (sample score range)	Mean	SE	Mean Proportion Score	SE Proportion Score
Age in months (48-59)	52.52	.42	-	-
MFIST (1-8)	5.11	.24	.64	.03
DCCS (0-8)	6.34	.37	.79	.05
MOCTC Flexibility Score (1-3)	1.39	.09	.46	.03
Matrix Completion (0-4)	1.48	.15	.30	.03
Matrix Sort (0-3)	2.54	.09	.85	.03
MCS Score (0-3)	2.40	.12	.80	.04
Self-Ordered Pointing (0-9)	3.93	.33	.33	.03
Black/White (0-21)	13.84	.81	.66	.04
PPVT Standardized score (84-131)	110.22	1.69	-	-
PTONI Standardized score (62-150)	108.59	2.34	-	-

Note. MFIST = Modified Flexible Item Selection Task; DCCS = Dimensional Change Card Sort; MOCTC = Modified Object Classification Task for Children; MCS = Multidimensional Card Selection Task; PPVT = Peabody Picture Vocabulary Test; PTONI = Primary Test Of Nonverbal Intelligence.

Preliminary Analyses and Data Preparation

Missing data.

Missing data analysis and other screenings were done using SPSS version 22 for Mac. To ascertain whether data was missing at random (Little, 1988), I entered a representative variable for each task. This was done because several tasks had several variables associated with them. For instance, the Modified Object Classification Task for Children had 4 scores associated with it (support scores for each Sort1, Sort2, and Sort3, as well as the flexibility score). Entering all these variables would have created spurious missingness patterns, as a child who was missing one of these variables typically was missing all four variables because at some point she refused to continue with the task. In addition, I entered other variables that had no missing values, so as to ensure that they did not affect missingness patterns. These included age (in months), the number of items that the child needed repeating in the screener, and the difference (in days) between the three sessions. The Peabody Picture Vocabulary Test, the Primary Test of Nonverbal Intelligence, and the Multidimensional Card Selection Task all had more than 5% missing values (14.9%, 7.4%, and 5.8%, respectively), and the Modified Object Classification Task for Children had 5% missing values.[20] Using Little's MCAR test (Little, 1988) I was able to establish that data was missing at random, $\chi^2(54) = 64.92$, $p = .15$. Moreover, no child had missing data for more than two tasks, and only 5 children had missing data for both the Peabody Picture Vocabulary Test and the Primary Test of

[20] The Peabody Picture Vocabulary Test, Primary Test of Nonverbal Intelligence, and Modified Object Classification Task for Children were the longest-running tasks in the battery, and children were more likely to be frustrated with these tasks than the other, shorter tasks. For the Multidimensional Card Selection Task, several children were excluded because they did not demonstrate that they could answer the question "are there any more" in the negative. Rather than excluding the entire battery, I preferred to have one or two tasks missing.

Nonverbal Intelligence. Therefore, no imputations were used, and the default option of excluding participants with missing data (pair-wise) was used.

Univariate normality and outliers.

Data was screened for normality using skewness and kurtosis Z-values (Field, 2013; Tabachnick & Fidell, 2007) as well as histograms, stem-and-leaf plots, and Q-Q plots (see Appendix K for normality indicators, histograms, and Q-Q plots). Age (in months) did not seem visually to be normally distributed, but kurtosis and skewness Z values were well within acceptable range, and the mean (48.12; SE = .49) was fairly close to the median (48 months), so it was assumed that this variable was normally distributed. PPVT and PTONI standardized scores were both normally distributed, although both had a mean that was slightly higher than the population (which is 100 for both tests; all means are presented in Table 3.3). The other continuous variables (i.e., Modified Flexible Item Selection Task, Preschool Matrix Completion Task, Self-Ordered Pointing, and Black/White scores) were also screened. The Self-Ordered Pointing scores were distributed normally. However, the Preschool Matrix Completion Task scores were highly positively skewed, with most children scoring 0-1 and only one child scoring 5 out of 5 trials. In fact, the Preschool Matrix Completion Task scores closely resembled a zero-inflated Poisson distribution. Therefore, this variable was treated as categorical in the Structural Equation Modeling. Both the Modified Flexible Item Selection Task and the Black/White were negatively skewed, and the Black/White scores also showed negative kurtosis. I decided not to transform any of the variables since several non-continuous variables were involved in the analysis, which precluded any estimation method that assumes a normal distribution (see Appendix A for details). All other variables were categorical by nature (i.e., the Modified Object Classification Task for Children flexibility score, Multidimensional Card Selection Task flexibility score, Dimensional Change Card Sort pass/fail score, and Matrix Sort Task score).

No univariate outliers (Z > 3) were detected in any of the variables either when examined for the sample as a whole, or when divided into age groups (i.e., examining outliers in 3- and 4-year-olds separately). There were no multivariate outliers (maximal Malhalanobis distance was 24.25, which was smaller than the critical value of $\chi^2(11)$ = 31.26 (see Tabachnick & Fidell, 2007).

Cognitive Flexibility Task Performance.

Reliability. All cognitive flexibility tasks were examined for reliability (using R, version 3.1.2 for mac, and based on Dunn, Baguley, & Brunsden's, 2014, recommendations; see Table 3.4). Note that these reliability estimates should be treated with caution, as there were very few trials in each task. Cortina (1993) showed that the number of items included in the scale affects Cronbach's alpha estimates and that these estimates are inaccurate when the number of items is low (see also Romano, Kromrey, & Hibbard, 2010). While the bootstrapping approach taken for the omega estimate should ameliorate this issue slightly (Dunn et al., 2014), these estimates should be interpreted carefully, as several of the tasks had as little as 3 items (trials).

Expectedly, the Dimensional Change Card Sort scores showed high consistency. Recall that this score is typically bimodal (see, e.g., Carlson, 2003; Doebel & Zelazo, 2013), and it is bimodal in this sample as well. While the Multidimensional Card Selection Task and the Modified Flexible Item Selection Task scores showed reasonable consistency, the Modified Object Classification Task for Children, the Preschool Matrix

Completion Task, and the Matrix Sort Task scores showed fairly low consistency scores. This was likely due to the small number of trials (3 trials each for the Modified Object Classification Task for Children and the Matrix Sort Task and 5 for the Preschool Matrix Completion Task).

Task Performance. Children performed surprisingly well on the Dimensional Change Card Sort: 70% of the sample passed the Dimensional Change Card Sort, with 68% of the 3-year-olds sorting 7 or more post-switch cards correctly. This is inconsistent with previous findings that 3-year-olds find the Dimensional Change Card Sort difficult (e.g., Zelazo, 2006). By comparison, a recent study using the Dimensional Change Card Sort found that 55% of 3-year-olds passed the standard version (Doebel & Zelazo, 2013). Thus, the 3-year-olds in my study did show a higher than expected rate of passing.

Children also performed reasonably well on the Flexible Item Selection Task, solving on average 61% of the trials correctly (with 3-year-olds solving 64% of the trials correctly). Again, this is inconsistent with previous research, which showed that most 3- and 4-year-olds had significant difficulties with this task (e.g., Jacques & Zelazo, 2001). As a group, however, the average number of trials solved correctly was comparable to previous samples we have tested with our modified Flexible Item Selection Task (see Podjarny et al., 2009), so the better performance may have resulted from the modifications made to the task.

Table 3.4

Consistency Indices for Cognitive Flexibility Tasks

Task	Score (number of trials)	Cronbach's Alpha	Omega		
			Lower Bound (95%)	Coefficient	Upper Bound (95%)
Modified Flexible Item Selection Task	Contingent score (8)	.69	.56	.70	.78
Dimensional Change Card Sort	Correct post-switch trials (8)	.97	.95	.97	.98
Modified Object Classification Task for Children	Sort 2 Support Score (3)	.44	.16	.44	.57
	Sort 3 Support Score (3)	.16	-	-	-
Preschool Matrix Completion Task	Correct Trials (5)	.50	.35	.54	.64
Matrix Sort Task	Correct Trials (3)	.39	-	-	-
Multidimensional Card Selection Task	Phase 2 Trials (3)	.78	.70	.78	.85
	Phase 3 Trials (3)	.80	.70	.80	.87

Note. The omega score for the third sort on the Modified Object Classification Task for Children and the Matrix Sort Task was invalid because there were only 3 items and too little variability in the scores.

In contrast, children's Modified Object Classification Task for Children flexibility score was fairly low, with an average of 1.39 (on a scale from 0 to 3). Recall that this score is an indication of the number of dimensions a child was able to sort on her own. This means that on average, children were mostly able to sort the cards on their own only along one dimension, but they could not switch to sort these cards along different dimensions without the experimenter's help. Most children, then, were only able to group the cards along a single dimension without the researcher's help. Recall that less than half of the children in Smidts et al.'s (2004) sample of a similar age range were able to do so. This provides reason to believe that children who performed poorly on the subsequent sorts did so because of their difficulty coordinating 2 and 3 dimensions, rather than confusion about the task requirements.

Children performed rather poorly on the Preschool Matrix Completion Task, averaging 1.2 correct trials out of 5, which is significantly below chance performance. This was lower than expected based on previous data collected with this task (Podjarny et al., in preparation). However, one possible explanation is that while in the previous study I used only two dimensions (shape and colour) in all trials, whereas in this study, while only two dimensions were relevant in each trial, the task overall included 3 relevant dimensions (shape, colour, and size). This addition of the size dimension was done to make the Preschool Matrix Completion Task more comparable to the Flexible Item Selection Task and the Modified Object Classification Task for Children, which all included these three dimensions. Other than adding the size dimension, the task was procedurally similar to the one used in the previous study. The addition of another relevant dimension may have contributed to children's difficulties with this task even thought they only had to consider two dimensions in any given trial. This explanation, of course, should be examined in future work.

Children performed very well on the Matrix Sort Task, averaging 2.25 correct trials out of 3 test trials (solving, on average, 75% of the trials correctly). However, because only solving 3 out of 3 trials correctly was considered better than chance, on average their performance did not differ from chance. I will discuss pass/fail patterns in Chapter 4.

On the Multidimensional Card Selection Task memory trial, most children (N = 87) were able to provide the experimenter with all the cards that complied with the third level description (i.e., give the experimenter all the hearts, stars and circles, but leave out the triangles). Moreover, almost all children (91%) scored higher on the memory baseline trial than they did on the cognitive flexibility trials. These results indicate that children's difficulties on the Multidimensional Card Selection Task were not primarily due to memory demands. Children performed fairly well on the cognitive flexibility part of the Multidimensional Card Selection Task, with children able to coordinate, on average, 2.22 dimensions (out of 3; see discussion of pass/fail frequencies in Chapter 4).

Separability of Consecutive and Concurrent Cognitive Flexibility

As I mentioned before, Structural Equation Modeling is a statistical method in which common variance among several indicators (in this study, behavioural tasks) is examined in order to provide information about the structure of the latent variables. The experimenter typically creates two or more models, and a comparison is made to determine which model best fits the data. Goodness-of-fit indices are used to determine which model is to be preferred.

In this study, I compared two models. The first model included one cognitive flexibility latent factor with all tasks loading onto it (i.e., no differentiation between consecutive and concurrent cognitive flexibility). The second model, which was hypothesized to be a better fit of the data, included two cognitive flexibility latent factors, one consecutive (with the consecutive cognitive flexibility tasks loading onto it) and the second concurrent (with the concurrent cognitive flexibility tasks loading onto it). I compared these two models both with, and without, a covariate latent factor that included age (in months), as well as the other control tasks (i.e., inhibitory control, working memory, receptive vocabulary, and nonverbal IQ measures).

Contrary to expectations, the results found that both models fit the data equally, though poorly (see below for a discussion of the goodness-of-fit). Because there was no difference in fit, the more parsimonious model is to be preferred (the one with only one cognitive flexibility latent factor). When fitted with the covariate latent variable, both models failed to provide a valid estimate. This was because the covariate latent factor was highly correlated with the latent cognitive flexibility factor in the single-factor solution and to the consecutive cognitive flexibility factor in the two-factor solution (both $rs > 1$; see Appendix A for details).

It is important to note that both models (estimated without the covariate variable) fit the data fairly poorly. For instance, a popular goodness-of-fit index, the RMSEA index, is recommended to show less than .05 to indicate a close fit, and should not exceed .08 (West, Taylor, & Wu, 2012). The RMSEA values for the two models (without the covariate variable) were .20 and .21 for the single-factor and dual-factors models, respectively (see Appendix A for details). Thus, both models should technically be discarded as poorly fitting the data. For the purposes of this thesis, I shall turn to a discussion of these results. Note, in addition, that despite the poor fit, several of the consecutive and concurrent cognitive flexibility tasks are correlated, even after age is partialled out (see Table 3.5).

Table 3.5

Non-Parametric Bivariate and Partial (with age controlled) Correlations

	PPVT	PTONI	B/W	SOP	DCCS	MFIST	MOCTC	PMC	MST	MCS
Age	.019	.053	.168*	.036	.106	.053	.233**	.324**	.292**	.233**
PPVT	1	.153*	.097	.098	.226**	.189**	.158	.165*	.069	.245**
PTONI	.153	1	.128	.066	.168*	.124	.114	.239**	-.014	.231**
B/W	.095	.121	1	-.048	.181*	.041	-.034	.263**	-.048	.282**
SOP	.097	.065	-.055	1	.168*	.093	.205**	.012	.106	.040
DCCS	.225*	.163	.167	.165	1	.199*	.078	.238**	.154	.261**
MFIST	.188	.122	.032	.092	.195*	1	.036	.059	.169*	.158*
MOCTC	.158	.105	-.077	.202*	.056	.025	1	.132	-.031	.043
PMC	.168	.235*	.223*	.001	.216*	.044	.061	1	.225**	.231**
MST	.066	-.031	-.103	.100	.130	.160	-.107	.144	1	.131
MCS	.247*	.225*	.254**	.032	.245**	.150	-.012	.169	.068	1

Note. PPVT = Peabody Picture Vocabulary Test; PTONI = Primary Test of Nonverbal Intelligence; B/W = Black/White; SOP = Self-Ordered Pointing Task; DCCS = Dimensional Change Card Sort; MFIST = Modified Flexible Item Selection Task; MOCTC = Modified Object Classification Task for Children; PMC = Preschool Matrix Completion Task; MST = Matrix Sort Task; MCS = Multidimensional Card Selection Task. Kendall’s Tau-b parameter used. Age-partialled correlations appear below the diagonal.

Discussion

The Structural Equation Modeling analysis revealed that both models equally fitted the data; however, when this happens, the more parsimonious solution should be chosen. In addition, in the second model I tested, in which consecutive and concurrent cognitive flexibility were separated into two factors, these two latent factors were highly correlated. Thus, contrary to my hypothesis, the best (most parsimonious) solution was the one that specified all cognitive flexibility tasks as loading onto a single factor.

My hypothesis that a statistical structural analysis would detect the difference between consecutive and concurrent cognitive flexibility latent factors was based, in addition to the theoretical considerations discussed in Chapter 2, on several structural analyses that found similar separation between different Executive Functions. For instance, Miyake et al.'s (2000) Executive Functions structure was based on a structural analysis. Moreover, several structural analyses found separate Executive Functions latent factors in children (e.g., Brydges et al., 2014; Miller et al., 2012). However, the data from Study 1 does not seem to support a statistical separation of consecutive and concurrent cognitive flexibility in the context of a structural analysis.

My findings are, however, consistent with several investigations using a confirmatory factor analysis with 3- to 6-year-olds, which demonstrated that a solution that specifies performance on all tasks (i.e., tasks designed to measure inhibitory control, working memory, and cognitive flexibility) as loading onto a single latent factor is a better fit for children's data than a solution that specifies three separate latent factors (e.g., Fuhs & Day, 2011; Wiebe et al., 2011; Willoughby, Wirth, & Blair, 2012). Moreover, in a longitudinal investigation published recently, Lee et al. (2013) measured executive functions (working memory, inhibitory control, and consecutive cognitive flexibility) annually over four years in a cohort-sequential design. Consequently, they had data on executive functions covering children between the ages of 6 and 15 years. They found that the best fit for the data of 6- to 13-year-olds was a dual-factor solution including two factors: working memory, and a combination of inhibitory control with (consecutive) cognitive flexibility. For 15-years-olds, they found evidence of a three-factor solution, including working memory, inhibitory control, and (consecutive) cognitive flexibility. It seems likely, then, that executive functions begin as a unitary process during preschool and gradually become differentiated into two, and then three factors, an interpretation suggested by Wiebe et al. (2011). It is possible that consecutive and concurrent cognitive flexibility would show structural separation in older children and in adults, a hypothesis that could be tested in future research.

Note, however, that both models I tested fit the data extremely poorly. Other investigations, whether finding a single factor (e.g., Wiebe et al., 2011) or finding more than one factor (e.g., Miller et al., 2012) all had models that fit the data well. One possible explanation of this discrepancy is related to task selection. Miller et al. (2012), for instance, showed that task selection plays a critical role in the results of a structural analysis. These authors collected data to replicate a study that revealed a single solution of executive functions structure in preschoolers (Wiebe et al., 2008), but they also collected data on several other executive functions tasks. Specifically, while they collected tasks such as the Boxes task (a self-ordered search task measuring working memory, similar to the Self-Ordered Pointing Task), the Boy-Girl Stroop (a measure of inhibitory control similar to the Black/White), and Tower of Hanoi (a measure of planning and inhibition; see Miller et al., 2012; Wiebe et al., 2008) which were collected by Wiebe et al., (2008), they also collected tasks such as the Backwards Word Span Task (a measure of working memory similar to the Backwards Digit Span) and the Dimensional Change Card Sort (see Miller et al., 2012).

Miller et al. (2012) replicated Wiebe et al.'s (2008) single solution finding with the tasks administered by Wiebe et al., (2008), but demonstrated that when using additional tasks with the same sample, a dual-factor solution that included working memory and inhibitory control latent factors was a better fit for the data. Thus, the indicators that the experimenters choose to include have a significant impact on the results of the structural analysis. Similarly, it is possible that the poor fit for the data in my study resulted from the task selection. Particularly, the Modified Object Classification Task for Children (measuring consecutive cognitive flexibility) and the Matrix Sort Task (measuring concurrent cognitive flexibility) both loaded poorly on the cognitive flexibility factors (in both models; see Appendix A for details). It is likely that without these two tasks the model would have shown a better fit for the data.

Despite the previous mixed findings regarding a statistical differentiation of Executive Functions in children, researchers still find the conceptual differentiation useful. For instance, Bull and Scerif (2001) found that working memory and inhibitory control independently explained unique variance of mathematics ability, over and above general IQ and reading skills in a sample of 7-year-olds. Similarly, St. Clair-Thompson and Gathercole (2006) tested 11-year-olds' Executive Functions, as well as scores on standardized tests in English, mathematics, and science. These authors demonstrated that working memory and inhibitory control each contributed independently to achievements in English and mathematics. In addition, inhibitory control predicted attainment in science over and above working memory skills.

Therefore, although the results of my structural analysis did not support a statistical differentiation between consecutive and concurrent cognitive flexibility, it is still possible that a conceptual differentiation would be useful. For instance, similar to the results reported by Bull and Scerif (2001) and St. Clair-Thompson and Gathercole (2006) it may be the case that consecutive and concurrent cognitive flexibility skills predict different developmental outcomes. For example, it could be that while consecutive cognitive flexibility is a better predictor of academic achievements (see, e.g., Coldren, 2013), concurrent cognitive flexibility would be a better predictor of problem-solving (e.g., Siegler & Svetina, 2002).

Moreover, while the Structural Equation Modeling analysis tells us that consecutive and concurrent cognitive flexibility skills are related, it does not tell us *how* they relate to each other. For example, while the Structural Equation Modeling analysis revealed that children who had relatively high consecutive cognitive flexibility skills also had relatively high concurrent cognitive flexibility skills, it could be that one skill develops before the other, or that some task factors affect the performance on consecutive and concurrent cognitive flexibility tasks differently.

In order to examine the relations between consecutive and concurrent cognitive flexibility development, the data collected in Study 1 was used in a different way than was originally planned. In this exploratory analysis, I first compared the performance on consecutive and concurrent cognitive flexibility tasks between the age groups, in order to examine the developmental pattern.

In addition, I explored the impact of two other factors. The first factor I was interested in was whether requiring children to identify the relevant dimension would affect performance, and if so, whether it affected both types of cognitive flexibility similarly. Jacques and Zelazo (2005) distinguished between deductive tasks—tasks in which all the required information is provided to the children—as compared with inductive tasks—tasks in which the children have to *abstract* the relevant information (i.e., make an additional inference step) before solving the main task. They noted that children find inductive (consecutive) cognitive flexibility tasks more difficult than they find deductive (consecutive) cognitive flexibility tasks. I wanted to explore whether the difference in performance between inductive and deductive tasks extended to concurrent cognitive flexibility tasks as well.

The second factor I was interested in was whether requiring the consideration of 2, versus 3, dimensions affected cognitive flexibility, both consecutively and concurrently. The tasks I used in Study 1 varied along these two factors (see Table 3.6), and so the data allowed me to explore the relation between these factors and consecutive and concurrent cognitive flexibility.

In Chapter 4, I review the research examining the role of these two factors—inductive task demands and number of dimensions—on consecutive and concurrent cognitive flexibility development. I then turn to describe an exploratory analysis I conducted in order to examine the role these factors play on children's consecutive and concurrent cognitive flexibility performance. I will describe and discuss the results before turning to Study 2.

Chapter 4: Effects of Inductive Demands And Number of Dimensions On Consecutive and Concurrent Cognitive Flexibility Performance

Based on the results from the structural analysis (briefly outlined in Chapter 3, reported in detail in Appendix A), we now know that consecutive and concurrent cognitive flexibility skills are highly related in preschool-aged children. However, we still know little about the *nature* of the relation between these two processes, mostly due to the paucity of research examining concurrent cognitive flexibility in this age group. Therefore, I wanted to take advantage of the data that I collected in Study 1 in order to explore this relation, as well as some factors that may affect consecutive and concurrent cognitive flexibility performance in preschoolers.

In a recent review of (consecutive) cognitive flexibility tasks, Cragg and Chevalier (2012) point out that because several task characteristics differ, comparing children's performance on tasks that are typically used with preschoolers and with school-aged children is difficult. Therefore, it is difficult to run cross-age comparisons. The authors urged researchers to take into account task characteristics and how they affect children's performance when examining cognitive flexibility development.

In this chapter, I will focus on two such task characteristics: abstraction task demands and the number of dimensions the child is required to consider (up to 3). These two factors were varied in the tasks I used for Study 1 in order to have a wide range of consecutive and concurrent cognitive flexibility tasks (see Table 4.1). Specifically, when planning Study 1, I chose both inductive and deductive tasks and included one task for each cognitive flexibility skill that allowed me to measure children's ability to consider 3 dimensions, in addition to the more traditional measures of the ability to consider 2 dimensions (e.g., the Dimensional Change Card

Sort). I therefore had the opportunity to explore the effects of these task characteristics on preschoolers' performance.

Table 4.1

Cognitive Flexibility Tasks Overview

Task	Concurrent/Consecutive	Inductive/Deductive	Number of dimensions
Dimensional Change Card Sort	Consecutive	Deductive	2
Modified Flexible Item Selection Task	Consecutive	Inductive	2
Modified Object Classification Task for Children	Consecutive	Inductive/Deductive	Up to 3
Preschool Matrix Completion Task	Concurrent	Deductive	2
Matrix Sort Task	Concurrent	Inductive	2
Multidimensional Card Selection Task	Concurrent	Deductive	Up to 3

The cognitive flexibility tasks employed in Study 1 included both inductive and deductive tasks. Recall that inductive tasks require children to identify the relevant dimension(s) on their own, whereas in deductive tasks the experimenter identifies the relevant dimension(s) explicitly. I had at least one inductive and one deductive task to measure each cognitive flexibility skill (i.e., consecutive and concurrent). In addition, I had one consecutive task and one concurrent task that allowed me to compare children's ability to coordinate two and three dimensions (the Modified Object Classification Task for Children to measure consecutive cognitive flexibility and the Multidimensional Card Selection Task to measure concurrent cognitive flexibility). Thus, the data from Study 1 allowed for an investigation of the effects of these two factors (inductive/deductive tasks and number of dimensions being considered) on children's performance. This investigation provides researchers with a better understanding of these factors' effects on cognitive flexibility development, thereby informing future research (Cragg & Chevalier, 2012). However, Study 1 was not specifically designed to investigate these factors, so not all of the possible combinations of concurrent/consecutive flexibility by 2 vs. 3 dimensions were crossed (see below for a more detailed discussion).

Prior to examining the effects of these two factors on preschoolers' cognitive flexibility performance, I will review some research related to these factors in the context of both consecutive and concurrent cognitive flexibility. I will then present my exploratory analyses, and discuss what the findings tell us about consecutive and concurrent cognitive flexibility development.

Factor 1: Abstraction Task Demands

As mentioned before, cognitive flexibility (both consecutive and concurrent) plays a role in problem-solving (e.g., Siegler & Svetina, 2002). Another process that plays an important role in problem-solving is *abstraction*—the ability to extract individual features of a stimulus (Bennett & Müller, 2010). For example, it is the ability to recognize that a small blue circle and a big blue triangle both have the same colour.

Abstraction and cognitive flexibility are also implicated together in conceptual development (Bennett & Müller, 2010; Inhelder & Piaget, 1964; Smidts et al., 2004). Abstraction is important for problem-solving, especially in "real-life" situations where there is no helpful experimenter to label the relevant dimension. In the context of the current work, an example of abstraction skills is identifying the relevant dimensions prior to having to flexibly consider them.

Jacques and Zelazo (2005) distinguished between inductive and deductive cognitive flexibility tasks. In inductive tasks, "children must make at least one inductive inference regarding how to go about solving the task" (p. 61), whereas in deductive tasks, "all of the information necessary for solving the task is provided to children" (p. 57). The authors reviewed over 40 tasks that require cognitive flexibility and concluded that preschoolers find inductive tasks more difficult than deductive tasks. These authors argued that the feature responsible for the difference in performance is "the amount of relevant information that is explicitly *labeled* in each kind of task" (p. 62; emphasis in original). In other words, while in deductive tasks the experimenter explicitly labels the relevant dimension(s), in inductive tasks children must identify the relevant dimension(s) to be coordinated on their own. Note that although Jacques and Zelazo (2005) define cognitive flexibility as “the ability to consider *simultaneously* multiple conflicting representations of a single object or event” (p. 54; emphasis added), most of the tasks they review tap consecutive cognitive flexibility, such as the Dimensional Change Card Sort and the Flexible Item Selection Task.

The relation between abstraction of the relevant dimension, which is required in order to solve inductive tasks, and cognitive flexibility, which is required to coordinate several dimensions of a single stimulus or stimuli set, has been noted by several researchers (e.g., Bennett and Müller, 2010; Inhelder & Piaget, 1964; Smidts et al., 2004). As both these skills are important for problem-solving (see, e.g., Bennet & Müller, 2010), understanding the relation between them would help provide a clearer picture of cognitive development. It is unclear from the literature if one of these skills depends on the other, both are driven by a third, related process, or perhaps their development is unrelated.

For example, based on research examining classification and sorting behaviours initiated by Piaget’s work (e.g., Inhelder & Piaget, 1964), Bennett and Müller (2010) state that “with development, children become able to abstract independent features, and later they learn to switch from considering one feature of an object to considering a different feature.” (p. 456). In other words, these authors argue that the ability to identify the relevant dimension(s) must *precede* cognitive flexibility development. This stance would be consistent with the finding that deductive and inductive tasks are mastered around the same time, as by the time the child is able to coordinate two dimensions consecutively, she had already mastered the skill of identifying the relevant dimension(s).

Bennett and Müller (2010) cite Jacques and Zelazo's (2001) work as support for their claim that the ability to identify the relevant dimension precedes cognitive flexibility development. This report provided data on 2- to 5-year-olds' performance on the Flexible Item Selection Task. Recall that in the Flexible Item Selection Task, children are shown an array of three items (e.g., a big blue flower, a big blue shoe, and a small blue shoe), and are asked first to select two items that "go together in one way", and then to select two items that "go together in another way". In their study, Jacques and Zelazo (2001) found that 3-year-olds are able to perform the first selection correctly, but not the second selection, whereas 4- and 5-year-olds show improvement in their second selection accuracy. Bennett and Müller (2010) interpreted these findings to indicate that the ability to identify the relevant dimension precedes cognitive flexibility, as the first selection was designed to measure children's ability to identify similarities between two items (e.g., that both are shoes; Jacques & Zelazo, 2001).

However, the Flexible Item Selection Task provides information on children's ability to identify a relevant dimension *separately* from their (consecutive) cognitive flexibility skills, but does not provide a direct comparison of the two skills. We cannot know, from scores on this task alone, whether children would be better able to solve the Flexible Item Selection Task had it been a deductive task.[21] We know that children are able to identify one dimension on the Flexible Item Selection Task when they are about 4 years old (Jacques & Zelazo, 2001). What we do not know is whether their difficulties identifying the second selection is due to undeveloped cognitive flexibility skills or with a combination of being tasked with both having to disengage from the first dimension *and* identifying a second dimension on their own. A direct comparison of children's performance on inductive and deductive cognitive flexibility tasks should provide a better understanding of the relation between children's ability to identify the relevant dimensions and coordinate them flexibly (whether consecutively or concurrently).

Smidts et al.'s (2004) Object Classification Task for Children has the potential to provide information about the relation between abstraction and consecutive cognitive flexibility, as the experimenter varies the levels of inductive support (see Chapter 2, p. 21 for details). Recall that children were first asked to sort trivalent objects on their own—they were asked to identify a dimension along which to sort. Only if they failed in sorting on their own, as well as in identifying the dimension along which the experimenter sorted the cards, did the experimenter provided the label for the relevant dimension. This procedure is based on the expectation that children would find it more difficult to switch to consider a second dimension of the stimuli inductively (i.e., on their own) as compared with deductively (i.e., when the experimenter labels the dimension along which they are required to sort the stimuli). Indeed, Smidts et al. (2004) demonstrated that most 3- and 4-year-olds could not sort along a second dimension on their own.

However, it is unclear from Smidts et al.'s (2004) report whether (and how many) children who continued to the deductive level of the task actually succeeded in sorting once the experimenter provided the explicit labels. Moreover, a direct comparison of the number of children who passed the inductive and deductive levels would not be possible

[21] Preliminary results in our lab indicate that children perform much better on a deductive version of the Modified Flexible Item Selection Task compared with an inductive version (Kamawar et al., unpublished data).

with this task, as the deductive level is dependent on the inductive level (i.e., a child would only see the deductive level if she failed the inductive level).

Another line of investigation that appears to inform the discussion on the relation between abstraction and cognitive flexibility includes studies that examined the effects of labels on children's (consecutive) cognitive flexibility performance. For instance, recall that Kirkham et al. (2003) had a 'label' version, which they compared with the standard version of the Dimensional Change Card Sort (see Chapter 2, p. 31). Recall that children performed better on the 'label' version than on the standard version of the task. Similarly, Doebel and Zelazo (2013) gave children three versions of the Dimensional Change Card Sort: in the 'relevant label' version, the relevant dimension was labeled in all post-switch trials (e.g., here's a blue one" when the post-switch dimension was colour). In contrast, in the 'both labels' version, the experimenter labeled both dimensions in all post-switch trials (e.g., "here's a blue rabbit"). Finally, in the 'non-descript label' version, the experimenter provided no specific labels on the post-switch trials (e.g., "here's one"). These authors found that children did better in the 'relevant label' version (which is consistent with the standard Dimensional Change Card Sort version; Zelazo, 2006) than they did on the 'both labels' and the 'non-descript label' versions.[22]

[22] Note that Jacques and Zelazo (2005) reviewed the effects of labeling the relevant dimension on both inductive and deductive tasks, and found that labels improved children's performance, but that this effect was "less reliable with deductive tasks because in deductive tasks, the experimenter *already* labels relevant information" (p. 73; emphasis in original). However, when the experimenter labels the relevant dimension in an inductive task she effectively turns the task into a deductive one. Therefore, I have taken their review of effects of labeling as indicating that deductive tasks are easier for children to solve as compared to inductive tasks.

At first glance, these works seem to support the idea that children find deductive tasks (in which the experimenter labels the relevant dimensions) easier than inductive tasks. However, both of these studies used the Dimensional Change Card Sort, which is already a deductive task. Thus, in both studies the experimenter identified the relevant dimension for the child when explaining the rules ("In the color (shape) game all the blue ones (all the trucks) go in this box, and all the red ones (all the stars) go in this box."; Kirkham et al., 2003, p. 454). Moreover, in Kirkham et al.'s (2003) study, the experimenter asked the child, for instance, "what colour is it?" when playing the colour game (p. 455). Thus, both works do not, in fact, compare an inductive and a deductive version of the same task. However, they do provide some support for the fact that labels affect performance.

While the claim that the ability to identify the relevant dimensions precedes the ability to coordinate these dimensions makes intuitive sense, it contrasts with some findings from empirical work. For instance, in Jacques and Zelazo (2005), the authors found that children were able to succeed on deductive tasks about a year before they were able to succeed on inductive tasks, though these were not within task comparison using different versions of the same task. These findings could suggest that cognitive flexibility skills precede children's ability to identify the relevant dimension(s) if children are able to coordinate two dimensions that are being explicitly identified by the experimenter, but they are unable yet to identify these same dimensions on their own. Such a pattern would clearly indicate that their ability to coordinate two dimensions precedes their ability to identify these dimensions. However, note that Jacques and Zelazo's (2005) review did not directly compare the same child's performance on inductive and deductive tasks (i.e., they were not within-subject designs), and the conclusion is based on a general review of findings across studies, and participants.

In summary, despite several researchers identifying this issue as important (e.g., Bennett & Müller, 2010; Jacques & Zelazo, 2005), no work has directly compared children's consecutive cognitive flexibility performance on deductive and inductive tasks, and thus it is unclear what the nature of the relation is between children's ability to identify the relevant dimension and their ability to consider more than one dimension consecutively. Although inductive cognitive flexibility tasks may be more applicable to "real-life" situations, they require both abstraction and cognitive flexibility. In other words, it is possible that inductive tasks underestimate children's cognitive flexibility skills because they require other cognitive skills for success. In addition, while researchers examining the relation between children's ability to identify the relevant dimension and their (consecutive) cognitive flexibility skills refer to cognitive flexibility in general, most of the work has been done with consecutive cognitive flexibility tasks (Bennett & Müller, 2010; Jacques & Zelazo, 2005; Smidts et al., 2004). Thus, a comparison of inductive and deductive concurrent cognitive flexibility performance would shed light on potential similarities and differences between the two types of cognitive flexibility.

In terms of concurrent cognitive flexibility, there is only indirect evidence pertaining to the effects of abstraction task demands on children's performance. For instance, recall that Halford (1980) used labeling of either one or both relevant dimensions as part of his training procedure. Similarly, Parker et al. (1972) used labeling the relevant dimension as part of their training procedure (e.g., asking the children "what colour goes in this [cell]?", p. 1784). The assumption inherent to this procedure, like the assumption inherent to the procedure used by Smidts et al. (2004), is that by identifying the relevant dimensions the experimenter supports the child's performance on concurrent cognitive flexibility tasks.

There is some evidence that concurrent cognitive flexibility performance benefits from the explicit labeling of the relevant dimension. Recall my earlier study that measured 4- and 5-year-olds' performance on the Preschool Matrix Completion Task (see Chapter 2, p. 47, and Podjarny et al., in preparation), which was a deductive version of Siegler and Svetina's (2002) Piagetian matrix completion task. While the children in my sample demonstrated more success than the 6-year-olds in Siegler and Svetina's sample, my task employed several changes to their matrix completion task, so the improved performance could have resulted from the other changes or from the combination of the changes I made. Thus, we have a very partial picture of children's performance on inductive and deductive concurrent cognitive flexibility tasks.

In summary, while the relation between children's ability to identify the relevant dimension and their cognitive flexibility development is unclear, data suggests that children should be able to solve deductive tasks before they can solve inductive tasks. However, no direct comparison has been made that included an examination of both inductive and deductive tasks, as well as both consecutive and concurrent cognitive flexibility. An examination of this relation would enhance our understanding of the development of both these processes.

Factor 2: Number of Dimensions

Cognitive flexibility skills (both consecutive and concurrent) are of particular interest as predictors of problem-solving (e.g., Siegler & Svetina, 2002) and creativity (e.g., Diamond, 2012). In order to come up with a novel solution to a problem, one typically must think about the problem at hand in *several* different ways before arriving at a suitable solution. Consistent with this notion, many studies examining cognitive flexibility in school-aged children and adults involve a measure of fluency, in which participants are asked to provide as many different responses as they can to a certain cue; participants who provide more responses are considered to be more flexible in their thinking (e.g., Gilhooly, Fioratou, Anthony, & Wynn, 2007; Snyder & Munakata, 2010; Stevenson, Kleibeuker, De-Dreu & Crone, 2014). In contrast, most studies measuring cognitive flexibility in preschoolers focused on children's ability to switch between only two dimensions of the same stimulus, typically shape and color (see Cragg & Chavlier, 2012; for a review). While this methodology has been informative, it limits our understanding of when and how the skill of thinking about a stimulus in more than two ways develops.

One exception to researchers' use of tasks that measure preschoolers' ability to switch between two dimensions only is the Object Classification Task for Children (Smidts et al., 2004). Recall that this task was design to measure children's ability to consider three dimensions consecutively. However, as I noted before, the authors reported that if a child could not sort the 6 objects on their own on the first sort (an abstraction task), the experimenter reduced the testing set to consist of four objects that varied along two dimensions only. In their sample, most 3- and 4-year-olds could not sort along even one dimension on their own. Thus, while their study provided information about 3- and 4-year-olds' inability to identify the relevant dimensions of a trivalent stimulus-set, it did not shed light on young preschoolers' ability to consider more than two dimensions. While the older children in the study were able to sort along two dimensions on their own (40%, 60% and 90% of 5-, 6-, and 7-year-olds, respectively) they found sorting the same trivalent stimuli in a third way more difficult (only 10%, 20%, and 50% of 5-, 6-, and 7-year-olds were able to perform the third sort on their own; see Smidts et al., 2004). Therefore, we have some evidence that considering a third dimension is not trivial even after the child is fully capable of considering two of them. Recall, however, that the Object Classification Task for Children begins as an inductive task. This task requires children both to identify the relevant dimension as well as coordinate it with previously identified dimensions. It is possible, then, that preschoolers would be able to consider three dimensions if the experimenter were to identify these dimensions for them (i.e., using a deductive task).

Deák and Wiseheart (2015) also recently reported a task that can be used to measure children's ability to consider 3 dimensions consecutively. In their study, they employed an adaptation of the Dimensional Change Card Sort that extends the stimuli to vary along three dimensions (the 3DCCS task). In this task, children are presented with four boxes with target cards affixed to them. For instance, the target cards may include a big yellow dog, a small red fish, a medium blue bird, and a big green frog (the last one acts as a distractor). Children are given five test cards (a small yellow bird, a medium yellow fish, a big blue fish, a medium red dog, and a big red bird) to sort into the boxes, and play first the shape game, then the colour game, and then the size game (with the same 5 test cards repeated for each game). This task is deductive, as the experimenter explains the rules at the beginning of every game (e.g., “all the birds go here”). Note that, similar to the Dimensional Change Card Sort, the test cards conflict with the target cards and that sorting the test cards correctly would put them in a different box in each game (e.g., the small yellow bird goes in the medium blue bird box when playing the shape game, in the big yellow dog box when playing the colour game, and in the small red fish box when playing the size game).

Deák and Wiseheart (2015) reported data from 3- and 4-year-olds ($N = 95$). As a group, the children in their study sorted about 90% of the test cards in the first (shape) game correctly, 60% of the test cards in the second (colour) game correctly, and 50% of the test cards in the third game (size) correctly (all comparisons were significantly different; see Deák & Wiseheart, 2015, pp. 41-42), showing a similar pattern to that of the older children’s performance on Smidts et al.’s (2004) Object Classification Task for Children. In other words, these younger children found considering the test cards along a third dimension more difficult that they found considering the test cards along the first two. However, note that in this study, children always saw the size game as the third game (i.e., the order of the relevant dimension was not counterbalanced across participants). Size could be a more difficult dimension to grasp than shape and colour (see, e.g., Siegler & Svetina, 2002), and the decreased performance could be due to the specific dimension as opposed to the general requirement to consider a third dimension.

In summary, the research reviewed here represent an emerging line of investigation in cognitive flexibility examining children’s ability to consider a stimulus along three dimensions. These works suggest that the number of dimensions the child is required to consider, sequentially, affects children's consecutive cognitive flexibility performance.

In terms of concurrent cognitive flexibility performance, these findings appear somewhat in conflict with Siegler and Svetina's (2002) claim that the number of dimensions 6- to 8-year-olds had to coordinate did not affect their performance. However, recall that while the number of relevant dimensions on the *problem* board varied, in order to select the correct answer from the *answer* board children had to consider all four dimensions (see Chapter 2, p. 41). Thus, though the authors reported that varying the number of relevant dimensions on the problem board did not affect children's performance (see Siegler & Svetina, 2002, p. 803), this could be due to the fact children always had to consider all four dimensions when selecting an answer. So, it is not clear that there was a clear comparison of the number of dimensions being coordinated.

We do have some preliminary evidence suggesting that the number of dimensions being coordinated affects children's performance. Recall that in a previous study I made some changes to Siegler and Svetina's (2002) matrix completion task. In my Preschool Matrix Completion Task (Podjarny et al., in preparation) only two dimensions (shape and colour) were ever relevant (that is, all the stimuli were of the same size and oriented the same way). The 4- and 5-year-olds in my previous study did perform better than the 6-year-olds in Siegler and Svetina's sample. However, as I mentioned before, I made other modifications to the task so the reason for the improved performance is yet to be determined. Thus, we have no studies directly comparing children's ability to coordinate two as compared to three (or more) dimensions simultaneously.

There is, however, reason to believe that the number of dimensions that children are required to consider can, in fact, impact their performance. For example, according to Relational Complexity Theory (Halford et al., 1998) tasks can be described in terms of their complexity, as defined by the number of dimensions that must be processed in parallel.[23] Halford et al. (1998) argued that the number of dimensions that children can process in parallel (namely, hold in their working memory) increases continuously throughout development. On their account, children's difficulties with cognitive flexibility tasks arise from having to process several dimensions simultaneously. Thus, increasing the number of dimensions to be coordinated should result in an ordered pattern of performance—children should find it more difficult to coordinate three dimensions as compared with coordinating two dimensions, more difficult to coordinate four dimensions as compared with coordinating three dimensions, and so on. This prediction seems to make sense intuitively—considering more dimensions should be more difficult. This prediction is consistent with previous findings that children could sort trivalent cards along one dimension, and then another, but found sorting stimuli along a third dimension difficult (Deák & Wiseheart, 2015; Smidts et al., 2004).

An extension of the Attentional Inertia Account, in contrast, should result in a different prediction. On this account, the difficulty children experience when attempting to solve a cognitive flexibility task is not to see the stimulus in a different way; their difficulty is with ceasing to see it in the first way. That is, children's difficulties on

[23] Note that Halford's (1980; Halford et al., 1998) concept of *parallel processing* has to do with working memory rather than cognitive flexibility. He refers to the ability to keep several dimensions in mind in order to coordinate them as being able to process these dimensions in *parallel*. However, on Halford's account, the requirement in consecutive cognitive flexibility tasks such as the Dimensional Change Card Sort is also to process several dimensions in parallel (see, e.g., Halford, Bunch, & McCredden, 2007). Thus, Halford does not distinguish between considering two dimensions consecutively and coordinating them simultaneously.

cognitive flexibility tasks are a result of their inability to disengage from a given dimension. Note that the Attentional Inertia Account was created to explain children's difficulties on the Dimensional Change Card Sort, and does not explicitly refer to coordinating more than two dimensions (see, e.g., Diamond, 2006, 2012). However, extrapolating from their claims, the Attentional Inertia Account should predict that once the child has mastered the ability to disengage from a no-longer relevant dimension, they should be able to do so repeatedly, regardless of the number of new dimensions (i.e., number of switches). That is, the prediction would be that children would find considering a third dimension of a stimulus equally difficult as considering a second dimension as the skill required is a constant one (i.e., disengage from the no-longer relevant dimension). While this notion seems to be in conflict with the findings from Smidts et al. (2004), recall that there was merit to the Attentional Inertia Account for 3-year-olds, but less so for 4-year-olds (see discussion in Chapter 2, p. 33). Similarly, it may be that for 3-year-olds considering a third dimension is as difficult as considering a second dimension, whereas for 4-year-olds (or older children), performance begins to show the ordered pattern predicted by Halford et al. (1998). We do not know, however, whether 3- and 4-year-olds show a graded pattern of performance because no work to date has reported this age group's ability to consider more than two dimensions.

The Cognitive Complexity and Control Theory (Revised) aligns closely with Halford et al.'s (1998) account in terms of predicting children's ability to coordinate more than two dimensions. This theory lends itself to predicting a graded pattern of performance. That is, based on the notion that children's difficulties on consecutive cognitive flexibility tasks, such as the Dimensional Change Card Sort arise from their inability to represent a hierarchical (embedded) rule structure, it could be extended to predict that representing a 3-level rule structure would be more difficult than representing a 2-level rule structure. Therefore, we should expect to see a developmental pattern in which children gradually become able to consider increasingly complex rule structures—that is, they should gradually become able to consider two dimensions, and then three, four, and so on. Note, however, that as with the Attentional Inertia Account, this aspect of children's consecutive cognitive flexibility performance has not been explicitly addressed by the proponents of the theory. While Halford et al.'s (1998) account differs from the Cognitive Complexity and Control Theory in other details (see, e.g., Halford et al., 2007), for the purposes of explaining children's ability to coordinate more than two dimensions the two accounts make similar predictions.

In summary, we know very little about preschoolers' ability to coordinate more than two dimensions in cognitive flexibility tasks. Examining children's ability to coordinate three, relative to two, dimensions would provide us with evidence as to the nature of children's difficulties with cognitive flexibility tasks (i.e., provide some indication of which theory may better fit the data). However, very little is known about this aspect of children's cognitive flexibility development, either consecutively or concurrently.

Both factors reviewed thus far—namely, inductive vs. deductive tasks and the number of dimensions being coordinated— are likely to affect preschoolers' performance on consecutive cognitive flexibility tasks. However, because so little research was done on concurrent cognitive flexibility development in preschoolers, there is limited information on how these factors might affect children's performance on concurrent cognitive flexibility tasks. Moreover, as I noted in my review, even our information on the relations between these factors in the context of consecutive cognitive flexibility is very limited. While the Structural Equation Modeling analysis I conducted did not provide me with decisive results, my data can still be used to explore the nature of the relation between the type of cognitive flexibility (consecutive vs. concurrent), and task characteristics such as abstraction demands and the number of dimensions being coordinated. Examining the way in which the two factors reviewed affect children's performance on consecutive and concurrent cognitive flexibility would provide us with a direction for future research. For instance, if the effects of the two factors for both consecutive and concurrent cognitive flexibility tasks are similar, it would suggest that the same underlying process is responsible for children's performance on both types of cognitive flexibility tasks. If, however, the two factors differentially affect performance, we would have evidence to suggest that investigating these two processes separately would provide us with evidence to suggest that consecutive and concurrent cognitive flexibility do not fully share the same underlying skills.

The Current Work: Exploratory Analysis

Even though the study was not originally designed to do so, the tasks used in Study 1 allowed me to begin to examine the effects of both factors discussed above, both with consecutive and concurrent cognitive flexibility. Specifically, I had both inductive and deductive tasks included, measuring both consecutive and concurrent cognitive flexibility. Similarly, I had two tasks that allowed me to compare children's ability to consider two and three dimensions, one measuring consecutive and the other measuring concurrent cognitive flexibility (see Table 4.1).

Although I chose my cognitive flexibility tasks to vary along these two factors, this was not the original purpose of Study 1. Therefore, three points must be kept in mind as I describe the exploratory analyses. First, the tasks did not completely cross all three factors (see Table 4.2). That is, I did not have tasks to cover all possible combinations of type of cognitive flexibility, inductive demands, and number of dimensions. For example, I did not have an inductive task to measure children's ability to coordinate three dimensions concurrently. Therefore, a straightforward three-way ANOVA, for instance, was not an appropriate analysis.

Table 4.2

Factors Examined in Exploratory Analysis And The Tasks Used to Measure Them

		2-Dimensions	3-Dimensions
Consecutive	Inductive	Flexible Item Selection Task; Modified Object Classification Task for Children (inductive, 2-dimensions score)	Modified Object Classification Task for Children (inductive, 3-dimensions score)
	Deductive	Dimensional Change Card Sort; Modified Object Classification Task for Children (deductive, 2-dimensions score)	Modified Object Classification Task for Children (deductive, 3-dimensions score)
Concurrent	Inductive	Matrix Sort Task	N/A
	Deductive	Preschool Matrix Completion Task; Multidimensional Card Selection Task (2-dimensions score)	Multidimensional Card Selection Task (3-dimensions score)

The second point to keep in mind is that the analysis is exploratory, and should be taken as such. Given that we know relatively little about concurrent cognitive flexibility development during the preschool years, it is appropriate to take advantage of the data in order to generate hypotheses to be tested empirically in future work. Any conclusions arrived at from the following analyses are therefore first steps in fine-tuning a more comprehensive theory of cognitive flexibility development which takes into account concurrent cognitive flexibility—in addition to consecutive cognitive flexibility—development.

Finally, it is important to note that because my study was not designed to examine the effects of abstraction demands and the number of dimensions being considered, the comparison was done across tasks. That is, when comparing consecutive inductive and deductive tasks, for instance, I had different tasks: the Flexible Item Selection Task was an inductive task, and the Dimensional Change Card Sort was a deductive task; the Modified Object Classification Task for Children had both a deductive and an inductive score, but because the scores were dependent I could not perform a direct comparison (see below for a discussion). Thus, while my exploratory investigation would provide us with a starting point, a more careful examination of the effects of the factors I reviewed would still be warranted.

Results

I first describe the comparisons I made between children's performance on consecutive vs. concurrent cognitive flexibility, and then inductive vs. deductive tasks (collapsed across type of cognitive flexibility). Then, I describe an interaction between these two factors. I then turn to describing the comparisons I made between considering

2 and 3 dimensions, both concurrently and consecutively, and how the number of dimensions being considered relates to the type of cognitive flexibility. I could not test for a possible 3-way interaction (i.e., an interaction between type of cognitive flexibility, type of task, and number of dimensions), because as noted above, I did not have tasks for all of the possible combination of the three factors.

In order to compare performance across the tasks, I used a pass/fail criterion for each task (see Methods section in Chapter 3). These pass/fail scores took into consideration the chance levels for each task, as each task had different chance levels. Criteria for each task are presented in Table 4.3, with frequency of passers summarized in Table 4.4. Whenever possible, however, I used the most information I could. So, for example, when comparing between children's ability to consider two and three dimensions within a task, I did not use the pass/fail score (see below). In those circumstances I used the support score for each sort (i.e., Sort2 and Sort3) the Modified Object Classification Task for Children and the total number of correct trials for each phase of the Multidimensional Card Selection Task (i.e., phases 2 and 3). I used these scores because they were more continuous than pass/fail, and I was able to use them because the chance levels were identical.

I made 20 comparisons in total (see below). When making multiple comparisons, we run the risk of finding significant findings by chance alone (see Field, 2013, for a discussion). Therefore, in order to control for the inflated chance of finding a significant finding by chance, I used a conservative Bonferroni's alpha of .05/20 = .0025. For each factor, I used a proportion of the number of appropriate tasks the child passed. For instance, to create each child's consecutive cognitive flexibility score I used the number of tasks passed out of the 3 tasks measuring consecutive cognitive flexibility (i.e., the Dimensional Change Card Sort, the Flexible Item Selection Task, and the Modified Object Classification Task for Children), divided by 3. This was done to facilitate comparisons between the different tests, as for the 2-way interaction scores I had to use proportions of tasks passed (because there was a different number of tasks in each group of tasks; e.g., I had two concurrent deductive tasks, but only one concurrent inductive task). I used tests appropriate for the nonparametric nature of these scores (see below).

Table 4.3

Performance Criteria for Cognitive Flexibility Tasks

Task	Number of Test Trials	Probability of Correct Answer per trial**	Minimum Trials Correct to Pass	Probability*
Dimensional Change Card Sort	8	.50	7	.03
Modified Flexible Item Selection Task	8	.22	5	.01
MOCTC (inductive sorts)	3	.22	3	.01
Preschool Matrix Completion Task	5	.17	3	.04
Matrix Sort Task	3	.33	3	.03
Multidimensional Card Selection Task	3	.20	3	.007

Note. MOCTC = Modified Object Classification Task for Children.
* Probability of solving the required number of trials to pass, based on the binomial distribution.
** See Methodology section, Chapter 3

Table 4.4

Number (and Percentage) of Children Performing Above Chance Levels On Cognitive Flexibility Tasks

Task	Full Sample (N = 121)	3-Year-Olds (N = 59)	4-Year-Olds (N = 62)
Flexible Item Selection Task	83 (68.6)	38 (64.4)	45 (72.6)
DCCS	85 (70.2)	40 (67.8)	45 (72.6)
MOCTC – Abstraction Inductive	81 (66.9)	39 (66.1)	42 (67.7)
MOCTC – Abstraction Deductive	111 (91.7)	54 (91.5)	57 (91.9)
MOCTC – Sort 2 Inductive	18 (14.9)	3 (5.1)	15 (24.2)
MOCTC – Sort 2 Deductive	106 (87.6)	52 (88.1)	54 (87.1)
MOCTC – Sort 3 Inductive	8 (6.6)	2 (3.4)	6 (9.7)
MOCTC – Sort 3 Deductive	105 (86.8)	51 (86.4)	54 (87.1)
MCS – 1 Dimension	79 (65.3)	34 (57.6)	45 (72.6)
MCS – 2 Dimensions	55 (45.5)	16 (27.1)	39 (62.9)
MCS – 3 Dimensions	49 (40.5)	18 (30.5)	31 (50.0)
Matrix Sort	59 (49.2)	18 (30.5)	41 (66.1)
Matrix Completion	19 (15.7)	5 (8.5)	14 (22.6)

Note. Percentages were calculated on the entire sample, with missing values considered as a “fail”. FIST = Flexible Item Selection Task; DCCS = Dimensional Change Card Sort; MOCTC = Modified Object Classification Task for Children; MCS = Multidimensional Card Selection Task.

Consecutive and Concurrent Cognitive Flexibility

In order to make direct comparisons across children’s consecutive and concurrent cognitive flexibility performance, I had to select measures in which the other two factors were matched (i.e., abstraction tasks and number of dimensions being coordinated). As there was no 3-dimension version of an inductive concurrent task, I could only use the 2-dimensional score for each task, holding the number of dimensions being considered constant at 2. That is, for both the Modified Object Classification Task for Children and the Multidimensional Card Selection Task, I only used the score for the second level or phase, respectively, which reflected children's ability to consider two dimensions. Moreover, in order to match the particular combination of inductive and deductive tasks for each cognitive flexibility type, I used two deductive and one inductive task for each consecutive and concurrent cognitive flexibility score. The scores are summarized in Table 4.5.

Note that the scale of the scores in Table 4.5 is ordinal. Moreover, they reflect a 'true order', as succeeding in three tasks, for instance, is better performance than succeeding on two. While there has been a debate in the literature regarding what the appropriate central tendency index to use (i.e., mean or median), many researchers find the means of ordinal variables more meaningful than the median (see, e.g., Agresti, 1989, for a discussion). I therefore report the means for these scores, along with using non-parametric tests. A Wilcoxon's Z was used to test within-subjects effects (e.g., compare between children's consecutive and concurrent cognitive flexibility score), and a Mann-Whitney's U was used to test between groups effects (e.g., compare the performance of 3- and 4-year-olds). In all analyses, I report the exact p-value unless otherwise specified (see Field, 2013, for more details).

For the *consecutive cognitive flexibility score*, I summed the number of 'passes' each child earned, across the Dimensional Change Card Sort, Modified Flexible Item Selection Task, and the deductive score of the second sort of the Modified Object Classification Task for Children, divided by 3 to create a proportion score (as there were 3 tasks). For the *concurrent cognitive flexibility score*, I summed pass scores across the Preschool Matrix Completion Task, the Matrix Sort Task, and the score for the second level of the Multidimensional Card Selection Task (i.e., the part of the task requiring coordination of two dimensions), again dividing by 3 to create a proportion score.

Table 4.5

Proportion Of Tasks Passed For Factors and Interactions

Score	Mean (SE)		
	Full Sample	3-Year-Olds	4-Year-Olds
Consecutive	.77 (.02)	.75 (.03)	.78 (.04)
Concurrent	.37 (.03)	.23 (.03)	.52 (.04)
Inductive	.45 (.03)	.34 (.03)	.56 (.04)
Deductive	.45 (.03)	.35 (.03)	.53 (.04)
Consecutive Inductive	.44 (.03)	.37 (.04)	.50 (.04)
Consecutive Deductive	.70 (.04)	.68 (.06)	.72 (.06)
Concurrent Inductive	.49 (.04)	.30 (.06)	.67 (.06)
Concurrent Deductive	.31 (.03)	.19 (.04)	.43 (.04)

Generally, children passed significantly more often on consecutive cognitive flexibility tasks than they did on concurrent cognitive flexibility tasks, *Wilcoxon's Z* = 8.10, $p < .001$ (see Table 4.5). This pattern was consistent for both age groups, both *ps* < .001. Comparing the two age groups, there was no difference between 3-year-olds' and 4-year-olds' performance on consecutive cognitive flexibility performance, $U = 1675.5$, $p = .393$ (see Figure 4.1). There was, however, an effect of age for concurrent cognitive flexibility performance, with 4-year-olds performing better than 3-year-olds, *Mann-Whitney's* $U = 884.0$, $p < .001$. This pattern suggests an improvement in concurrent—but not consecutive—cognitive flexibility skills between the ages of 3- and 4-years in the current sample.

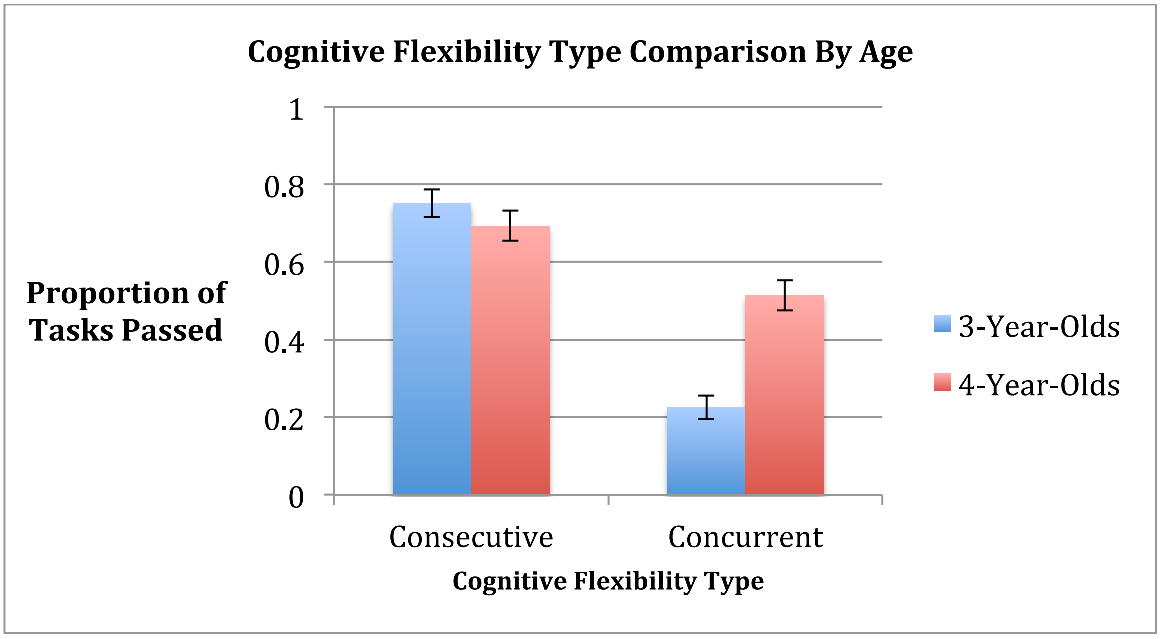


Figure 4.1 Comparison of Cognitive Flexibility Type Performance By Age. Error bars indicate standard errors.

Inductive and Deductive Tasks

In order to compare children's performance on inductive and deductive tasks, I examined the proportion passed for each type of task. As noted before, I only used the scores that reflected performance using two dimensions, and I only used the inductive score for the Modified Object Classification Task for Children in order to match the number of inductive and deductive tasks.

To calculate each child's *Inductive Score*, I summed the number of tasks passed across the Modified Flexible Item Selection Task, the inductive score from the Modified Object Classification Task for Children, and the Matrix Sort Task, divided by 3. For the *Deductive Score*, I summed the number of tasks passed across the Dimensional Change Card Sort, the Preschool Matrix Completion Task, and the Multidimensional Card Selection Task, again divided by 3. Overall, children performed similarly on both types of tasks, *Wilcoxon's* $Z = 0.05$, $p = .95$. This finding held when comparing within the age groups, both *ps* > .63 (see Figure 4.2). This finding was in contrast to Jacques and Zelazo's (2005) review that found that children generally succeed on deductive tasks about a year before they succeed on inductive tasks. However, there was an effect of age, with four-year-olds performing better than 3-year-olds on both deductive and inductive tasks, *Mann-Whitney's* $U = 1246.0$ and 1079.0, respectively, both *ps* < .002.

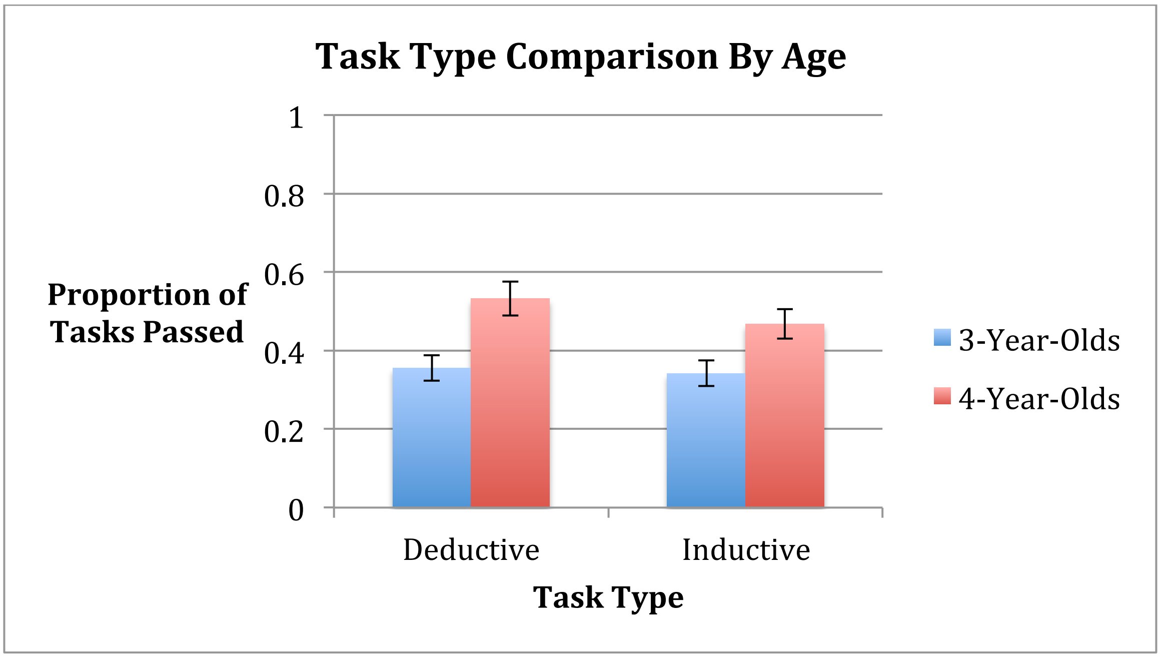


Figure 4.2 Comparison of Task Type By Age. Error bars indicate standard errors.

Task Type By Cognitive Flexibility Type Interaction

The finding that children did not perform better on inductive tasks as compared with deductive tasks was surprising, considering that Jacques and Zelazo's

(2005) review included over 40 tasks and found a fairly robust effect. I therefore examined the interaction between task type (inductive vs. deductive) and cognitive flexibility type (consecutive vs. concurrent). To do so, I calculated for each combination of the factors a score that comprised the proportion of tasks passed (i.e., above chance performance). I held the number of dimensions being considered constant, taking only scores for considering 2 dimensions (see Table 4.2, right-hand column), and calculated a score for each cell (i.e., consecutive inductive, consecutive deductive, concurrent inductive, and concurrent deductive).

There was an interaction between type of cognitive flexibility and task type (see Figure 4.3). For consecutive cognitive flexibility tasks, I found the pattern documented in the literature: children found inductive tasks more difficult than deductive tasks. This pattern was significant both for the entire sample, *Wilcoxon's* $Z = 4.99$, $p < .001$, as well as for each age group separately, both *ps* $< .002$. In contrast, for concurrent cognitive flexibility, I found the *reverse* pattern: children found inductive tasks easier than deductive tasks. This pattern was significant for the full sample, *Wilcoxon's* $Z = 3.57$, $p < .001$, as well as for the 4-year-olds, *Wilcoxon's* $Z = 3.15$, $p = .001$. However, the comparison did not quite reach significance for the 3-year-olds, *Wilcoxon's* $Z = 1.91$, $p = .05$. The younger children, however, displayed a pattern that was in the same direction: their inductive score was slightly higher than their deductive score.

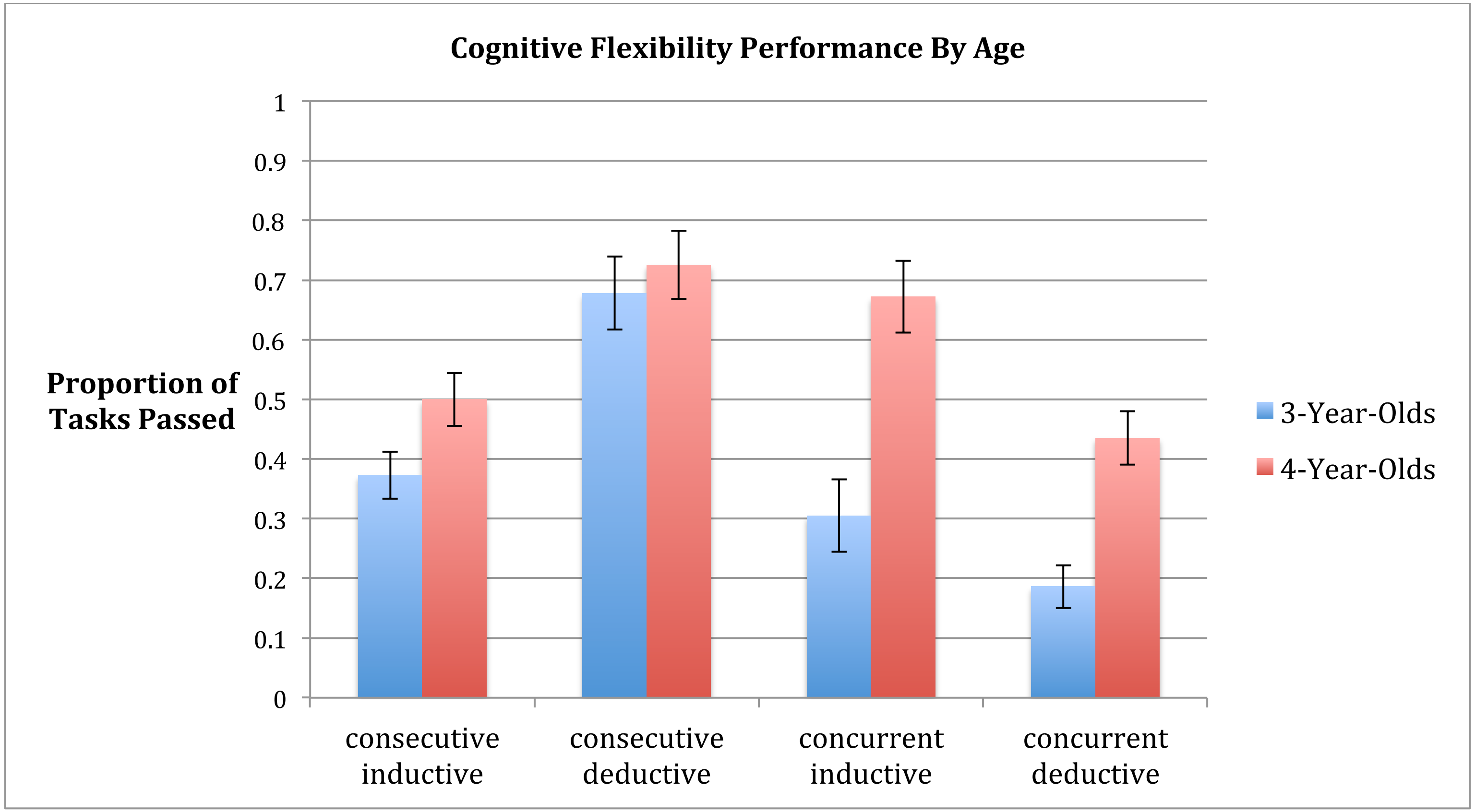


Figure 4.3 Cognitive Flexibility Type By Task Type Interaction. Figure plots mean proportion of tasks passed by cognitive flexibility type, task type, and age. Error bars represent standard errors.

Number of Dimensions

In order to examine children's ability to consider two versus three dimensions, I compared their performance on two tasks: the Modified Object Classification Task for Children, and the Multidimensional Card Selection Task. These were the only two tasks that included a measure of children's ability to consider both two and three dimensions and, therefore, allowed for a direct comparison of the number of dimensions to be considered. Note that, as one of these tasks measures consecutive cognitive flexibility and the other measures concurrent cognitive flexibility, I was also able to compare them in order to examine the relation between cognitive flexibility type and number of dimensions being considered. However, I compared the deductive score on the Modified Object Classification Task for Children to children's score on the Multidimensional Card Selection Task, which was a deductive task, so as to compare two deductive scores (i.e., to hold this factor constant). In light of the interaction pattern described above, this comparison should be interpreted with caution. I turn first to describing children's ability to consider 2 vs. 3 dimensions in each task.

For the Modified Object Classification Task for Children, performance on the inductive sort was at floor (14.9% and 6.6% of the sample were able to consider two and three dimensions, respectively), whereas performance on the deductive sort was at ceiling (recall that children received automatic credit for the Instructed Sort level if they succeeded on earlier levels; 87.6% and 86.8% of the sample received credit for the deductive score for 2 and 3 dimensions, respectively). For this reason, as well as to maximize the information I had available, I decided to compare the support score on the two cognitive flexibility sorts (i.e., Sort2 and Sort3) for this task. The support scores, which indicated the level of deductive support the child needed to succeed on

Sort2 and Sort3, were more continuous and had higher variability. I therefore preferred to use these scores when comparing children's ability to consider two and three dimensions consecutively. Recall that children received higher support scores for requiring less support; more specifically, they received 3 points for passing the Category Generation level, 2 points for Category Identification, and one point for Instructed Sort (for details on the different support levels, see Chapter 3, p. 68). The distribution of the support scores for Sort2 and Sort3 is presented in Figure 4.4.

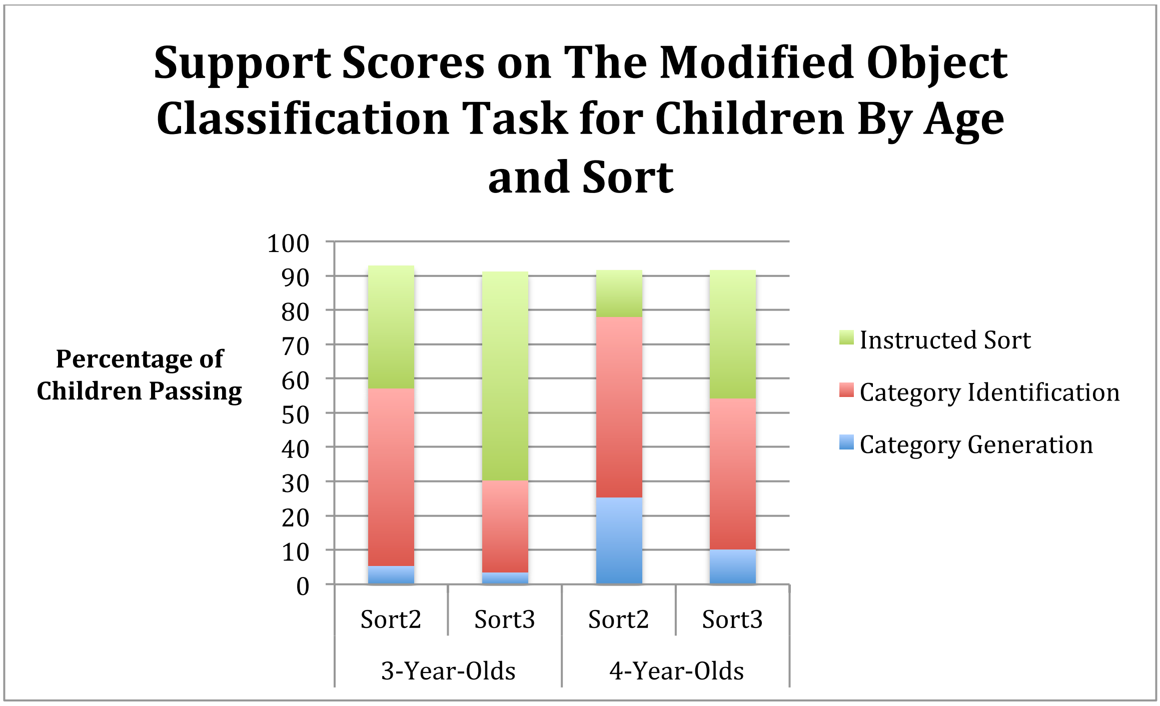


Figure 4.4 Distribution of support scores for the Modified Object Classification Task for Children by age and sort.

To compare children's ability to consider 2 and 3 dimensions, I compared the mean support score for Sort2 with Sort3.[24] Overall, children found Sort3 (M = 1.41, SD = 0.75) more difficult than Sort2 (M = 1.75, SD = 0.81), *Wilcoxon's Z* = 5.00, p <

[24] It is appropriate to treat the support scores as ordinal variables because they reflect a true order (with higher scores corresponding to less support, and so better performance). Therefore, as mentioned before, I decided to use means for these variables (see, e.g., Argesti, 1989, for discussion).

.001. This pattern was driven by the 4-year-olds, who did significantly better on Sort2 (M = 1.95, SD = 0.86) than on Sort3 (M = 1.56, SD = 0.79), Z = 4.13, p < .001. The 3-year-olds, however, did only marginally better on Sort2 (M = 1.55, SD = 0.71) as compared to Sort3 (M = 1.25, SD = 0.67), Z = 2.96, p = .004. Consistent with this finding, 4-year-olds outperformed 3-year-olds on Sort2, *Mann-Whitney's* U = 1171.0, p = .003, but not Sort3, U = 1268.5, p = .02 (see Figure 4.5).

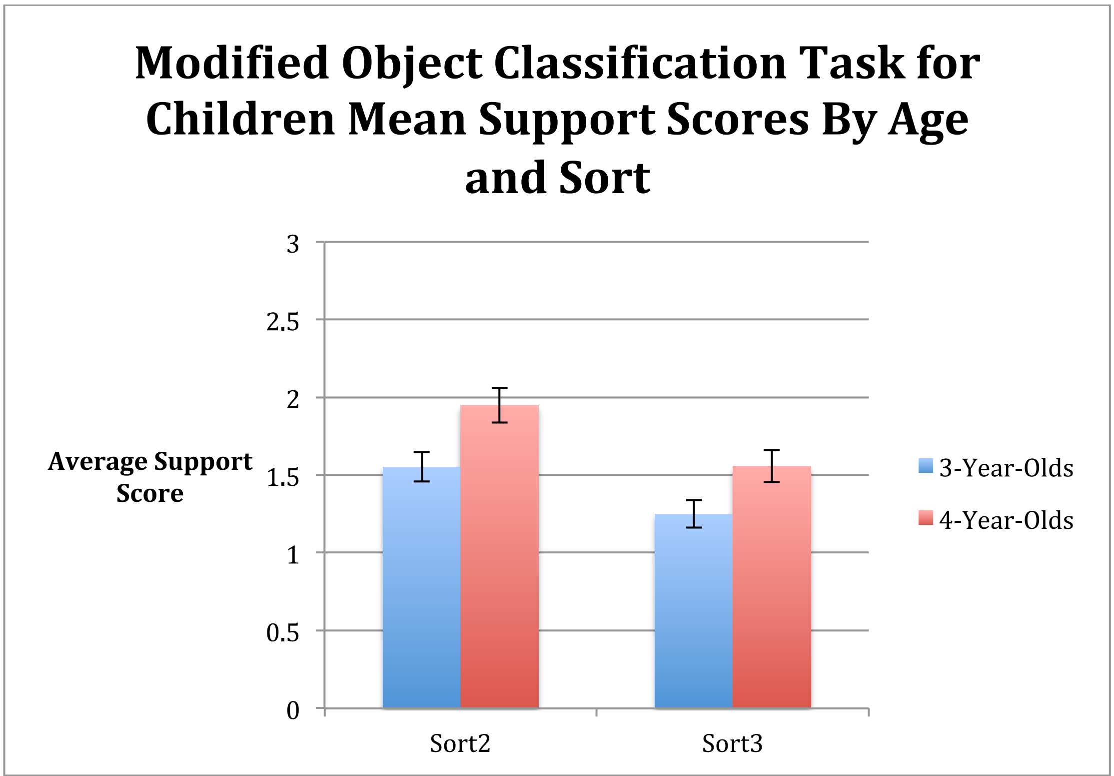


Figure 4.5 Modified Object Classification Task for Children Support Scores By Age and Sort. Error bars indicate standard errors.

To examine performance on the Multidimensional Card Selection Task, I used a Wilcoxon Rank Test to compare the number of trials children solved correctly when coordinating 2 dimensions (e.g., "give Ben all the yellow triangles") and the number of trials they solved correctly when coordinating 3 dimensions (e.g., "give Grace all the small red circles"). All results are reported with exact p-values. I used a Mann-

Whitney test of association to examine the difference in the likelihood of coordinating 2 and 3 dimensions across the two age groups. I again use the means when reporting descriptive stats and in the graph, for the same reasons discussed before.

A Wilcoxon test showed that children were equally likely to coordinate 2 dimensions as 3 dimensions (see Table 4.4), $Z = 2.49$, $p = .01$. This was true both for 3-year-olds, $Z = 1.13$, $p = .31$, and for 4-year-olds, $Z = 2.39$, $p = .02$. Four-year-olds were more likely than 3-year-olds to coordinate 2 dimensions, $U = 1112.5$, $p = .002$. However, there was no difference between 3- and 4-year-olds in terms of their likelihood to coordinate 3 dimensions, $U = 1308.0$, $p = .06$ (see Figure 4.6). This was due to 4-year-olds' slightly decreased performance when coordinating three dimensions.

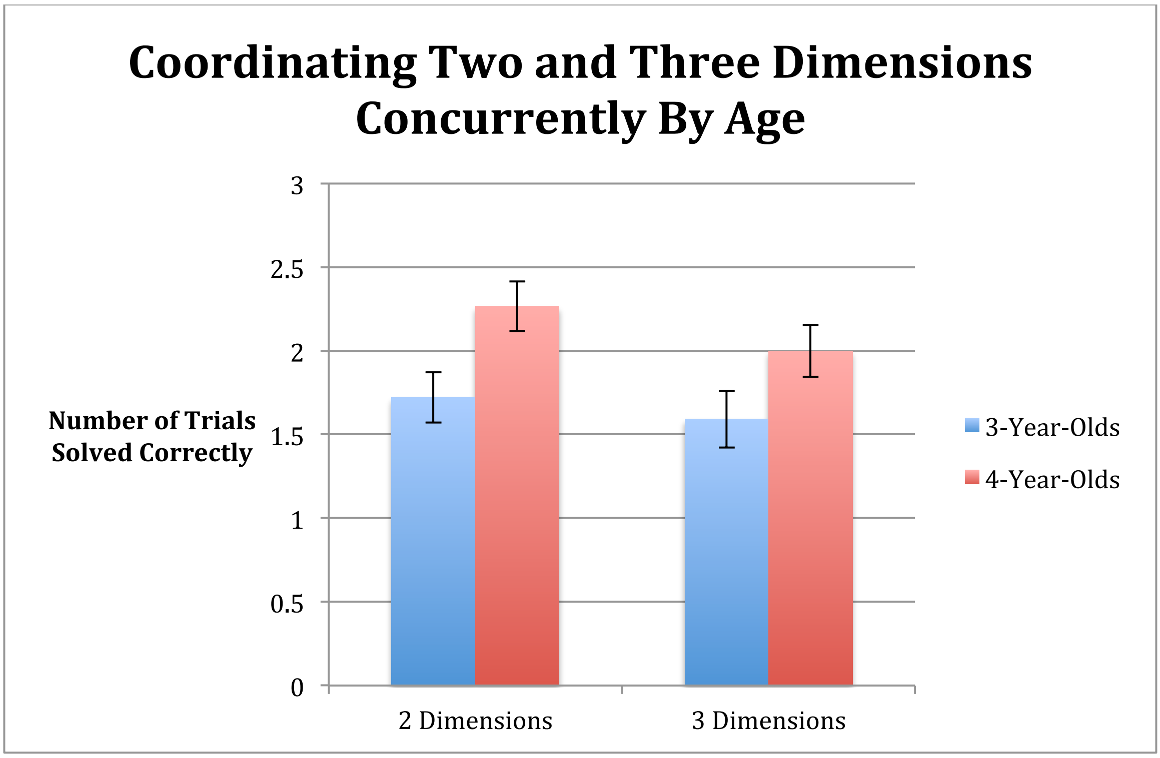


Figure 4.6 Coordinating 2 and 3 dimensions concurrently by age. Error bars indicate Standard Errors.

Interaction between Cognitive Flexibility Type and Number of Dimensions. In order to examine whether children found considering two and three dimensions equally challenging in consecutive and concurrent cognitive flexibility tasks, I compared performance on the Modified Object Classification Task for Children and the Multidimensional Card Selection Task. Because both require children to coordinate two, and then three dimensions (within a stimuli-set), they allowed for a direct comparison. The proportion of children passing each level or sort at each age group was compared. Note that I used the deductive score of the Modified Object Classification Task for Children so that the abstraction demands would remain constant in this comparison. Table 4.6 presents crosstabs for each level or sort for each age group.

Overall, children were better at considering 2 dimensions consecutively than concurrently, *McNemar* χ^2 (1) = 41.49, $p < .001$. Similarly, children were more likely to consider 3 dimensions consecutively than concurrently, χ^2 (1) = 50.16, $p < .001$. This was true for each age group separately, all *ps* < .001 (see Figure 4.7).

The more interesting comparison, however, is between the differences between considering 2 and 3 dimensions consecutively and concurrently. I could not make a statistical comparison, but could make a descriptive one. Table 4.7 summarizes these comparisons. For concurrent cognitive flexibility, children showed no difference in performance between coordinating 2 and 3 dimensions. Similarly, the 3-year-olds found considering a stimulus along a second dimension as difficult as they found considering the stimulus along a third dimension. In contrast, the 4-year-olds found considering 2 dimensions consecutively easier than considering 3 dimensions consecutively.

Table 4.6

Contingency Table For Consecutively and Concurrently Coordinating Two and Three Dimensions

	Consecutive/ Concurrent	Pass	Fail	Total
		3-Year-Olds		
2 Dimensions	Pass	15 (28.8)	1 (1.9)	16 (30.8)
	Fail	33 (63.5)	3 (5.8)	36 (69.2)
	Total	48 (92.3)	4 (7.7)	52 (100)
3 Dimensions	Pass	16 (30.8)	1 (1.9)	17 (58.9)
	Fail	31 (59.6)	4 (7.7)	35 (41.1)
	Total	47 (90.4)	5 (9.6)	52 (100)
		4-Year-Olds		
2 Dimensions	Pass	37 (69.8)	1 (1.7)	38 (65.5)
	Fail	16 (27.6)	4 (6.9)	20 (34.5)
	Total	53 (91.4)	5 (8.6)	59 (100)
3 Dimensions	Pass	29 (50.9)	0 (0)	29 (50.9)
	Fail	24 (42.1)	4 (7.0)	28 (49.1)
	Total	53 (93.0)	4 (7.0)	57 (100)

Note. Missing values were excluded pair-wise. Percentages calculated out of total sample (per age group).

Table 4.7

Summary of Number of Dimensions Effects

	2 Dimensions Vs. 3 Dimensions	
	Consecutive	Concurrent
3-Year-Olds	2 = 3	2 = 3
4-YearOlds	2 > 3	2 = 3

Note. The '=' sign indicates that children's ability to consider 2 and 3 dimensions was equal; the '>' sign indicates that children's ability to consider 2 dimensions was better than their ability to consider 3 dimensions.

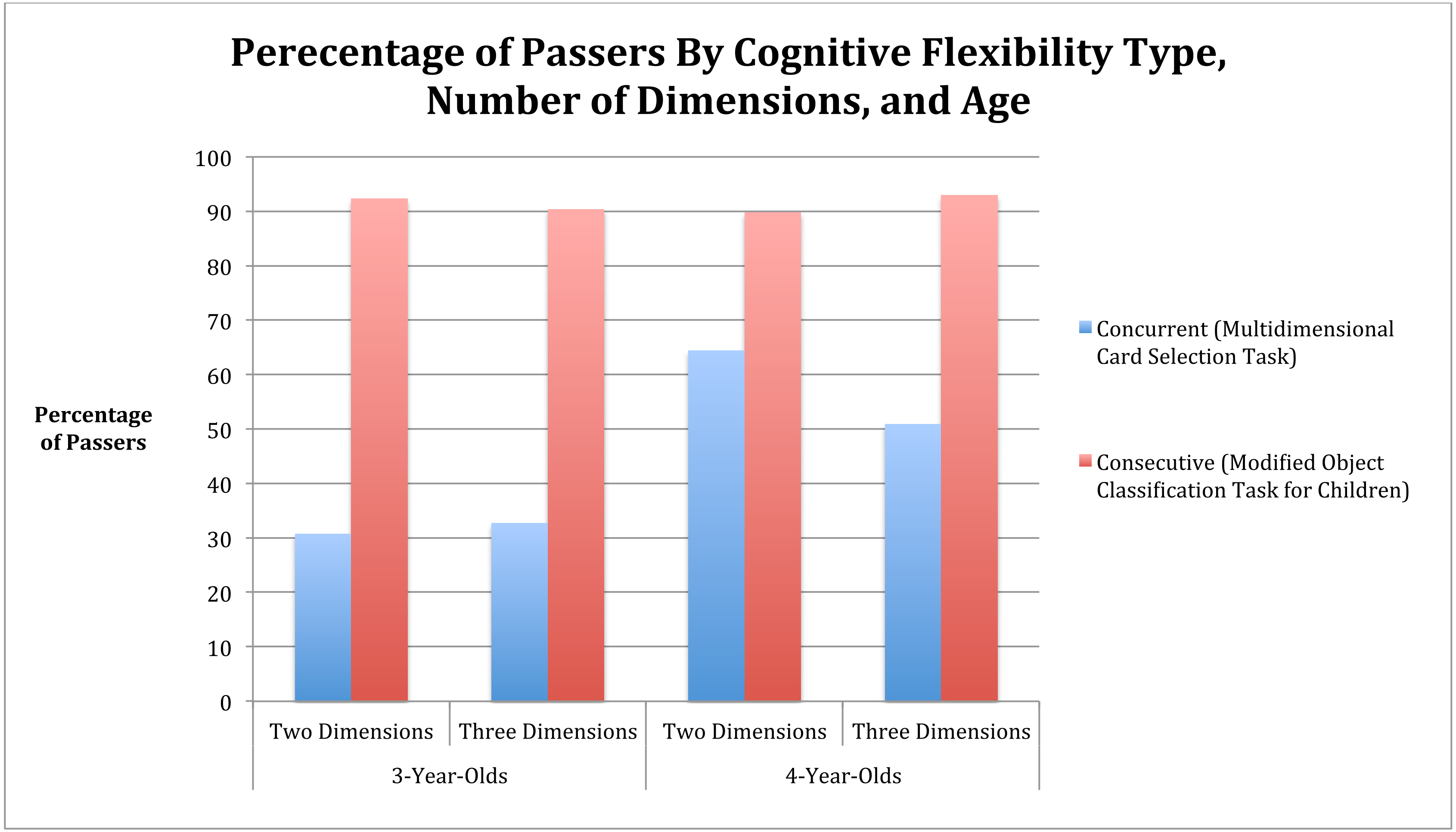


Figure 4.7 Cognitive Flexibility Type By Number of Dimensions Interaction.

Discussion

The original goal of Study 1 was to demonstrate a structural separation between consecutive and concurrent cognitive flexibility in preschoolers, however, this was not supported by the structural analysis. I therefore undertook an exploratory analysis in order to make use of the data to inform us about the development of concurrent cognitive flexibility vis-à-vis the development of consecutive cognitive flexibility during the preschool years examining the effects of two factors (inductive vs. deductive, and 2 versus 3 dimensions to be considered). While the findings from the Structural Equation Modeling I conducted showed that consecutive and concurrent cognitive flexibility skills are highly related, the findings from the exploratory analysis reported in this chapter suggest that consecutive and concurrent cognitive flexibility show different performance patterns. Thus, examining both of these skills has merit. I will outline these findings and discuss each in turn before turning to discuss how this study can inform future research.

Age-Related Trends

The first interesting finding was that while there was no difference between 3- and 4-year-olds' performance on consecutive cognitive flexibility tasks, 4-year-olds outperformed 3-year-olds on concurrent cognitive flexibility tasks. The findings that 3- and 4-year-olds perform equally well on my measures of consecutive cognitive flexibility is inconsistent with some previous works that found that typically 3-year-olds fail consecutive cognitive flexibility tasks much more frequently than 4-year-olds (e.g., Jacques & Zelazo, 2001; Zelazo, 2006). However, there are some other studies that report no age difference between 3- and 4-year-olds' performance (e.g, Smidts et al., 2004, pp. 394-396). The 3-year-olds in my sample, as I mentioned in Chapter 3, performed fairly well on both the Dimensional Change Card Sort and the Flexible Item Selection Task, with 70% and 64% passing, respectively.

One possible explanation to the 3-year-olds' better performance is a learning effect. It is possible that seeing several cognitive flexibility tasks affected performance on tasks that were seen later in the battery (e.g., Carlson & Moses, 2001). The Dimensional Change Card Sort was the 6th cognitive flexibility task the children saw, so there may have been a learning effect explaining their better-than-usual performance. Nevertheless, the Flexible Item Selection Task was the first task this sample saw (preceded only by the screener), so the explanation of a learning effect does not extend to performance on this task.

Another possible explanation is that the 3-year-olds in my sample were particularly skilled at cognitive flexibility. I cannot rule out this explanation based on the data I collected. Moreover, while no demographic data was collected for Study 1, the city in which the data was collected has relatively high education levels (e.g., 68.4% of adults hold a postsecondary certificate, as compared with the national average of 59.6%; Statistics Canada, 2011), and a relatively high annual income (35.6% of adults have an annual income of $51K and over, as compared with only 25% nationally; Statistics Canada, 2011). These two indicators are important components of socioeconomic status. Because socioeconomic status relates to cognitive functions in general, including cognitive flexibility (e.g., Sarsour, Sheridan, Jutte, Nuru-Jeter, Hinshaw, & Boyce, 2011), it is possible that if children in Ottawa enjoy a higher-than-average socioeconomic status, they may exhibit higher-than-average cognitive function in general. The data I have does not allow me to test this explanation because no demographic data was collected. However, I did collect children's receptive vocabulary and nonverbal IQ scores on standardized tests (the

Peabody Picture Vocabulary Test and Primary Test of Nonverbal Intelligence, respectively). The children in my sample did not show higher-than-average scores on either of these tests (see Table 3.3, p. 92). Thus, the children in my sample do not seem to be performing generally better than a representative sample; their strengths seemed to be particular to the Dimensional Change Card Sort and the Flexible Item Selection Task.

While it is unclear why the 3-year-olds in my sample exhibited higher levels of consecutive cognitive flexibility than is typically reported, the 4-year-olds in my sample seemed to exhibit performance that is fairly consistent with previous reports (see, e.g., Jacques & Zelazo, 2005; Kirkham et al., 2003; Smidts et al., 2004; Zelazo, 2006). Moreover, comparing the 3-year-olds in my sample to their 4-year-olds peers is still fairly informative. That said, general age trends should not be concluded based on this sample. In other words, it would be inadvisable to conclude that 3-year-olds can consider 2 dimensions consecutively but not concurrently, based on this sample. The data does seem to suggest, however, that children perform better on consecutive cognitive flexibility tasks than on concurrent cognitive flexibility tasks. Future longitudinal studies can pinpoint exactly when each of these skills emerges, and perhaps link it to other underlying capacities. For example, if we follow children from 3- to 6 years of age and measure both consecutive and concurrent cognitive flexibility as well as other Executive Functions and general cognitive skills, we may be able to understand when each skill develops and how earlier-developing skills lay the groundwork for later-developing skills.

The Effects of Inductive/Deductive Tasks

The second interesting finding was the different effect of abstraction task demands on consecutive and concurrent cognitive flexibility tasks. On consecutive tasks, children performed better when the experimenter specified the relevant dimension (by using pictorial and verbal labels) as compared to when they had to abstract these dimensions themselves. This is not surprising, as one would expect that a task requiring both abstraction and flexibility would be more difficult than one requiring only flexibility. In contrast, however, on concurrent tasks children performed *worse* when the experimenter specified the relevant dimension as compared to when they had to abstract these dimensions on their own. As mentioned before, the first part of the interaction is consistent with Jacques and Zelazo's (2005) review of (consecutive) cognitive flexibility tasks; the second is not.

The surprising finding here is that children find concurrent inductive tasks *easier* than concurrent deductive tasks. This finding was particularly surprising because: (a) researchers have consistently found that children perform better on consecutive cognitive flexibility tasks when the relevant dimensions are labeled, as compared to tasks in which the dimensions are not labeled (e.g., Doebel & Zelazo, 2013); and (b) the findings from my previous study in which I modified the inductive Piagetian matrix completion task reported by Siegler and Svetina (2002) to be a deductive one, resulting in higher rate of success (on my Preschool Matrix Completion Task as compared to Siegler & Svetina's, 2002, task) shown by preschoolers (Podjarny et al., in preparation). The latter can be explained fairly easily: I made several modifications to the matrix completion task in order to turn it into my Preschool Matrix Completion Task. It is possible that other modifications (for instance, reducing the number of dimensions to be coordinated from 4 to 2) were responsible for the improved performance for preschoolers.

How, then, can the different effects of abstraction task demands on consecutive and concurrent cognitive flexibility be reconciled? One possible explanation is that when children must disengage from a previously relevant dimension—as they do in a consecutive task—hearing the label of the other, now-relevant, dimension helps them direct their attention to the relevant dimension. However, when these same children must consider two (or more) dimensions at the same time, the consecutive nature of verbal labels might create a focus on a single dimension. Thus, for example, when the experimenter asked children to give a character "all the red circles" (in the Multidimensional Card Selection Task), children tended to focus on either colour or shape, and found it more difficult to coordinate both dimensions, as compared to their ability to coordinate these two dimensions when the experimenter did not label the dimensions (in the Matrix Sort Task). When children were required to induce the dimensions on their own, performance was much better, possibly because their attention was *not* directed to a single dimension.

This explanation is consistent with the Attentional Inertia Account proposed by Kirkham et al. (2003). Recall that this account argues that children perform poorly on (consecutive) cognitive flexibility tasks such as the Dimensional Change Card Sort because of their inability to inhibit attending to the previously relevant dimension. On this account, the beneficial effect of labels on children's performance on consecutive cognitive flexibility tasks stems from labels' attention-directing properties—labels direct children's attention to the now relevant dimension. To extend this explanation to concurrent cognitive flexibility tasks, when children are required to coordinate two dimensions simultaneously, labels' attention-directing properties may cause them to focus on a single dimension.[25] This finding also speaks to the expectation that abstraction must precede flexibility, and more generally to the

[25] As I mentioned in Chapter 2, this theory does not account for concurrent cognitive flexibility performance because it was developed to explain children's performance on consecutive cognitive flexibility tasks (particularly the Dimensional Change Card Sort). However, it can be expanded to include my findings in a fairly straight-forward fashion.

relation between cognitive flexibility and abstraction. It may be that the type of cognitive flexibility the child is required to perform modulates the relation between cognitive flexibility and abstraction.

We already have some preliminary evidence that the relation between abstraction and (consecutive) cognitive flexibility is not as straightforward as one preceding the other. For instance, Jacques and Zelazo (2005) argued that "the effects of labels may change qualitatively between 3 and 4 years of age." (p. 74). They propose that for 3-year-olds, labels served as attention-getting tools—that is, they serve to direct the child's attention to the relevant dimension. In contrast, for 4-year-olds, these authors argue that this explanation is insufficient. Specifically, they refer to an experiment done using the Flexible Item Selection Task, in which the experimenter asked the children to label the dimension of their first selection (e.g., "Why do these pictures go together?"; Jacques & Zelazo, 2005, p. 72). This manipulation improved 4-year-olds' performance on the second selection (Jacques, Zelazo, Lourenco, & Southerland, 2005, as cited in Jacques & Zelazo, 2005). Jacques and Zelazo (2005) argue that the attention-directing properties of labels cannot account for 4-year-olds' improved performance on the second, unlabeled, selection. Thus, as argued by Jacques and Zelazo (2005), the effects of abstraction demands on performance in (consecutive) cognitive flexibility tasks may be qualitatively different depending on the age of the child. It could be that, similarly, the relation between abstraction and cognitive flexibility is qualitatively different depending on the type of cognitive flexibility the child is required to perform.

Another related explanation is related to the nature of the tasks that I used in Study 1. Specifically, in both concurrent deductive tasks (the Multidimensional Card Selection Task and the Preschool Matrix Completion Task) the child was asked to select a certain card from an array of several cards. These cards always included distractors that matched the correct answer on at least one dimension. In contrast, in the Matrix Sort Task (the only inductive concurrent task), children were asked to sort 4 cards onto a grid. In this situation, it is impossible to be distracted by a card that only matches the correct answer on one dimension, as all cards had to go onto the grid and no distractor items were included. Thus, it could be that the presence of the distractor cards affected children's performance on concurrent deductive tasks in this study, thereby making this finding an artefact of the particular measures employed. Future work is needed to test whether the effect was due to methodological characteristics of the task as opposed to a true interaction. For instance, in Study 2 I examined children's performance on inductive and deductive versions of two concurrent cognitive flexibility tasks (the Preschool Matrix Completion Task and the Matrix Sort Task), so the findings reported in Chapter 5 will help to distinguish between these two explanations. In other words, using the findings from Study 2 we will be able to determine whether the finding that children find inductive concurrent cognitive flexibility tasks easier than deductive concurrent cognitive flexibility tasks is due to the methodological characteristics of the tasks.

This interaction between type of task and type of cognitive flexibility may be the first step towards a better understanding of the relation between abstraction and cognitive flexibility processes. As mentioned before, while several researchers see abstraction as necessarily preceding cognitive flexibility (e.g., Bennett & Müller, 2010; Smidts et al., 2004), the consistent empirical finding that children find deductive consecutive cognitive flexibility tasks easier than inductive ones calls this conceptualization into question. My comparison between children's performance on inductive and deductive consecutive and concurrent cognitive flexibility tasks provides a first step in further unpacking the relation between abstraction and cognitive flexibility. It appears that the type of cognitive flexibility the child is required to perform could modulate the relation between abstraction and cognitive flexibility. That said, the children in this study seemed to exhibit fairly high abstraction skills, as many of them (68.6%) were able to solve the Flexible Item Selection Task (in which they have to abstract the relevant dimensions before considering them), their performance on Sort1 of the Modified Object Classification Task for Children was fairly high (66.9% were able to abstract at least one dimension), and almost half of them (49.2%) were able to solve the Matrix Sort Task (in which they had to abstract the relevant dimension). Therefore, a more careful and controlled comparison between children's abstraction and cognitive flexibility skills (both consecutive and concurrent) is warranted. Fortunately, Study 2 had already been designed in a way that allowed me to examine this relation more closely (see Chapter 5).

Number of Dimensions Being Considered

A third interesting finding that emerged from the exploratory analysis was that the effect of the number of dimensions required to be considered interacts with the type of cognitive flexibility the child is required to perform. For consecutive flexibility, 3-year-olds found considering three dimensions as difficult as they found considering two dimensions, while 4-year-olds found considering two dimensions easier than considering three dimensions. For concurrent cognitive flexibility, there was no effect for the number of dimensions that children were required to coordinate, with both 3- and 4-year-olds finding coordinating 3 dimensions no more difficult than they did coordinating 2 dimensions.

Recall that I extended both the Cognitive Complexity and Control Theory (Revised) and the Attentional Inertia Account to make different predictions about children's ability to consider 2 vs. 3 dimensions. I argued that Cognitive Complexity and Control Theory (Revised) should predict that 3 dimensions would be more difficult to consider than 2, but that the Attentional Inertia Account should predict that there would be no effect for the number of dimensions on performance. Because the findings were inconsistent, neither prediction can be supported. It is possible, however, that these findings can be explained using Jacques and Zelazo's (2005) framework. Recall that these authors propose that the relation between abstraction and (consecutive) cognitive flexibility changes qualitatively with age. Similarly, it could be that the relation between the number of dimensions being considered and the type of cognitive flexibility changes with age. Specifically, Jacques and Zelazo (2005) argued that for 3-year-olds, the attention-directing properties of labels may improve their performance on (consecutive) cognitive flexibility tasks, but that for 4-year-olds, labels may provide an opportunity to reflect on the hierarchical structure of the (consecutive) task.

Similarly, in the context of the number of dimensions and consecutive cognitive flexibility, it could be that for 3-year-olds, considering 2 dimensions is as difficult as considering 3 dimensions because their difficulty lies with disengaging from seeing the stimulus in terms of the first dimension as opposed to switching to seeing the stimulus in terms of a second dimension. Thus, consistent with the Attentional Inertia Account, these children did not perform differently when asked to consider 3 dimensions as compared to when they were asked to consider 2 dimensions. In contrast, for 4-year-olds, considering the stimulus in terms of a second dimension is easier than considering it in terms of a third dimension because while they are able to disengage from the previous dimension, they find it difficult to see the stimulus in terms of a third dimension after seeing it in two different ways already. Both the Cognitive Complexity and Control Theory (Revised; Zelazo et al., 2003) and the relational complexity theory (Halford, 1980; Halford et al., 1998), are consistent with the expectations that the more dimensions the child must consider, the more difficult the task (see above, p. 126, for a discussion). Thus, we again see a qualitative shift in children's consecutive cognitive flexibility performance between 3- and 4 years of age (see Jacques & Zelazo, 2005, and discussion above).

In the context of concurrent cognitive flexibility, there are two possible explanations for the finding that children found coordinating 3 dimensions as difficult as they found coordinating 2 dimensions. The first possible explanation is that the children in this age group find it too difficult to coordinate even two dimensions simultaneously, thus there is no difference in performance across tasks requiring 2 versus 3 dimensions. However, this does not seem to be the case. The 4-year-olds demonstrated overall good ability to coordinate two and three dimensions concurrently, with 63% and 50% of the sample, respectively, performing above chance. Moreover, their performance on the Matrix Sort Task was similar, with 66% of the 4-year-olds passing this task. Therefore, the explanation of floor performance cannot account for the pattern detected in data.

Another possible explanation is taking into account the type of task the children were asked to perform (i.e., inductive vs. deductive). Specifically, the Multidimensional Card Selection Task is a deductive task, and the investigation did show that children found deductive concurrent cognitive flexibility tasks more difficult than inductive concurrent cognitive flexibility tasks. Recall that I did not have an inductive concurrent task to which we can compare children's performance on the Multidimensional Card Selection Task. Therefore, it may be that examining the 3-way-interaction between the type of cognitive flexibility, abstraction task demands, and the number of dimensions to be coordinated directly would lead to different conclusions. Future work should take into consideration all three of these factors when examining children's cognitive flexibility performance. For instance, a review of tasks (such as Jacques & Zelazo, 2005; Cragg & Chevalier, 2012) should take into account both the number of dimensions that are being considered, as well as the abstraction demands. While Cragg and Chevalier's (2012) review did take the number of dimensions the stimuli varied on into account, they counted the Flexible Item Selection Task as well as the Object Classification Task for Children as 'trivalent'. While it is true that Flexible Item Selection Task includes three dimensions in the task as a whole, it does not require children to consider the same stimulus in three different ways at any given time, as the Object Classification Task for Children does. Similarly, Jacques and Zelazo's (2005) review took abstraction demands into account, but not the number of dimensions that the child is required to consider. As mentioned before, neither of these investigations was able to contrast the type of cognitive flexibility given the lack of research into young children's concurrent cognitive flexibility skills. Thus, more work examining the effects of these factors on children's cognitive flexibility development is needed.

Limitations and Future Directions

An obvious limitation of this analysis has been mentioned before. This was an exploratory analysis, and as such should be interpreted with caution. Although I took measures to reduce the likelihood of finding a significant result by chance (by using a Bonferroni-corrected alpha level), this study was still not designed to test any direct hypotheses. Nevertheless, if this analysis is taken as a hypothesis-generating opportunity, quite a few questions arise from the data, which can guide direct future research.

Another major limitation of this analysis was that I could not examine the 3-way interaction between cognitive flexibility type, abstraction demands, and the number of dimensions being considered. Therefore, the findings from this work are limited. Future work, as I mentioned, could examine all three factors more carefully. For instance, a study using inductive and deductive tasks (preferably an inductive and a deductive version of the same task) that measure both consecutive and concurrent cognitive flexibility, and which include at least trivalent stimuli (and measure children's ability to consider all three dimensions) would be able to shed more light on what seems to be a complex relation among the three factors. Of course, other Executive Function measures (age-appropriate measures of working memory and inhibitory control) would allow us to examine the differential role of these Executive Functions in consecutive and concurrent cognitive flexibility performance. Such research would help to pinpoint the specific factors, or combinations of factors, that prove most challenging to young children. Likewise, they would provide insight into the factors (more likely the combination of factors) that best allow young children to demonstrate their cognitive flexibility skills. Further, such research could include a wider age range than studied in my Study 1, allowing for a better understanding of how the different factors (and combinations thereof) affect children across development. This would enable us to test my interpretation that the effect of these factors varies across age.

One interesting question is a general age-range for the emergence of concurrent cognitive flexibility. Because the children in my sample performed well on the consecutive cognitive flexibility tasks, it is impossible to know whether their performance on the concurrent cognitive flexibility tasks is representative. However, it seems that many children are able to coordinate at least two dimensions concurrently around the time they are 4 years old, as opposed to 7 years old as previous works may have indicated (see, e.g., Cartwright et al., 2010; Halford, 1980; Inhelder & Piage, 1964; Rittle-Johnson et al., 2008; Siegler & Svetina, 2002). Note that because of these previous findings, very little work documented concurrent cognitive flexibility skills in 3- to 6-year-olds. Therefore, research examining children's concurrent cognitive flexibility skills in this age group are warranted. These include correlational studies investigating the kinds of skills that underlie children's ability to consider two dimensions simultaneously, as well as the kinds of skills that benefit from it. For instance, Perner, Stummer et al., (2002) argued that it is children's ability to confront perspectives—as opposed to their ability to switch perspectives—that underlies Theory of Mind developments around 4 years of age. Now that we have tasks to measure 4-year-olds' concurrent cognitive flexibility, we can test this claim more directly. Another line of research that can take advantage of the tasks measuring emerging concurrent cognitive flexibility skills in preschoolers would be longitudinal studies examining the unique predictive power of concurrent cognitive flexibility, along that of consecutive cognitive flexibility and other Executive Functions, over developmental outcomes such as problem-solving, creativity, and academic achievements.

Another interesting finding pertains to the relation between abstraction and cognitive flexibility. As noted, many researchers consider abstraction as necessarily preceding (consecutive) cognitive flexibility, but this may not be the case. For example, I found that abstraction demands differentially affect performance on different types of cognitive flexibility tasks (i.e., consecutive and concurrent). It is likely, for instance, that because researchers only used inductive tasks to measure concurrent cognitive flexibility (often inductive measures), their finding seemed to indicate that abstraction is required before concurrent cognitive flexibility can develop. However, the results from my analysis indicate that using both deductive and inductive tasks is beneficial for understanding the relation between abstraction and cognitive flexibility.

Moreover, it may be that the type of cognitive flexibility the child is asked to perform modulates the relation between abstraction and cognitive flexibility. Future work could examine this relation more carefully, using both inductive and deductive consecutive and concurrent cognitive flexibility tasks. For instance, the Flexible Item Selection Task can be fairly easily modified to have both an inductive and a deductive version. Similarly, as I will discuss in Chapter 5, I have constructed both inductive and deductive versions of the Preschool Matrix Completion Task and Matrix Sort Task. Thus, we can use these kinds of manipulations to examine the relation between abstraction and cognitive flexibility. The advantage of such manipulations, over the exploratory analyses presented here, is that comparisons will be within task-type, as opposed to across. Thus, the other task demands will be held relatively more constant.

Another related interesting question is whether the relation between abstraction and cognitive flexibility can be used to predict later developmental outcomes. I noted before that inductive tasks, for instance, may be more applicable to real-life situations in which children must first define the problem before turning to solving it (see Snyder & Munakata, 2010). However, these tasks do conflate abstraction skills with cognitive flexibility skills. More work is required to tease apart the effects of abstraction and cognitive flexibility on problem-solving.

A third interesting question arising from the findings of the exploratory analysis pertains to the relation between the number of dimensions the child is asked to consider and performance on consecutive and concurrent cognitive flexibility tasks. Future work could examine more carefully, using both inductive and deductive tasks, children's ability to consider two and three dimensions both consecutively and concurrently. For example, the Preschool Matrix Completion Task is a task that can be fairly easily modified to vary 2, 3, and 4 dimensions. Similarly, the Multidimensional Card Selection Task and the Modified Object Classification Task for Children could use bi-, tri- and quadrivalent stimuli to examine when and how children's ability to consider 2, 3, and 4 dimensions, consecutively and concurrently develops. These kinds of investigation would allow for a more continuous conceptualization of cognitive flexibility development, and would allow for the same measures to be used across a wider age range. While useful in cross-sectional designs, they would be particularly useful in longitudinal studies.

In addition, I noted before that seeing a problem in several ways is helpful to find a solution. It would be interesting to see whether, for instance, the ability to consider three dimensions, as opposed to two dimensions, at a young age is a better predictor of later problem-solving skills. Similarly, it would be interesting to see whether the ability to consider three dimensions is more closely related to fluency measures that are often used to indicate cognitive flexibility with older children and adults (Gilhooly et al., 2007; Snyder & Munakata, 2010; Stevenson et al., 2014).

Another important aspect to keep in mind is the role that other Executive Functions, namely, inhibitory control and working memory, play in the context of consecutive and concurrent cognitive flexibility development. In my study, I only found anecdotal correlations between inhibitory control, working memory, and cognitive flexibility tasks, but I only used one task to measure inhibitory control and one to measure working memory. Future work can use more tasks in order to arrive at a more stable score for each skill, and examine the interaction between inhibitory control, working memory, consecutive and concurrent cognitive flexibility.

Conclusion: Consecutive and Concurrent Cognitive Flexibility as Distinct Skills

In summary, three main findings arise from the exploratory analysis. First, age interacts with the type of cognitive flexibility in terms of children's performance. Specifically, the data suggested that concurrent cognitive flexibility is a little easier for children than consecutive cognitive flexibility, but children do not have to master consecutive cognitive flexibility in order to consider two dimensions simultaneously. The second finding is that abstraction demands interact with the type of cognitive flexibility. Specifically, the data indicates that children's performance could not be characterized solely in terms of the type of task they saw (i.e., inductive or deductive) or in terms of the type of cognitive flexibility the task measured. The third finding is that number of dimensions the child is required to consider interacts with age as well as with the type of cognitive flexibility. Specifically, it seems that considering 2 versus 3 dimensions varies in difficulty depending on whether the child is asked to consider these dimensions consecutively, or concurrently.

The overall conclusion that can be drawn from these findings is that the type of cognitive flexibility should be taken into account when we approach the examination of preschoolers' cognitive flexibility development. We know that the two skills are highly correlated, but because they show different developmental patterns and because the type of cognitive flexibility interacts with other task factors (i.e., abstraction task demands and the number of dimensions the child is asked to consider), there is reason to believe that investigating both of these processes has merit. Recall that several structural analyses found that inhibitory control and working memory are closely related in children (e.g., Wiebe et al., 2008, 2011; see Chapter 3, p. 105, for a discussion). Despite these findings, several studies showed that investigating inhibitory control and working memory separately has merit, as they uniquely predict developmental outcomes (e.g., Bull & Scerif, 2001; St. Clair-Thompson & Gathercole, 2006). Similarly, it is possible that despite findings that consecutive and concurrent cognitive flexibility are correlated, they might uniquely predict developmental outcomes. More work is needed to provide a better understanding of the relation between these two skills and their development during the preschool years.

In the next chapter, I turn to describe Study 2. As I mentioned before, Study 2 was designed, prior to starting Study 1, to investigate the relation between abstraction and concurrent cognitive flexibility in more detail. Specifically, I compared children’s performance on inductive and deductive versions of two concurrent cognitive flexibility tasks in order to better understand the effect of abstraction task demands on concurrent cognitive flexibility performance. Thus, Study 2 provides a within-task comparison of the effects of abstraction on concurrent cognitive flexibility performance.

Chapter 5: Study 2 – Factors Affecting Concurrent Cognitive Flexibility Performance

As seen in the results from Study 1, children's performance on concurrent cognitive flexibility tasks is affected by the abstraction demands of the task (i.e., whether the task is inductive or deductive). A better understanding of the effects of inductive/deductive tasks is valuable for researchers faced with the decision about which tasks to include when examining concurrent cognitive flexibility development, as well as for researchers who are planning interventions or designing curricula to promote concurrent cognitive flexibility skills. In addition, a better understanding of factors affecting children's concurrent cognitive flexibility performance would improve our grasp of the development of this skill, and enhance our ability to use it to predict various developmental outcomes, such as flexible problem-solving (Siegler & Svetina, 2002) and creativity (Diamond, 2012).

In Study 2, which was planned prior to conducting Study 1, I focused on two factors I hypothesized would affect children's performance on matrix tasks that are used to measure concurrent cognitive flexibility in preschoolers. These factors both stemmed from changes I made to the traditional Piagetian matrix completion task (Siegler & Svetina, 2002; see details in Chapter 2, p. 40). The first factor was whether the task was inductive or deductive (i.e., whether or not the experimenter labeled the relevant dimensions), and the second concerned the structure of the practice/demonstration trial (i.e., whether it included a single dimension or two).

Recall that in Siegler and Svetina's (2002) study, 6-year-olds performed at chance levels. In contrast, in a previous study I conducted (Podjarny et al., in preparation), a sizeable group (48%) of 4- and 5-year-olds in my sample performed above chance on the Preschool Matrix Completion Task. My original goal for Study

2, then, was to localize the source of the difference in performance between Siegler and Svetina's (2002) original task and my Preschool Matrix Completion Task.

From the results of Study 1, it later became clear that abstraction demands interacted with the type of cognitive flexibility. Thus, the motivation I now had for this study was doubled: In addition to localizing the source of performance difference between Siegler and Svetina's (2002) matrix completion task and my Preschool Matrix Completion Task, I would be able to provide a more careful and controlled examination of the effects of abstraction demands on children's concurrent cognitive flexibility task performance.

In addition to receiving the Preschool Matrix Completion Task, preschoolers also received the Matrix Sort Task in order to corroborate the effects of abstraction demands on concurrent cognitive flexibility performance. I chose the two matrix tasks I used in Study 1 because they allowed for this comparison: for both tasks it was possible to manipulate the abstraction demands in a fairly straightforward way. Specifically, I provided labels (both visual and verbal) in the deductive versions of both tasks and did not provide labels in the inductive versions (see Methods section).

I begin this chapter with an overview of the two factors I manipulated in this study (i.e., abstraction demands and the number of dimensions presented in the introductory trials) and how they might affect children's performance. I then detail the experimental method I used to examine the effects of these factors and the results, concluding with a discussion of the findings and how they relate to previous work—including the exploratory analysis I described in Chapter 4.

Factor 1: Abstraction Task Demands

The first—and main—change I made to the Piagetian matrix completion task (Inhelder & Piaget, 1964; Siegler & Svetina, 2002) was to make the task a deductive one by adding the relevant labels: in the original matrix completion task, children had to identify the relevant dimensions on their own (see Siegler & Svetina, 2002). Therefore, while the original task was inductive, my Preschool Matrix Completion Task was a deductive task.

This change underscores the nature of the relation between abstraction and cognitive flexibility. Recall that both abstraction and cognitive flexibility play a role in problem-solving, and investigating the relation between them would enable us to better predict this skill (see, e.g., Bennett & & Müller, 2010; Smidts et al., 2004; Snyder & Munakata, 2006; see Chapter 4, p. 114, for a more detailed discussion). As I mentioned in Chapter 4, while researchers have discussed the relation between abstraction and cognitive flexibility (e.g., Bennett & Müller, 2010; Smidts et al., 2004), there are two points to consider in regards to this discussion.

The first point is that most of the work to date has focused on consecutive, rather than concurrent, cognitive flexibility. Thus, we know very little about the relation between abstraction and concurrent cognitive flexibility. Recall that in Study 1, children's performance on deductive concurrent cognitive flexibility was lower than their performance on inductive tasks. This was unexpected, as identifying the relevant dimensions for the children (in the deductive tasks) was expected to reduce the task demand and therefore improve performance. Moreover, in a previous study (Podjarny et al., in preparation), about half of the 4- and 5-year-olds in my sample performed above chance on this deductive task. In addition, this pattern was reversed from the one found with consecutive cognitive flexibility (i.e., that children perform better on deductive than on inductive tasks; see Jacques & Zelazo, 2005). But, it is important to note, that the results from Study 1 were based on findings across tasks, so the results may have been specific to the tasks employed, as opposed to the abstraction demands. Study 2 makes the comparison within tasks, and so the results from this investigation have the potential to provide us with a better understanding of the relation between abstraction and concurrent cognitive flexibility.

The second point to consider when discussing the relation between abstraction and cognitive flexibility is that several researchers imply, in their description of the relation between these two skills, that abstraction must precede cognitive flexibility (e.g., Bennett & Müller, 2010; Smidts et al., 2004). However, at least some empirical findings seem to contradict this description. As I explained before (see p. 115), if the ability to identify relevant dimensions necessarily precedes the ability to flexibly coordinate these dimensions, children should perform fairly equally on inductive and deductive tasks, because by the time they are able to flexibly consider two dimensions they should have no difficulties with identifying relevant dimensions. Jacques and Zelazo's (2005) review of (consecutive) cognitive flexibility tasks reported that children tend to perform better on deductive than on inductive tasks. While their comparison was across groups, and in fact across different studies, we have some evidence that this is true for individual children as well. Specifically, I found a similar pattern of performance using a within-subject comparison of 3- and 4-year-olds' performance on consecutive cognitive flexibility tasks in my exploratory analysis (see Chapter 4, p. 139). This pattern was therefore consistent with previous findings indicating that children do better on consecutive deductive tasks than they do on consecutive inductive tasks (e.g., Jacques & Zelazo, 2005).

Study 2 would allow me to examine the relation between abstraction and concurrent cognitive flexibility skills more closely. Particularly, a comparison between inductive and deductive versions of the same task would provide insight as to whether abstraction is required for children to solve concurrent cognitive flexibility tasks. For instance, if children are able to solve a deductive version of a concurrent cognitive flexibility task, but not an inductive version of the same task, we have evidence to suggest that children do not require abstraction skills in order to flexibly coordinate two dimensions (simultaneously).

Recall that I argued that the attentional inertia account could provide an explanation for my finding of an interaction between task type (inductive/deductive) and cognitive flexibility type (consecutive vs. concurrent). The Cognitive Complexity and Control Theory (Revised), in contrast, could not. Specifically, I proposed that the attention-directing properties of the labels directed children's attention to a single dimension. Thus, the labels impaired children's performance on concurrent cognitive flexibility tasks instead of improving it. If, however, labeling the relevant dimension (as in deductive tasks) improves children's consecutive cognitive flexibility performance by providing them with an opportunity to reflect on the hierarchical structure of the cognitive flexibility task (as proposed by Jacques & Zelazo, 2005; Zelazo, 1999), then we would expect this effect to be consistent regardless of the cognitive flexibility type. In other words, we would expect children to perform better on deductive concurrent cognitive flexibility tasks than they do on inductive concurrent cognitive flexibility tasks. Again, it is important to note that the Cognitive Complexity and Control Theory (Revised) did not include any predictions of the effects of labels on concurrent cognitive flexibility performance, as it was not developed to account for concurrent cognitive flexibility development.

As I mentioned before, we cannot conclude from the findings from Study 1 that children do better on inductive concurrent cognitive flexibility tasks as compared with deductive concurrent cognitive flexibility tasks. First, the analysis was exploratory, and thus a confirmation study is required. Moreover, I compared two different tasks: the Matrix Sort Task was an inductive task that measured concurrent cognitive flexibility whereas the Preschool Matrix Completion Task and the Multidimensional Card Selection Task were deductive tasks measuring concurrent cognitive flexibility performance. Thus, a direct comparison of inductive and deductive versions of the same concurrent cognitive flexibility task is necessary, and may help to tease apart the two proposed explanations. If children in Study 2 perform better on the inductive versions of the concurrent cognitive flexibility tasks as compared to the deductive versions of the same tasks, we have evidence to suggest that the finding from Study 1 was not due to different task demands (i.e., methodological differences between the Preschool Matrix Completion Task and the Matrix Sort Task). Then, the theories proposed to explain consecutive cognitive flexibility development could be extended to account for this finding.

Based on findings from my first study, I hypothesized that children would find the deductive version of the matrix tasks more difficult than the inductive version of the same tasks. The original hypothesis, however, was reversed: I had expected children to find the inductive versions more difficult than the deductive versions, consistent with my previous findings (Podjarny et al., in preparation) and with Jacques and Zelazo's (2005) review.

Factor 2: Number Of Relevant Dimensions In The Practice Trial

Another significant change I made to the original matrix completion task (as run by Siegler & Svetina, 2002) was to increase the number of dimensions varied in the practice trials (from one to two). Previously, the practice trials held all other dimensions constant (e.g., shape, colour, and orientation). For example, their practice trial included "a large green fish facing left in each of the two squares on the left and a small green fish facing left in the top right square." (p. 797). Children had to select a picture to complete the matrix; in this example, the correct answer would be a small green fish facing left. Children who could not answer at least half of the 8 practice trials correctly were excluded from the study (10 children were excluded based on this criterion; see Siegler & Svetina, 2002, p. 797). Note that the correct answer exactly matched the item in the adjacent cell (in this example, the cell directly above the empty cell).

As noted earlier, young children in particular may conclude from practice trials such as these that only one dimension should be considered (see Chapter 2, p. 42). As noted by Siegler and Svetina (2002), this kind of practice trial may have encouraged children to use a matching strategy (i.e., choose the duplicate of the item in the adjacent cell), as doing so lead to success in all practice trials. Indeed, Siegler and Svetina (2002, p. 799) reported that most errors (about 60% of all errors) were duplicate errors—selecting an item that duplicates the adjacent cell.

While Siegler and Svetina (2002) argued that children make duplicate errors because they tend to “rely on perceptual matches at the expense of relational similarity.” (p. 805), they also conceded that it is possible that children made more duplicate errors because the practice trial encouraged it (see p. 805). However, their data did not allow them to decide between these two explanations.

In my Preschool Matrix Completion Task, I employed a practice trial that required children to consider two dimensions, as they would have to in the test trials. While the children in my previous study made fewer errors overall (see Podjarny et al., in preparation), duplicate errors did make up the majority of them (they averaged 85% duplicate errors out of all errors). Note that while it appears that the children in my sample made more duplicate errors, we cannot conclude that children would make more duplicate errors with a practice trial that varies on two dimensions (as opposed to a practice trial that varies on a single dimension) for several reasons. First, Siegler and Svetina's (2002) answer boards had two duplicate options on some trials, and only one duplicate option on other trials, whereas my answer boards always included both duplicate options. Therefore, the probability of selecting duplicate errors by chance in my study was higher. Second, as I mentioned before, I made several changes to the task, and so it is impossible to localize the source of performance difference between Siegler and Svetina's (2002) matrix completion task and my Preschool Matrix Completion Task. Thus, it is still unclear what the effect was of a practice trial that included one, as compared to two, relevant dimensions.

In Study 2, I manipulated the practice trial across participants, while holding other factors constant, to allow me to test this question. Specifically, some preschoolers received a practice trial that varied on only one dimension (as in Siegler & Svetina, 2002), while others received a practice trial that varied on two dimensions (similar to the test trials). Both versions, of course, contained test trials that varied on two dimensions. Understanding how (and whether) this change affected children's performance would further our understanding of factors that play a role in children's concurrent cognitive flexibility performance. This would be beneficial for researchers when they are faced with choosing tasks to examine concurrent cognitive flexibility development.

Study 2 was designed to allow me to determine between the two alternative explanations of duplicate errors suggested by Siegler and Svetina (2002). Thus, if I find that children make more duplicate errors when they see a practice trial that varies on a single dimension (as compared with when they see a practice trial that varies on two dimensions), we can conclude that at least some of the duplicate errors are made due to the practice trial structure as opposed to children's tendency to focus on a single dimension in general. Moreover, as mentioned before, the study would help localize the source of performance difference between children in Siegler and Svetina's (2002) study (in which 6-year-olds performed at chance) and the children in my studies (in which 48% of 4-year-olds were able to coordinate two dimensions concurrently; see Podjarny et al., in preparation).

Note that this factor was not expected to affect Matrix Sort Task performance because the Matrix Sort Task does not afford a duplicate error. In other words, there are no answer options that include a focus on a single dimension. Instead, children have to sort all 4 cards onto the grid, and so a focus on a single dimension is less likely to be affected by the number of dimensions on the practice trial. However, in order to facilitate comparison between the two tasks, I employed two versions of the introduction trial in the Matrix Sort Task to match the different types of practice trials for the Preschool Matrix Completion Task (see Methods section for details). I then examined this factor in addition to the inductive/deductive task demands when examining Matrix Sort Task performance, but with the expectation that it would not affect performance.

Based on previous work (Podjarny et al., in preparation), I hypothesized that children who saw a practice trial that varied on two dimensions would perform better on the test trials of the Preschool Matrix Completion Task as compared with children who saw a practice trial that varied on one dimension. I further hypothesized that children who saw a practice trial that varied on two dimensions would make fewer duplicate errors than children who saw a practice trial that varied on one dimension. In other words, I expected this factor to affect specifically the duplicate errors because seeing a practice trial that varies on one dimension reinforces a matching strategy.

Methods

Participants

I recruited a total of 162 4- and 5-year-old[26] children from daycares and schools.[27] Two 4-year-old boys were excluded because they were unable to sit through the testing sessions, and so the final sample included 160 children (see Results section for descriptive statistics).

Procedure

After a parent or guardian signed the informed consent form, children gave verbal assent before participating. They were then interviewed in a quiet space in two 25-minutes sessions by one of two researchers (myself and an honours student). The two factors examined in this study were crossed, resulting in four combinations. Children were randomly assigned to one of them, with an approximately equal number in each cell, for each age group (see Table 5.1).

Table 5.1

Number of Children Assigned to Each Condition

	Dimensions Varied On The Practice Trial		
Task Version	One	Two	Total
Deductive	37	47	84
Inductive	39	37	76
Total	76	84	160

[26] One of the 5-year-olds who participated in this study also participated in the pilot study as a 3-year-old. However, since the elapsed time was two years, I did not exclude him.

[27] While the planned sample size was smaller (n = 80), I recruited an additional 80 children. This was done because a preliminary analysis revealed an order effect, and I wanted to be able to examine this effect (see Results section).

I chose to use a between-subject design because using a within-subject design would have created the risk of learning effects, and raise issues related to orders of presentation. For example, if labels allow children the opportunity to reflect on the hierarchical rule structure of a task, as proposed by Zelazo (1999), then seeing a deductive version first might have affected their performance on an inductive version. The effects in the other direction would be different (i.e., seeing an inductive version first should not have affected their deductive version performance), and so another variable would have to be taken into account (i.e., the order of the version). As this was not the focus of the current study, a between-subject design was preferred.

The order of the matrix tasks was counterbalanced: half of the children in each condition (each cell of Table 5.1) received the Preschool Matrix Completion Task in the first session and the Matrix Sort Task in the second session, while the others received them in the opposite order.

In order to check that the groups were well matched on other factors that may play a role in their concurrent cognitive flexibility performance, I administered measures of consecutive cognitive flexibility (Modified Flexible Item Selection Task), working memory (Self-Ordered Pointing), inhibitory control (Black/White Stroop-like Task), receptive language (Peabody Pictures Vocabulary Test), and nonverbal intelligence (Primary Test of Nonverbal Intelligence). These tasks were included so that I could determine that the participants were comparable across the four groups. The order of the tasks was fixed, except for the concurrent cognitive flexibility tasks, which were counterbalanced across children as noted before.

Tasks.

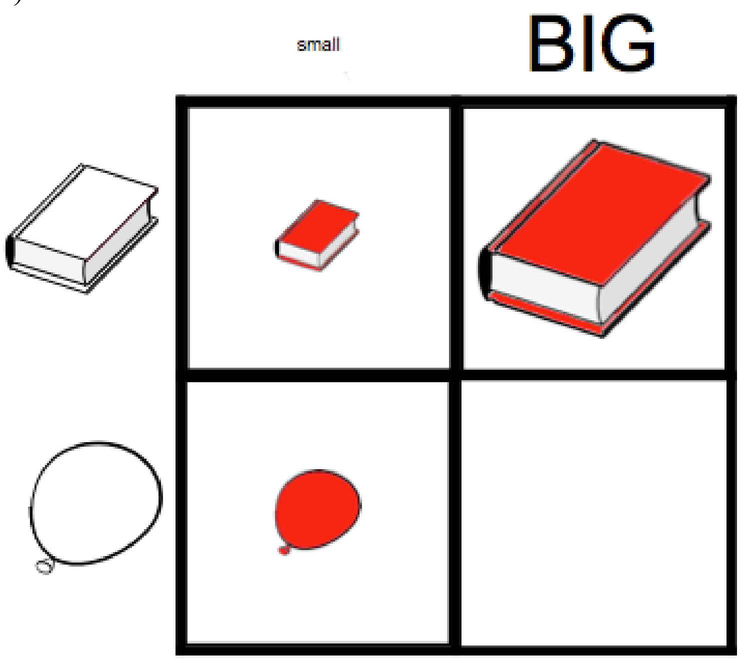
For both the Preschool Matrix Completion Task and the Matrix Sort Task, I used the same general procedure as detailed in Study 1 (see Chapter. 3, p. 76 for the

Preschool Matrix Completion Task and p. 79 for the Matrix Sort Task, as well as Appendices L and M for the full protocols used in this study). They did differ in that they had 6 test trials, in contrast to the 3 test trials for the Matrix Sort Task and 5 test trials for the Preschool Matrix Completion Task I used in Study 1. I decided to have 6 test trials because a scale with 6 items or more can be considered continuous (Rhemtulla, Brosseau-Liard, & Savalei, 2012), and therefore allow for the use of parametric, instead of nonparametric, analyses. Children were scored on the total number of trials they solved correctly.

Abstraction Manipulation.

For both the Preschool Matrix Completion Task and the Matrix Sort Task, I had both a deductive version and an inductive version. In the deductive version, the matrix board included pictorial labels (colorless line-drawings to denote shapes, color swatches to denote colors, and the words 'BIG' and 'small' in 50 and 12 font size, respectively, to denote size without requiring the child to actually be able to read; see Figure 5.1). Moreover, the experimenter labeled the relevant dimensions in each trial, saying, for instance "remember, the small [pointing at the "small" label] tells us all the small ones go on this side [motioning along the left-hand column], and the big [pointing to the "BIG" label] tells us all the big ones go on that side [motioning along the right-hand column]. Also, the book [pointing to the book label] tells us all the books go on top [motioning along the top row] and the balloon [pointing to the balloon label] tells us all the balloons go on the bottom [motioning along the bottom row]". While the dimensions of the rows and columns changed from trial to trial, the order of labeling was always the same: left-hand column, right-hand column, top row, and bottom row.

(a)



(b)

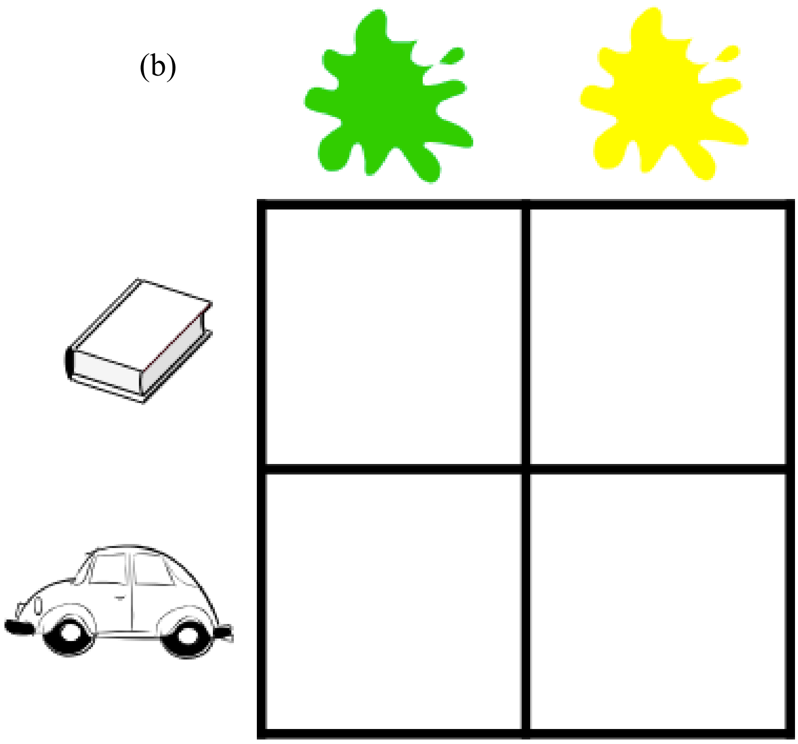


Figure 5.1 Example boards for Preschool Matrix Completion Task (panel a) and Matrix Sort Task (panel b) in the deductive condition

In the inductive condition, the grids were devoid of labels (see Figure 5.2), and the experimenter did not use labels that made any mention of dimensions, saying, for example “remember, the ones on this side [motioning along left column] go together and the ones on that side [motioning along right column] go together. And also the ones up here [motioning along the top row] go together and the ones down here [motioning along the bottom row] go together”. Regardless of the condition, children received an initial trial to familiarize them with the tasks (as described earlier).

The experimenter’s script for the test trials was identical for both matrix tasks, except for what the experimenter asked the child to do at the end of the script. So, the children heard, “can you tell me which one of these pictures [motioning to the array of 6 items] belongs here [pointing to the empty cell]?” for the Preschool Matrix Completion Task, and “can you put these cards [motioning along the 4 cards] on the board for me?” for the Matrix Sort Task). Children received either the inductive or deductive tasks (e.g., if assigned to the deductive condition, they received both the Preschool Matrix Completion Task and the Matrix Sort Task in their deductive versions).

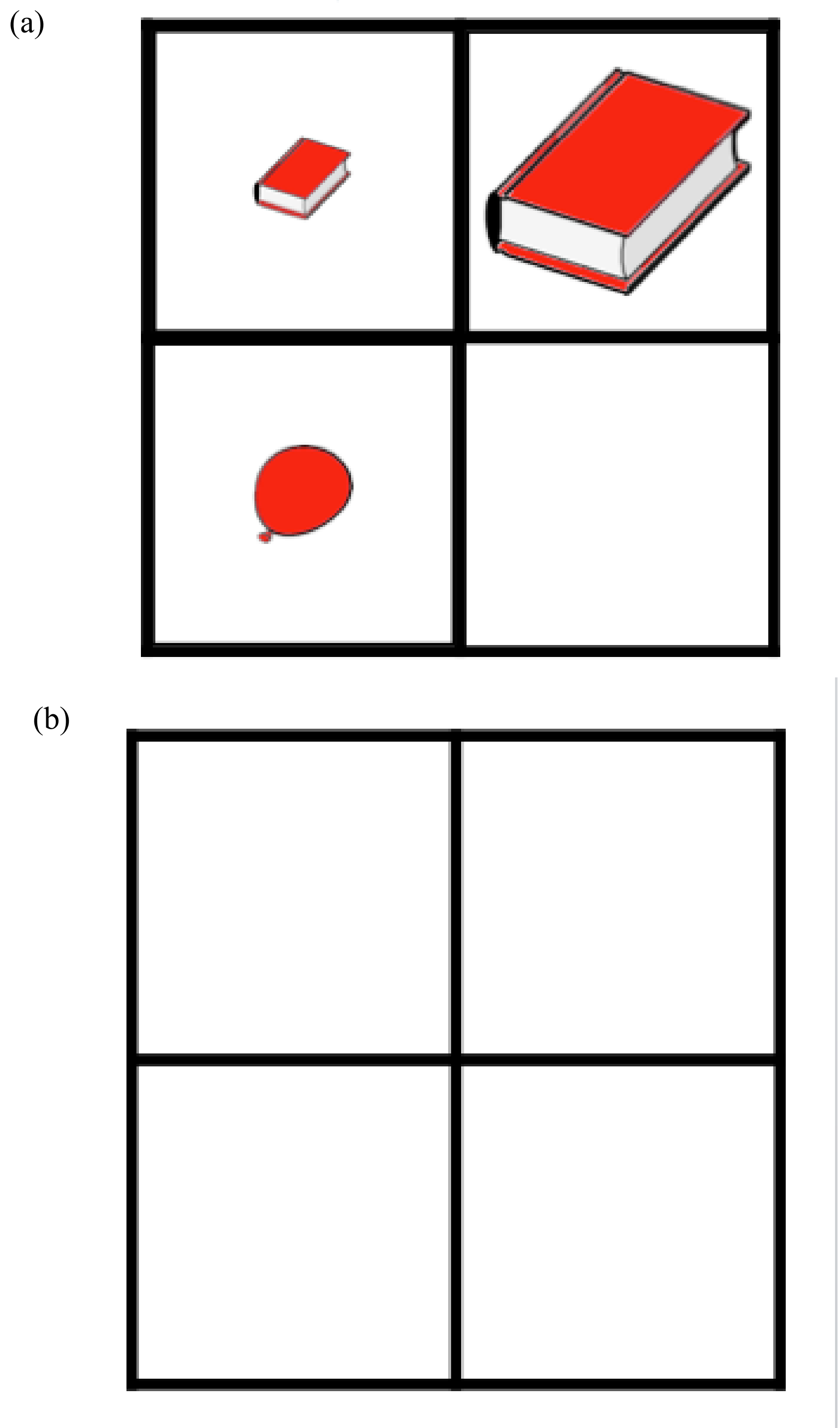


Figure 5.2 Example boards for Preschool Matrix Completion Task (panel a) and Matrix Sort Task (panel b) in the inductive condition

Practice/Demonstration Trial.

Both matrix tasks included began with an initial trial (a demonstration trial for the Matrix Sort Task, and a practice trial for Preschool Matrix Completion). These were run as detailed in Chapter 3 (see p. 76), with one notable exception: half of the children received an initial trial in which items varied only along one dimension (as run in Svetina & Seigler, 2002), whereas the others received an initial trial that varied along two dimensions (i.e., was structurally the same as the test trials; see Figure 5.1). Thus, a one-dimensional practice trial would include, for example, a yellow car in the top left-hand cell, a yellow book in the top right-hand cell, a yellow car in the bottom left-hand cell, and the answers included a yellow book (correct answer), and yellow car, plane, cup, fish, and bird (see Figure 5.3). In the deductive condition, the experimenter labeled the dimension(s) that appeared in the practice trial (see Appendices L and M for full task protocols).

Scoring and Chance Levels.

In addition to totaling the number of correct trials (per task), I also calculated a pass/fail score for each child, based on chance level performance. This was done in order to allow comparison between the two tasks, and in the case of the Matrix Sort Task, to allow comparison between the conditions (see below).

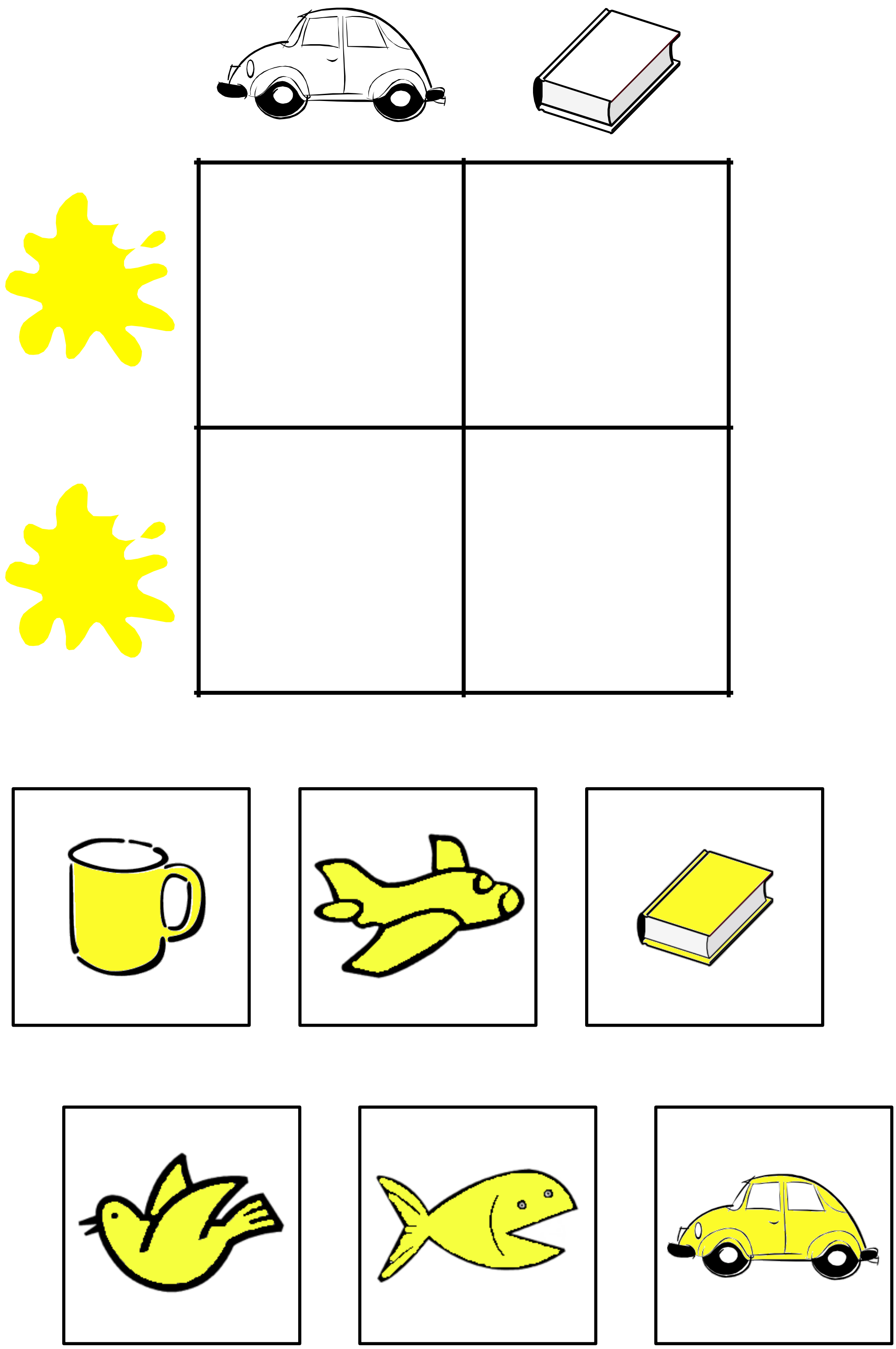


Figure 5.3 Sample practice trial for study 2. The top panel depicts a practice trial that varied on one dimension, and the bottom panel depicts the answers that would accompany this trial. Deductive version shown.

For the Preschool Matrix Completion Task, chance level was 0.17 for each trial (one correct answer out of an array of 6 choices), regardless of whether the task was inductive or deductive. Children were counted as passing if they solved 4 or more trials correctly ($p < .01$ on a binomial distribution). Because of the identical chance levels, when comparing conditions within this task, the original score of the total number of trials solved correctly was used in the analyses. This score was calculated, then, to facilitate comparison with the Matrix Sort Task.

The chance levels for the Matrix Sort Task differed based on the task version: in the inductive version there were 8 correct ways (out of 24 possible ways) to sort the four cards onto the 2x2 grid; in the deductive version, only one way out of 24 possible ways was correct (the one that followed the labels). Therefore, children were counted as passing the inductive version if they could solve 5 or more trials correctly ($p = .01$ on a binomial distribution), passing the deductive version if they could solve 2 or more trials correctly ($p = .02$ on a binomial distribution). Because of the different chance levels, when comparing conditions for the Matrix Sort Task, the pass/fail score was always used in the analyses. Note that while solving two trials out of six does not sound intuitively as deserving a “pass” score, I decided to use this coding because it does take into account the significantly lower probability of solving a trial correctly in the deductive version.

The control tasks that were used for group comparison were all run exactly as done in Study 1 (see Chapter 3, p. 63 and 87).

Results

The final sample included 160 participants: 84 4-year-olds (42 girls) and 76 5-year-olds (45 girls). Table 5.2 shows the distribution of variables of interest across the conditions. Descriptive statistics for the control variables (for each age group separately) are presented in Table 5.3.

I will report descriptive statistics and preliminary analyses first, followed by two analyses I have made in order to examine the effects of the factors I manipulated in Study 2 on children's performance. I will then describe the results of an error analysis in which I examined my hypothesis that the number of dimensions varied on the practice trial would affect duplicate errors.

Table 5.2

Frequencies Per Condition: Number (Percentages) Of Children In Each Condition

Condition	Total n	Girls	4-Year-Olds	PMC First
Deductive, One Dimension	37	21 (57)	21 (57)	17 (46)
Deductive, Two Dimensions	47	28 (60)	22 (47)	29 (62)
Inductive, One Dimension	39	20 (51)	20 (51)	20 (51)
Inductive, Two Dimensions	37	18 (49)	21 (43)	18 (49)

Note. PMC = Preschool Matrix Completion Task. The sample size for the deductive-2-dimensions combination was slightly larger because I wanted to compare that condition to another condition I collected which is outside of the scope of the current document.

Descriptive Statistics and Preliminary Analyses

Distributions.

Only the Peabody Picture Vocabulary Test and the Primary Test of Nonverbal Intelligence scores were distributed normally according to a Kolmogorov-Smirnov's test, both *ps* > .05. While age (in months) was not normally distributed, *Kolmogorov-Smirnov's test statistic* = .096, *p* = .002, the mean (59.11) was fairly close to the median (59 months). Moreover, the Q-Q plot showed a good distribution (see

Appendix N for all plots and normality indicators). Therefore, this variable was treated as normally distributed. The Self-Ordered Pointing scores were fairly normally distributed, but the Flexible Item Selection Task scores were negatively skewed. The Black/White Stroop scores were highly negatively skewed, with an overall sample mean of 17.07 correct trials (out of 21; see Table 5.3), showing a ceiling performance pattern. Therefore, while the Self-Ordered Pointing Task was treated as a normally distributed variable, I used non-parametric tests to examine both the Flexible Item Selection Task and the Black/White scores.

Neither the Preschool Matrix Completion Task nor the Matrix Sort Task scores were normally distributed. However, the Preschool Matrix Completion Task score's Q-Q plots showed a good distribution (see Appendix N for all plots), and as the sample size was fairly large, it was appropriate to examine the Preschool Matrix Completion Task score using parametric tests (see Field, 2013 for a discussion on parametric test assumptions).

Outliers, Missing Data, And Descriptive Statistics.

There were no outliers ($Z > 3.29$) in the main concurrent cognitive flexibility tasks, whether calculated across the entire sample, separately for each age group, or separately for each condition. No tasks had more than 5% missing values. Little's MCAR test showed the data missing at random, $\chi^2(20) = 20.84$, $p = 41$. Therefore, missing values were excluded pair-wise as per the SPSS default. Table 5.3 summarizes the descriptive statistics for the control variables. Table 5.4 details the descriptive statistics for each condition for the main tasks (Preschool Matrix Completion Task and Matrix Sort Task).

Table 5.3

Study 2 Control Variables Descriptive Statistics

4-Year-Olds		
Variable (sample score range)	Mean	SE
Age in months (48-59)	53.50	.37
FIST (0-8)	5.08	.24
Self-Ordered Pointing (0-12)	3.84	.29
Black/White (1-21)[1]	16.62	.59
PPVT Standardized score (82-131)[2]	108.15	1.46
PTONI Standardized score (65-150)	110.31	1.83
Note. *N* = 84 except: 1. *N* = 81; 2. *N* = 80.		
5-Year-Olds (*N* = 76)		
Task (sample score range)	Mean	SE
Age in months (60-71)	65.30	.35
FIST (2-8)	6.20	.14
Self-Ordered Pointing (0-12)	4.79	.34
Black/White (2-21)	17.55	.46
PPVT Standardized score (86-148)	110.09	1.36
PTONI Standardized score (79-150)	111.60	2.01
Full Sample		
Task (sample score range)	Mean	SE
Age in months (48-71)	59.11	.53
FIST (0-8)	5.61	.15
Self-Ordered Pointing (0-12)	4.29	.22
Black/White (1-21)[1]	17.07	.38
PPVT Standardized score (82-148)[2]	109.10	1.00
PTONI Standardized score (65-150)	110.92	1.35
Note. *N* = 160 except: 1. *N* = 157; 2. *N* = 156.		

Note. FIST = Flexible Item Selection Task; PPVT = Peabody Picture Vocabulary Test, 3rd Edition; PTONI = Primary Test of Nonverbal Intelligence.

Table 5.4

Mean Scores for Concurrent Cognitive Flexibility Tasks By Condition and Age

	Mean (S.E.)					
	Preschool Matrix Completion Task			Matrix Sort Task		
Condition	Full Sample	4-Year-Olds	5-Year-Olds	Full Sample	4-Year-Olds	5-Year-Olds
Deductive, One Dimension	2.43 (.34)	2.14 (.41)	2.81 (.56)	4.59 (.20)	3.48 (.31)	4.69 (.27)
Deductive, Two Dimensions	3.04 (.33)	2.64 (.45)	3.40 (.47)	4.00 (.23)	4.18 (.32)	4.96 (.22)
Inductive, One Dimension	2.56 (.33)	1.70 (.40)	3.47 (.44)	4.18 (.28)	3.50 (.38)	4.89 (.35)
Inductive, Two Dimensions	2.92 (.34)	2.19 (.40)	3.87 (.52)	4.68 (.25)	4.38 (.39)	5.06 (.28)

Note. Matrix Sort Task means are provided for descriptive purposes—pass/fail score was used in analyses. See Table 5.6 for pass/fail frequencies.

Reliability.

The cognitive flexibility tasks were examined for reliability in the same way detailed in Study 1 (see Chapter 3, p. 97). Omega and Cronbach's alpha reliability estimates are presented in Table 5.5. Reliability was examined on the entire sample (collapsed over condition) because the condition was not expected to affect the inter-trial consistency of the task. Preschool Matrix Completion Task showed fairly good reliability, but the Matrix Sort Task showed only reasonable reliability, with a lower bound of .53, which is poor (see Dunn et al., 2014, for a discussion).

Table 5.5

Consistency Indices for Cognitive Flexibility Tasks

Task	Score (number of trials)	Cronbach's Alpha	Omega		
			Lower Bound (95%)	Coefficient	Upper Bound (95%)
Preschool Matrix Completion Task	Correct Trials (6)	.82	.77	.82	.85
Matrix Sort Task	Correct Trials (6)	.63	.53	.63	.71
Flexible Item Selection Task	Contingent score (8)	.73	.68	.74	.78
Self-Ordered Pointing Task	Correct Trials (12)	.83	.70	.79	.85
Black/White	Correct Trials (21)	.90	.84	.90	.93

Note. The omega score for the third sort on the Modified Object Classification Task for Children and the Matrix Sort Task was invalid because there were only 3 items and too little variability in the scores.

Comparability of Groups.

To determine whether the 4 groups were matched in terms of age and general cognitive ability (factors that could affect their performance on the matrix tasks), I conducted a series of one-way ANOVAs to examine the groups' comparability with age in months, Self-Ordered Pointing Task, Peabody Picture Vocabulary Test, and Primary Test of Nonverbal Intelligence scores as dependent variables (one ANOVA for all variables run together), with the matrix version (see Table 5.1 for the four groups) as the independent variable. This analysis showed that the variances were equal among the groups, all *Levene's test ps* > .11. There were no significant differences among the groups, all *ps* > .31. Because the scores for the Flexible Item Selection Task and the Black/White did not show normally distributed errors (see Appendix N for histograms and Q-Q plots), I used the non-parametric equivalent of a one-way ANOVA, the Kruskal-Wallis H test (see Field, 2013). This test revealed no significant differences between the groups, both asymptotic *ps* > .32. Finally, gender was equally distributed among the four groups, Pearson's $\chi^2(3) = 1.24$, exact $p = .75$.

Comparing Across Conditions

Matrix Sort Task.

Table 5.6 presents the number and percentage of children passing in each condition for the Matrix Sort Task, collapsed across orders as well as for each order separately. In order to examine the effects of inductive/deductive task demands and the structure of the practice trial, I used binary logistic regression with the pass/fail score on the Matrix Sort Task as the dependent variable. Binary logistic regression is appropriate to predict a binary outcome variable (such as pass/fail; Field, 2013). Task version (inductive vs. deductive), number of dimensions included in the demonstration trial (1 vs. 2), order (Matrix Sort Task first vs. Preschool Matrix

Completion Task first), and age group (4 vs. 5) main effects were entered in the first block, two-way interaction terms were entered in the second block, three-way interaction terms were entered in the third block, and the four-way interaction term was entered in the fourth block.

Table 5.6

Frequencies and Percentages of Children Passing the Matrix Sort Task

	Mean (SE)		
Condition	Full Sample	4-Year-Olds	5-Year-Olds
Deductive, One Dimension	35 (94.6)	19 (90.5)	16 (100.0)
Deductive, Two Dimensions	46 (97.9)	21 (95.5)	25 (100.0)
Inductive, One Dimension	20 (51.3)	8 (40.0)	12 (63.2)
Inductive, Two Dimensions	23 (62.2)	12 (57.1)	11 (68.8)

Results for the first step of the regression are summarized in Table 5.7. There was a main effect for age, *Wald* = 4.29, $p = .04$, with 5-year-olds outperforming 4-year-olds (see Figure 5.4).

Table 5.7

Predicting Matrix Sort Task Performance

Variable	B (SE)	95% CI for Odds Ratio		
		Lower	Odds	Upper
Constant	-0.55 (0.45)			
Age (in years)	0.95 (0.46)*	1.05	2.59	6.36
Task Version	3.11 (0.64)**	6.32	22.34	78.91
Number of Dimensions in Practice Trial	0.57 (0.45)	0.74	1.77	4.26
Task Order	0.23 (0.45)	0.53	1.26	3.03

Note. Only main effects are shown, as none of the interaction terms tested were significant.
$R^2 = .24$ (Cox & Snell) .37 (Nagelkerke). Model $\chi^2(2) = 1.41$, $p = .49$.
*$p < .05$. **$p < .01$.

There was also a main effect for the version of the task, *Wald* = 23.28, $p < .01$. Children were more likely to pass the task if they saw the deductive version as compared with the inductive version (see Figure 5.5). There were no main effects for order or the number of dimensions included in the practice trial, and no interaction terms were significant. While the residuals for this analysis seemed in order (see Field, 2013, pp. 789-791, for a discussion on interpreting residuals), note that only three children who received a deductive version (all 4-year-olds, 2 girls) failed the

Matrix Sort Task. Thus, performance on the deductive version was at ceiling. Table 5.8 presents a cross-tabulation of age in years, inductive/deductive version, and performance on the Matrix Sort Task.

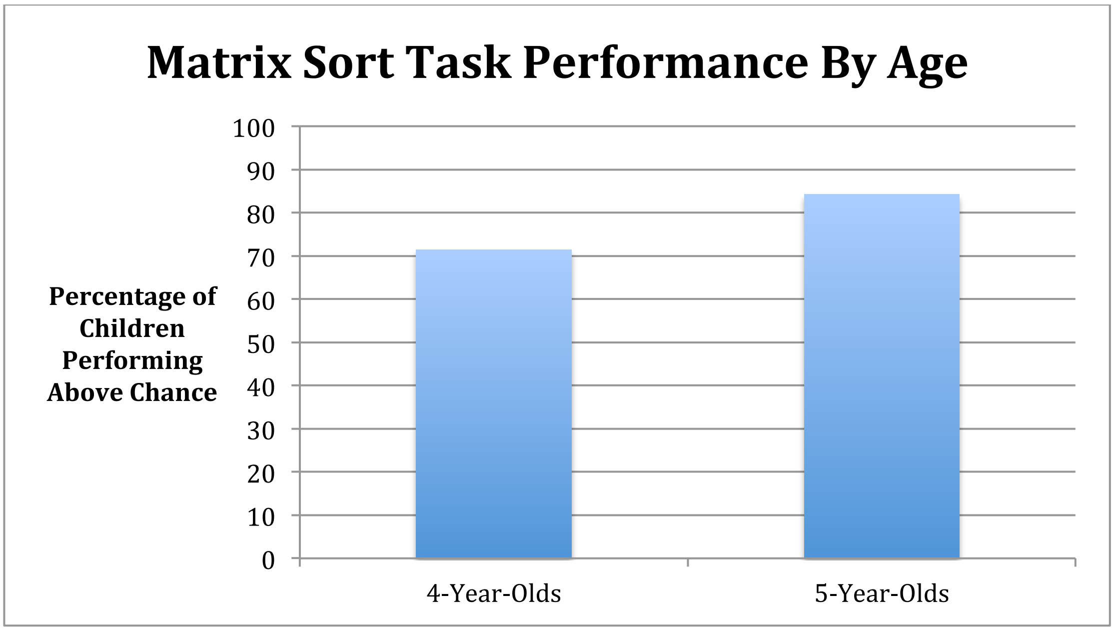


Figure 5.4 Percentage of children performing above chance on the Matrix Sort Task by age (collapsed across conditions).

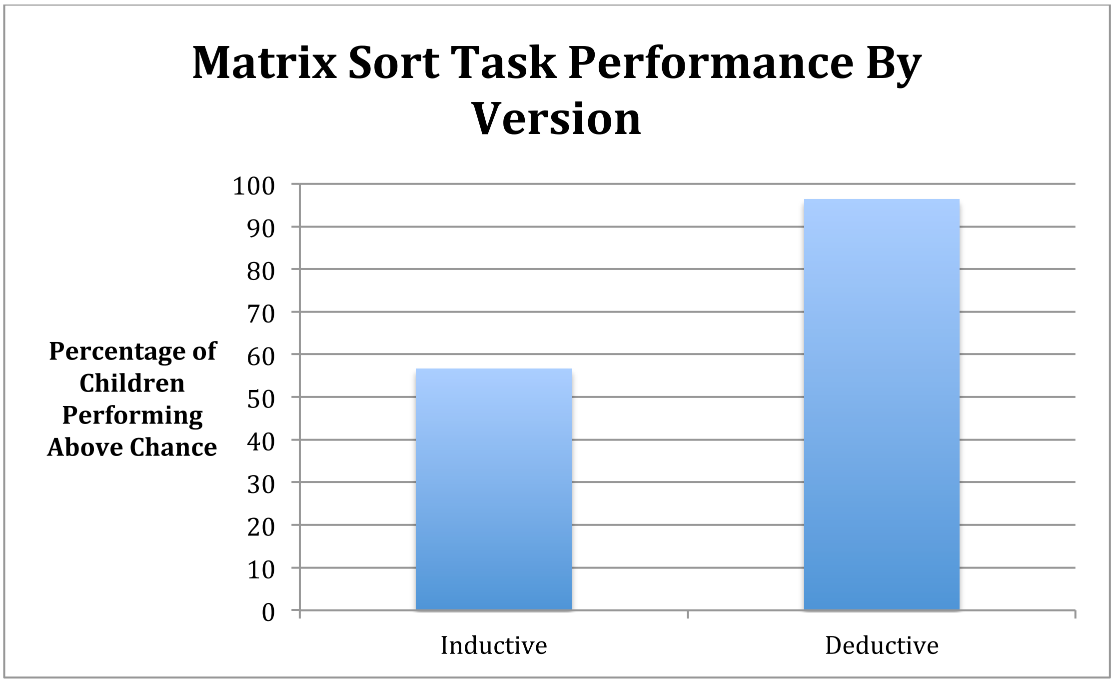


Figure 5.5 Percentage of children performing above chance on the Matrix Sort Task by version (collapsed across age groups).

Table 5.8

Matrix Sort Task Number of Passers By Age and Task Version

Age Group	Task Version	Matrix Sort Task Performance		Total
		Fail	Pass	
4-Year-Olds	Inductive	21	20	41
	Deductive	3	40	43
	Total	24	60	84
5-Year-Olds	Inductive	12	23	35
	Deductive	0	41	41
	Total	12	64	76
Total		36	124	160

***Preschool Matrix Completion Task*.**

Table 5.9 presents scores for the Preschool Matrix Completion Task for each condition and each order separately. An ANOVA, with task version (deductive vs. inductive), practice trial (1 vs. 2 dimensions demonstrated), task order (Preschool Matrix Completion Task first vs. Matrix Sort Task first) and age group (4 vs. 5 years) as predictors was used to examine performance on the Preschool Matrix Completion Task. Note that I decided to use an ANOVA despite the non-normal distribution of the Preschool Matrix Completion Task scores. I chose to use an ANOVA because: (a) the sample was large enough to allow for the assumption of normally distributed error terms (Field, 2013); (b) the Q-Q plots reflected normally distributed residuals (see appendix N); and (c) because there is no non-parametric equivalent for a factorial ANOVA, and the interactions between the factors were of interest.

Table 5.9

Mean Scores On The Preschool Matrix Completion Task By Condition, Order, and Age

	Mean (SE)					
	Full Sample		4-Year-Olds		5-Year-Olds	
Condition	PMC First	MST First	PMC First	MST First	PMC First	MST First
Deductive, One Dimension	1.71 (.48)	3.05 (.43)	1.90 (.66)	2.36 (.53)	1.43 (.75)	3.89 (.63)
Deductive, Two Dimensions	2.65 (.40)	3.67 (.56)	2.78 (.54)	2.37 (.86)	2.53 (.60)	4.70 (.58)
Inductive, One Dimension	2.75 (.50)	2.37 (.42)	1.67 (.67)	1.72 (.51)	3.64 (.64)	3.25 (.62)
Inductive, Two Dimensions	2.39 (.52)	3.42 (.44)	1.50 (.52)	2.82 (.55)	3.50 (.84)	4.25 (.65)

There were main effects for age, $F(1, 144) = 15.05$, $p < .01$, as well as for task order, $F(1, 144) = 6.08$, $p = .01$. These main effects, however, were qualified by a significant three-way interaction for age, task order, and version, $F(1,144) = 4.58$, $p = .03$. An examination of the simple effects (see Figure 5.6) showed that for 4-year-olds, there were no effects of task version or order—their performance was below chance and equally low on all variations. For 5-year-olds, however, the task version (inductive/deductive) interacted with the order in which the task was given. Specifically, in the deductive version: (a) performance was significantly poorer if the 5-year-olds received the Preschool Matrix Completion Task first; and (b) performance on the Preschool Matrix Completion Task was comparable to their performance on the inductive version if they received Matrix Sort Task first (recall that order had no effect on children's performance on the Matrix Sort Task).

Overall, 5-year-olds performed better than chance on the inductive version of the Preschool Matrix Completion Task. They also performed better than chance on the deductive version if they saw (a deductive) Matrix Sort Task first. However, if they saw the Preschool Matrix Completion Task first, in its deductive version, their performance was significantly below chance, similar to that of the 4-year-olds (see Figure 5.6).

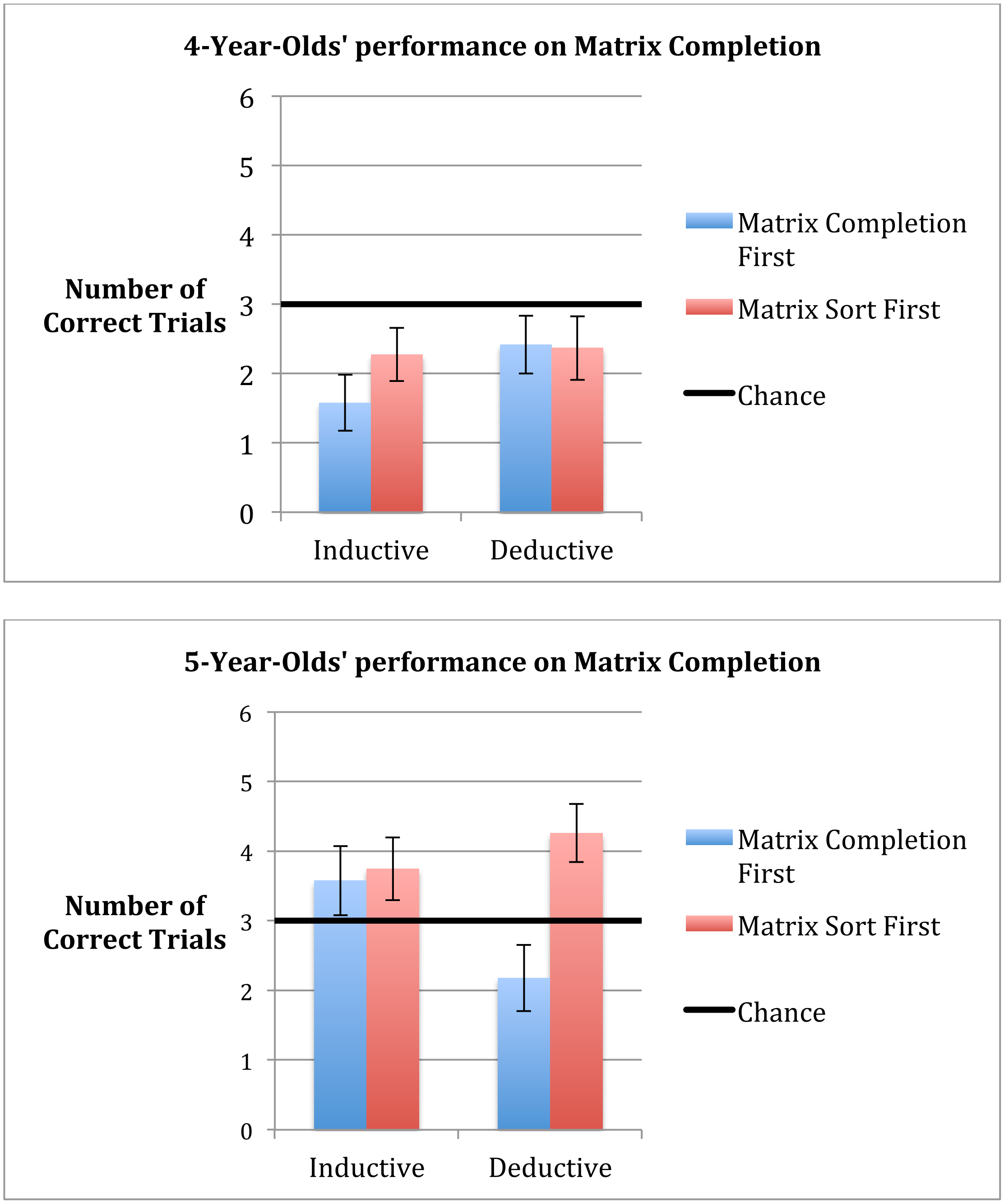


Figure 5.6 Performance on the Preschool Matrix Completion Task by condition and order, for 4-year-olds (top panel) and 5-year-olds (bottom panel). Error bars indicate standard errors. Bold black lines indicate chance performance.

Comparison Across Tasks

For descriptive purposes, I wanted to compare children's performance on the two tasks (to determine whether one was more difficult than the other). To do so, I used the pass/fail score for the Preschool Matrix Completion Task and compared it to the pass/fail score of the Matrix Sort Task. Table 5.10 presents the frequencies and percentages of children who passed the Preschool Matrix Completion Task, per condition and order.

Table 5.10

Frequencies and Percentages of Children Passing the Preschool Matrix Completion Task

	Frequency of Passers (Percentages out of condition)		
	All Age-Groups		
Condition	Full Sample	PMC First	MST First
Deductive, One Dimension	12 (32.4)	4 (23.5)	8 (40.0)
Deductive, Two Dimensions	24 (51.1)	13 (44.8)	11 (61.1)
Inductive, One Dimension	14 (25.9)	8 (40.0)	6 (31.6)
Inductive, Two Dimensions	15 (40.5)	6 (33.3)	9 (47.4)

(continued)

	Frequency of Passers (Percentages out of condition)		
	4-Year-Olds		
Condition	Full Sample	PMC First	MST First
Deductive, One Dimension	6 (28.6)	3 (30.0)	3 (27.3)
Deductive, Two Dimensions	10 (45.5)	7 (50.0)	3 (37.5)
Inductive, One Dimension	3 (15.0)	1 (11.1)	2 (18.2)
Inductive, Two Dimensions	5 (23.8)	1 (10.0)	4 (36.4)
	5-Year-Olds		
Condition	Full Sample	PMC First	MST First
Deductive, One Dimension	6 (37.5)	1 (14.3)	5 (55.6)
Deductive, Two Dimensions	14 (56.0)	6 (40.0)	8 (80.0)
Inductive, One Dimension	11 (57.9)	7 (63.6)	4 (50.0)
Inductive, Two Dimensions	10 (62.5)	5 (62.5)	5 (62.5)

Four-year-olds were more likely to pass the Matrix Sort Task than the Preschool Matrix Completion Task, regardless of the task version, *McNemar* $\chi^2(1) = 6.05$, $p = .01$, and *McNemar* $\chi^2(1) = 22.04$ and $p < .01$, for the inductive and the deductive versions, respectively. Five-year-olds, in contrast, were more likely to pass the Matrix Sort Task than the Preschool Matrix Completion Task, but only for the deductive version, $p < .01$ (binomial distribution used because no 5-year-old failed the Matrix Sort Task, deductive version). When they saw the inductive version, 5-year-olds were as likely to pass the Preschool Matrix Completion Task as they were to pass the Matrix Sort Task, *McNemar*

$\chi^2(1) = 0.06$, $p = .80$. In other words, performance on an inductive Preschool Matrix Completion Task was comparable to an inductive Matrix Sort Task for the older children. Children were as likely to pass the Preschool Matrix Completion Task and the Matrix Sort Task in both orders, and using both types of practice trials (see Table 5.10). Table 5.11 presents a cross-tabulation of children's performance on the matrix tasks by age and version.

Table 5.11

Cross-Tabulation of Age, Task Version, And Performance (Pass/Fail) On Concurrent Cognitive Flexibility Tasks

Age	Task Version	Preschool Matrix Completion Task Performance	Matrix Sort Task Performance		Total
			Fail	Pass	
4-Year-Olds	Inductive	Fail	17	16	33
		Pass	4	4	8
	Total		21	20	41
	Deductive	Fail	3	24	27
		Pass	0	16	16
	Total Deductive		3	40	43
	Total 4-Year-Olds		24	60	84

(continued)

Age	Task Version	Preschool Matrix Completion Task Performance	Matrix Sort Task Performance		Total
			Fail	Pass	
5-Year-Olds	Inductive	Fail	5	9	14
		Pass	7	14	21
	Total Inductive		12	23	35
	Deductive	Fail	0	21	21
		Pass	0	20	20
	Total Deductive		0	41	41
	Total 5-Year-Olds		12	64	76

Error Analysis

Though children did not perform differently on the Matrix Completion Task in terms of the overall number of errors made, as evidenced by the lack of a statistical difference in performance for the two types practice trials, the specific types of errors that children made, in addition to the number of errors that were made, were of interest for two reasons. The first reason was to test my hypothesis that children would make more duplicate errors when they saw a practice trial that varied on one dimension as compared with when they saw a practice trial that varied on two dimensions.

The second reason for the error analysis was to examine whether my interpretation of the performance from Study 1 had support. Because duplicate errors indicate children's tendency to focus on a single dimension, I could use this variable to examine my interpretation. Recall that I argued that labeling the relevant dimensions on a concurrent cognitive flexibility task direct children's attention to a single dimension. Thus, if children made more duplicate errors in the deductive as compared to the inductive version of the task, it would be in support my interpretation of Study 1 results. While this was not the original purpose of the study, I took advantage of the data in order to explore this possible explanation.[28]

In order to examine the errors children made on the Preschool Matrix Completion Task, I coded all errors as either matching one of the adjacent cells (a duplicate error), or as any other type of error, and used the proportion of duplicate errors out of all errors for each child as the dependent variable. Note that 81% of the errors children made were duplicate errors, and most children (67% of the children who made any errors) made *only* duplicate errors. Thus, the proportion of duplicate errors was not normally distributed, and non-parametric tests were used (see Appendix N for histograms and Q-Q plots). Descriptive statistics by condition are summarized in Table 5.12.

I examined main effects using 4 different Mann-Whitney tests (one for each factor: age in years, order of tasks, task version, and number of dimensions included in the practice trial). Moreover, from the descriptive statistics it appeared that the combination of inductive version and two dimensions included in the practice trial yielded a relatively low proportion of duplicate errors (see Table 5.12). I therefore

[28] Note that the Matrix Sort Task does not afford duplicate errors, and therefore no error analysis was done on this task.

examined this interaction with two more Mann-Whitney tests.[29] I used a family-wise alpha of .05/6 = .008, and exact p-values are reported unless otherwise indicated.

Table 5.12

Descriptive Statistics For Duplicate Errors on the Matrix Completion Task

	Mean (SE)		
Condition	Full Sample	4-Year-Olds	5-Year-Olds
Deductive, One Dimension	.92 (.04)	.88 (.06)	.98 (.02)
Deductive, Two Dimensions	.90 (.03)	.89 (.04)	.90 (.05)
Inductive, One Dimension	.84 (.04)	.80 (.06)	.88 (.05)
Inductive, Two Dimensions	.55 (.07)	.50 (.08)	.65 (.13)

Four-year-olds (*M rank* = 64.61) were as likely to make duplicate errors as 5-year-olds (*M rank* = 76.24), *Mann-Whitney's U* = 1929.0, *p* = .054. Similarly, the proportion of duplicate errors (out of all errors) was not significantly different when children saw the Preschool Matrix Completion Task first (*M rank* = 71.70) as compared with when they saw the Matrix Sort Task first (*M rank* = 66.80), *U* = 2188.5, *p* = .41. Thus, it seems that age and order of tasks affected the general performance in terms of the number of errors made, rather than specifically affecting children's likelihood of making duplicate errors.

[29] Because most errors children made were duplicate errors, the median for all tested groups was 1. As this seems uninformative, I report the mean rank for all the Mann-Whitney tests instead of the median.

The proportion of duplicate errors out of all errors was greater when children saw a one-dimensional practice trial (*M rank* = 77.08) than when they saw a two-dimensional practice trial (*M rank* = 61.92), although this comparison did not reach significance level, $U = 1857.5$, $p = .01$. In contrast, children were much more likely to make duplicate errors in the deductive version (*M rank* = 81.04) than in the inductive version (*M rank* = 56.91), $U = 1545.0$, $p < .001$.

These last two comparisons were qualified by a version by number of dimensions in the practice trial interaction. Specifically, when children saw a practice trial that varied along a single dimension, they were as likely to make duplicate errors in the inductive version (*M rank* = 31.21) as they were in the deductive version (*M rank* = 38.90), $U = 462.5$, $p = .05$. In contrast, when children saw a practice trial that varied along two dimensions, they were more likely to make duplicate errors in the deductive version (*M rank* = 43.16) as compared with the inductive version (*M rank* = 25.00), $U = 279.0$, $p < .001$. Thus, it appears that a practice trial that varies on two dimensions, on its own, cannot help children make fewer duplicate errors. However, when combined with an inductive task, a practice trial that varies along two dimensions did help children make less duplicate errors as compared with a practice trial that varied along a single dimension. Note that the difference between the inductive and deductive versions was not significant if children saw a practice trial that varied along

Discussion

Study 2 set out to carefully examine the effects of abstraction demands on children's concurrent cognitive flexibility performance, and the effects of the number of dimensions in the practice trial on children's performance on the Preschool Matrix

Completion Task. This study was the first systematic investigation of the effects of these factors in the context of preschoolers' concurrent cognitive flexibility performance.

One of my original goals was to localize the source of the difference in performance between Siegler and Svetina's (2002) matrix completion task and my Preschool Matrix Completion Task. In addition, following Study 1, I wanted to examine the relation between abstraction and concurrent cognitive flexibility more closely. This work provides a first step to understanding concurrent cognitive flexibility development in preschoolers, an area of research that has been thus far neglected. I begin with a review and discussion of the effects the two factors I examined in this study had on concurrent cognitive flexibility tasks, followed by a discussion of the implications the findings have on understanding concurrent cognitive flexibility development, along with some consideration of the limitations of this study.

Effects Of Inductive/Deductive Task Demands

Recall that I hypothesized, based on findings from Study 1, that children would find the deductive version of the concurrent cognitive flexibility tasks more difficult than the inductive version. The two tasks yielded conflicting findings. While performance on the Preschool Matrix Completion Task partially supported this hypothesis, performance on the Matrix Sort Task showed the reversed pattern: children performed better on the deductive version. I will first discuss the findings from the Matrix Sort Task and then from the Preschool Matrix Completion Task.

Matrix Sort Task.

Performance on the Matrix Sort Task did not support the hypothesis that children would find the deductive version more difficult than the inductive version, for this concurrent measure. In fact, children were significantly more likely to pass the deductive version than they were the inductive version.

One possible explanation for the finding that children were more likely to pass the deductive version of the Matrix Sort Task than the inductive version is that inductive/deductive task demands do, in fact, affect concurrent cognitive flexibility performance the same way they affect consecutive cognitive flexibility performance. In other words, it is possible that the findings from Study 1 were incidental, and that the findings from the Matrix Sort Task in this study provide a more accurate representation of the true relation between abstraction and concurrent cognitive flexibility. Unlike in Study 1, this finding is based on a *within*-task comparison of the task demands, thereby rendering it more likely to be a more accurate reflection of the effect of this factor. While this explanation cannot be ruled out based on the current study, it is important that we also consider the findings from the Preschool Matrix Completion Task (see below for a more detailed discussion on this topic).

In absolute terms, children performed similarly on both versions of the sort task: children solved, on average, about 4 trials correctly (that is, as a group, in about 4 trials out of 6 they placed the cards onto the grid exactly according to the labels) on both the inductive and deductive versions. It is important to note that performance on the inductive version was by no means poor, with more than half of the children passing this version (see Figure 5.5 and Table 5.8). But, performance was better for the deductive version once chance performance was considered (as it should be).

Note that, unsurprisingly, 5-year-olds did better on the Matrix Sort Task as a group than 4-year-olds. Nevertheless, age did not interact with the version of the task, indicating that both age groups found the deductive version easier than the inductive version. Note that only 3 children (all 4-year-olds) failed the deductive version of the Matrix Sort Task. It would be interesting, then, to examine 3-year-olds' performance on a deductive Matrix Sort Task to see whether the labels help even younger children with their concurrent cognitive flexibility performance. If so, it would suggest that under the right conditions, even 3-year-olds can coordinate two dimensions of the same stimulus, bringing the age of cognitive flexibility emergence even lower than what is currently believed (see, e.g., Cragg & Chevalier, 2012; Jacques & Zelazo, 2005).

Another point to consider with regards to the finding that children found the deductive version of the Matrix Sort Task easier than the inductive version is that the reliability measures of this task were much lower than those of the Preschool Matrix Completion Task (see Table 5.5). Note that this discrepancy was not due to the version differences I discussed before, as when I calculated the reliability estimates for each version (i.e., deductive and inductive) separately I received similar estimates. Thus, this task seems to be less reliable that the Preschool Matrix Completion Task.[30] Nevertheless, it may be that the different manipulations I used in this study affected the reliability of the Matrix Sort Task, and so an investigation of the reliability of this task—as well as other concurrent cognitive flexibility tasks that were developed for the purposes of this work—is warranted.

Preschool Matrix Completion Task.

Recall that while 4-year-olds performed fairly poorly on the Preschool Matrix Completion Task across the different conditions, they were not significantly different for the inductive versus deductive versions. In contrast, 5-year-olds' performance suffered in

[30] The reliability indices in Study 1 were consistent with this (see Table 3.4, p. 99).

the deductive condition (relative to the inductive), but *only* when the Preschool Matrix Completion Task was the first task they saw. These older children performed fairly well on the inductive version of the Preschool Matrix Completion Task, regardless of when they saw it.

The performance pattern exhibited by the 5-year-olds in the sample suggests that completing the Matrix Sort Task before performing the Preschool Matrix Completion Task had ameliorated the negative effect of the deductive version of the Preschool Matrix Completion Task. Note that I did not expect *a priori* that the order of the tasks would affect performance, and when I discovered that order affected performance on the original sample (the first 80 children collected), I decided to increase the sample so as to be able to examine this effect. Even with a doubled sample size (and greater power), order still exerted an effect on performance, indicating that it is important to take the effects of order on performance into consideration when designing studies examining cognitive flexibility development.

One possible explanation for this finding is that the Matrix Sort Task may have served as an *overlearning* opportunity for the 5-year-olds (Marcovitch et al., 2008). Typically, when learning a new response, repeated exposure to the stimulus-response pairing increases the strength of the response (i.e., the likelihood of the organism to perform the response). However, at some point (once learning is established), the behaviour becomes habitual; from that point on, the likelihood of the response does not increase, but rather remains stable (e.g., Mazur & Hastie, 1978)—this is the learning curve asymptote. Consider, for example, learning how to drive. The first time you took the driver’s seat the huge amount of information seems overwhelming, and responses are slow and halting. In short, you have to think about every single response. With repeated exposure and practice, however, driving becomes automatic, or habitual—your reach the learning curve asymptote (Marcovitch et al., 2008). Overlearning is when you are exposed to the stimulus-response pairing after your learning has reached an asymptote.

Marcovitch et al. (2008) argue that overlearning trials allow for an opportunity to reflect on the habitual responses. In the example of driving, it is much easier to navigate an unfamiliar area once your driving is automatic as compared to when you are still learning how to drive. The habitual response frees our cognitive resources—we no longer have to focus on operating the car and are able to think about navigating the space. The reflection afforded by overlearning trials allows the participant to overcome the habitual response in favour of a flexible one. Thus, argue Marcovitch et al. (2008), "overlearning should lead to more flexibility" (p. 137).

Children's performance on the Preschool Matrix Completion Task in Study 2 can be interpreted thus: overall, children succeeded less frequently on the deductive version of the Preschool Matrix Completion Task than they did on the inductive version. However, if they saw the Matrix Sort Task prior to the Completion Task, the Matrix Sort Task provided them with the opportunity to reflect on the task (via overlearning) and increased their likelihood to perform a flexible response instead of the habitual one (see Marcovitch et al., 2008).

That interpretation appears to fit the data, but then raises the question: Why, then, were the 4-year-olds not affected similarly? One explanation is that there were not enough trials to provide an overlearning opportunity, except perhaps for children who were already close to solving the task on their own. Specifically, the Matrix Sort Task contained 6 test trials, and previous research suggests that 6 habitual trials are not enough for infants and toddlers to arrive at a learning asymptote; they only begin to show more flexible responses after 11 trials (Marcovitch & Zelazo, 2006; Marcovitch, Zelazo, & Schmuckler, 2002). Adults, in contrast, show effects of overlearning after 5 habitual trials (Grant & Berg, 1948), and it could be that 5-year-olds require fewer trials to arrive at a learning curve asymptote than infants, toddlers, and, 4-year-olds. For instance, Vaughter (1968) demonstrated that 3- and 5-year-olds' flexibility in a reversal-learning task increased after 8 habitual trials as compared with 2 and 4 habitual trials. It seems that the number of trials required to arrive at an asymptote decreases with age.

Future research could test this explanation by varying the number of trials of Matrix Sort Task that the children receive before turning to the Preschool Matrix Completion Task. For instance, a study assigning 4- and 5-year-olds into three conditions, each receiving 3, 7, or 11 trials of the Matrix Sort Task before receiving a deductive version of the Preschool Matrix Completion Task, would be able to determine whether the number of Matrix Sort Task trials would affect its effectiveness as an overlearning opportunity. Moreover, it would be interesting to examine whether an inductive version of the Matrix Sort Task would have the same overlearning effect as a deductive version of the Matrix Sort Task. This would provide information regarding the role that inductive/deductive task demands play in children's tendency to engage in reflection (see, e.g., Jacques & Zelazo, 2005). If it were found that exposing children to more trials of the Matrix Sort Task prior to the Completion task improved performance, this approach could be utilized in interventions to help children perform better on concurrent cognitive flexibility tasks. Further, if future research finds that performance on these measures is predictive of other skills (e.g., problem-solving, creativity, and academic achievement), either concurrently or longitudinally, such an intervention could be tested to see if any gain extends to better developmental outcomes in these skills.

Effects Of Practice Trial Structure

My hypothesis that children who saw a practice trial that varied on one dimension would perform better on the Preschool Matrix Completion Task than children who saw a practice trial that varied on two dimensions was not supported. The number of dimensions varied on the practice trial did not affect performance on the Preschool Matrix Completion Task, nor did it interact with any of the other predicting variables (i.e., age, task version, and order).

I had also predicted that children who saw a practice trial that varied on one dimension would make more duplicate errors than children who saw a practice trial that varied on two dimensions. This hypothesis was partially supported. Children made more duplicate errors—in proportion to other errors they made—in the deductive version when they saw a practice trial that varied on one dimension as compared to when they saw a practice trial that varied on two dimensions. In other words, while the number of dimensions varied on the practice trial did not affect the number of errors children made overall, it did affect their likelihood to make a duplicate error when combined with a deductive (labeled) version.

The findings, then, seem to suggest that, on a deductive version of the Preschool Matrix Completion Task, children do make more duplicate errors if they see a practice trial in which the correct choice is a duplicate (i.e., a practice trial that varies on only one dimension). Children were least likely to make duplicate errors when they saw an inductive version of the task and a practice trial that varied on two dimensions (see Table 5.12). It is possible that an inductive version together with a practice trial that included two dimensions (and simulated the actual task the children were required to solve) helped children to avoid focusing on a single dimension of the stimulus. I will discuss possible explanations for this interaction below (in the section concerning the relation between abstraction and concurrent cognitive flexibility).

It may be worthwhile to examine whether seeing an inductive version of the Preschool Matrix Completion Task with a practice trial that varies on two dimensions has long-lasting effects on children's concurrent cognitive flexibility performance more generally. Future work could give children this combination of the Preschool Matrix Completion Task and then examine their performance later on a deductive version of the task. It is possible that this specific combination, as it yields the least likelihood of children focusing on a single dimension, may help children understand the structure of concurrent cognitive flexibility tasks more generally.

Localizing The Source Of Performance Differences

The original goal of this study was to localize the difference in performance between Siegler and Svetina's (2002) matrix completion task and my Preschool Matrix Completion Task. Recall that while in Siegler and Svetina's (2002) study 6-year-olds performed at chance, in a previous version of the Preschool Matrix Completion Task (Podjarny et al., in preparation) a sizable group of 4- and 5-year-olds reliably demonstrated the ability to consider two dimensions simultaneously. Recall that I made three changes to Siegler and Svetina's (2002) matrix completion task (see detailed discussion in Chapter 2, p. 40): (a) the task was deductive instead of inductive; (b) the practice trial varied on two dimensions instead of one; and (c) the number of relevant dimensions was reduced to two per trial. In this study, I examined the effects of the first two changes—inductive and deductive task demands and the number of dimensions varied on the practice trial—by experimentally manipulating these factors.

It appears that neither one of the factors I manipulated can individually account for the difference in performance between Siegler and Svetina's (2002) finding and my previous findings (Podjarny et al., in preparation). While children did better on the inductive version as compared to the deductive version, this was under specific conditions, namely, only 5-year-olds benefitted from this manipulation, and even then, only if they had the opportunity for overlearning created by first completing the Matrix Sort Task. Thus, this change cannot, on its own, account for the difference in performance.

Similarly, while the number of dimensions varied on the practice trial did not affect children's overall performance, it did have a specific effect on children's likelihood to make duplicate errors. As I mentioned before, duplicate errors are thought to reflect children's tendency to focus on one dimension instead of two or more (see, e.g., Siegler & Svetina, 2002; Inhelder & Piaget, 1964). Moreover, the combination of an inductive version of the Preschool Matrix Completion Task and a practice trial that varied on two dimensions seems to particularly affect children's likelihood of making duplicate errors. However, this combination did not have a particular effect on overall performance.

Note that the final change I made to the task, the number of relevant dimensions in the test trials, was not examined and instead were held constant across versions. An examination of this factor may clarify the results from this study. As I mentioned before, for the studies reported in this document I varied three dimensions (i.e., colour, shape, and size) as opposed to only varying two dimensions in a previous study (i.e., only shape and colour; Podjarny et al., in preparation). While the test trials only ever varied on two dimensions in both cases, it would appear that the mere inclusion of size as a relevant dimension in the task affected 4-year-olds' performance on the Preschool Matrix Completion Task: while in my previous study 48% of them passed the Preschool Matrix Completion Task, in the studies reported in this document the passing rates for this age group were between 22.6% in Study 1 (see Table 4.4, p. 136) and 28.6% in Study 2 (see Table 5.10, p. 201). Thus, the number of dimensions relevant in the task, as well as the number of dimensions varied in the test trials could explain the difference in performance.

An alternative explanation to the discrepancy between my previous study, in which 48% of the preschoolers passed the Preschool Matrix Completion Task, and the current work, is that they were done on different samples. While all three samples (i.e., in Study 1 and Study 2 of the current work and my previous study; Podjarny et al., in preparation) were taken from largely the same population (in the same city), we cannot rule out that the sample in my previous study was unrepresentative. This seems unlikely as, similar to Study 1, the sample in Study 2 exhibited fairly typical scores on the standardized tests (i.e., the Peabody Picture Vocabulary Test and the Primary Test of Nonverbal Intelligence), and fairly high performance on both the Black/White and the Flexible Item Selection Task (see Table 5.3). Thus, it is unlikely that the sample in this Study is very different from the sample in my previous study.

Future work could examine the effects of the number of dimensions included in the task more closely by manipulating both the number of dimensions varied in the test trials as well as the number of dimensions relevant for the task in general. For instance, one could have several version of the Preschool Matrix Completion Task, with one version varying only on shape and colour (both in the task in general and in each test trial), another version varying on shape, colour, and size in the task in general, but only two dimensions are relevant in each test trial (e.g., shape and colour in one trial, size and colour in the next, and so on), and a third version varying all three dimensions (colour, shape, and size) for each test trial. This kind of study would provide us with a better understanding of the specific effects that the number of dimensions has on children's performance on this task. For instance, if children find tasks that vary the stimuli along three dimensions but require a consideration of only two dimensions in each trial more difficult than tasks that only vary the stimuli along two dimensions, it would suggest that the context of the other trials in the task should be taken into consideration when examining children's cognitive flexibility skills. This insight would be useful for researchers when selecting tasks to examine children's cognitive flexibility performance and development.

Relation Between Abstraction And Concurrent Cognitive Flexibility

It appears that under some conditions children find inductive concurrent cognitive flexibility tasks easier, whereas under other conditions they find inductive tasks more difficult. Specifically, children found the deductive version of the Matrix Sort Task easier than the inductive version, but the 5-year-olds in the sample found the inductive version of the Preschool Matrix Completion Task easier than the deductive version, provided that they had the opportunity for overlearning.

One possible explanation for the discrepancy in performance between the two tasks is that I used a pass/fail score in the Matrix Sort Task and a continuous score in the Preschool Matrix Completion Task. A pass/fail score is less sensitive than a continuous score, and so it is possible that the results are due to the differences in sensitivity of the dependent variable.

One way to test this hypothesis is to manipulate abstraction demands on a different task that allows for a continuous score. For instance, the Pattern Completion Task's (Bennett & Müller, 2010) abstraction demands can be manipulated in a fairly straightforward way. Recall that in this task children are presented with a pattern and they need to complete it (see Chapter 2, p. 36, for a more detailed discussion of the task). This task is typically run without any labels, so it is an inductive task. The experimenter could provide labels for the items to create a deductive version (e.g., "this one is a red spider, this one is a red dragonfly, and this one is a blue dragonfly. Here we have another red spider, and another red dragonfly. What comes next?"). Using an array from which the child can choose an item to complete the pattern would enable researchers to control the chance levels of each trial, and using 6 or more test trials would allow researchers to use a continuous score as a dependent variable.

Another possible explanation for the discrepancy in performance between the two tasks is that the Matrix Sort Task does not allow for the possibility of making a duplicate error. Recall that almost all the errors children made in the Preschool Matrix Completion Task were duplicate errors. The Matrix Sort Task does not afford this kind of error because 4 different cards are presented for sorting. Duplicate errors, as noted before, reflect children's tendency to focus on one dimension instead of two.

One difference between a task that affords duplicate errors and a task that does not is that the former type of task may require higher inhibitory control skills. In other words, in the Preschool Matrix Completion Task children had to tap into their inhibitory control skills in order to inhibit using a perceptual matching strategy (i.e., choosing a card that is identical to one of the adjacent cells). In the Matrix Sort Task, in contrast, there was no such requirement.

As noted before, it appears that a combination of inductive demands and a practice trial that varied on two dimensions produced a relatively lower likelihood of duplicate errors. Recall that I argued before (see Chapter 4, p. 154) that when the experimenter labels the relevant dimensions she directs children's attention to a single dimension. It is possible, then, that when there is an option that is visually appealing (such as the duplicate cards, which match the adjacent cells) to focus on a single dimension, children are more likely to choose this option if their attention was directed to a single dimension (i.e., in the deductive version of the concurrent cognitive flexibility task). In contrast, if they had to induce the relevant dimensions on their own (as in the inductive version of the Preschool Matrix Completion Task) *or* if the visually appealing option to focus on a single dimension does not exist (as in the Matrix Sort Task), children can overcome their tendency to focus on a single dimension. Note that consistent with this notion, 5-year-olds, who as a group were affected by the task version on the Preschool Matrix Completion Task when it appeared first (i.e., before the Matrix Sort Task), found the inductive version of the Preschool Matrix Completion Task as easy as the inductive version of the Matrix Sort Task. This suggests that in the absence of labels to interfere with their performance, these children were able to coordinate two dimensions in both tasks. The 5-year-olds, however, did find the deductive version of the Matrix Sort Task easier than the deductive version of the Preschool Matrix Completion Task (see Table 5.11).

Note that one fairly straightforward way to examine this explanation would have been to examine the correlations between inhibitory control and the two deductive versions of the matrix tasks. If inhibitory control skills can account for the difference in performance, we would expect inhibitory control to be correlated with children's ability to solve the deductive version of the Preschool Matrix Completion Task, but not the deductive version of the Matrix Sort Task. That is, we would expect the correlation between inhibitory control and the deductive Preschool Matrix Completion Task to be significantly higher than the correlation between inhibitory control and the deductive Matrix Sort Task.

This was not the case in my sample (see Appendix O for non-parametric correlations). However, recall that children's performance on my inhibitory control measure, the Black/White, was very high (see Table 5.3), and so had little variability. It appears that the Black/White may be too easy for this age group, especially the 5-year-olds. Thus, the lack of correlation in my sample between inhibitory control and concurrent cognitive flexibility may be due to less variability in the inhibitory control task, as opposed to a true lack of relation between inhibitory control and concurrent cognitive flexibility.

Future research could test this explanation initially by using more difficult inhibitory control measures (i.e., ones that yield more variability in performance). A more difficult task may be required to tap this age group's inhibitory control skills and achieve sufficient variability to test the difference in correlation between the deductive versions of the Preschool Matrix Completion Task and the Matrix Sort Task. In fact, due to the task impurity problem (Miyake et al., 2000), a preferable approach would be to use several (at least 3; Kenny & Milan, 2012) inhibitory control measures, preferably tapping different input modalities (see discussion in Chapter 3, p. 53), and to extract a latent factor inhibitory control score to be used as a measure of inhibitory control.

Another way to test the idea that inhibitory control skills can account for the discrepancy in performance I found between the two tasks would be to vary the inhibitory control demands of each task and examine how that affects children's performance. For instance, based on the explanation I hypothesized, we would expect children to do better on a version of the Preschool Matrix Completion Task that contained no duplicate options in the answer cards. Akin to the manipulation done by Perner and Lang (2002; see Chapter 2, p. 17 for more details), this manipulation would reduce the 'visual clash' of the stimuli, and thus the inhibitory control demands of the tasks. However, note that the concurrent cognitive flexibility demands of coordinating two dimensions simultaneously would still be present in such a version. Based on my explanation, we would expect children to perform better on a version of the Preschool Matrix Completion Task that did not allow for any duplicate errors. Moreover, it would be expected that children with lower inhibitory control skills would benefit the most from this manipulation, with the assumption that children with high inhibitory control may be better able to handle the duplicate options.

Note that the second explanation I provided is generally consistent with the attentional inertia account. Specifically, the attentional inertia account argues that labels direct children's attention to a certain dimension (e.g., Kirkham et al., 2003). Similarly, I propose that, under certain conditions, when the experimenter labels the relevant dimensions it appears to direct children's attention to a single dimension, hindering their ability to coordinate both relevant dimensions. Again, the Cognitive Complexity and Control Theory (Revised) would not do as well when accounting for the findings from Study 2. So, though not designed to handle concurrent cognitive flexibility, the theories do differ in terms of the ease with which they could be extended to interpret my findings. Nevertheless, more work is required in order to tease apart these two theories in the context of concurrent cognitive flexibility development.

General Limitations and Conclusion

There are several general limitations to the current study that must be taken into consideration (in addition to those that have been discussed throughout the preceding sections). First, both tasks were of the matrix family. Inhelder and Piaget (1964) argued that the particular spatial arrangement of the matrix tasks may encourage a matching strategy (based on visual similarities rather than on relational ones). It could be that this characteristic of the matrix tasks affected the results, so these should be replicated with a concurrent cognitive flexibility task that does not follow the 2x2 grid arrangement. For example, as noted before, the abstraction demands of the Pattern Completion Task can be manipulated fairly easily. While I noted some limitations of this task before (see chapter

2, p. 36), we can use this task to test whether the results were derived by the 2x2 grid structure of the matrix tasks.

Another general limitation is that this study employed a between-subject design, for reasons I discussed above. A within-subject design—with order of administration carefully controlled—would allow us to test two things. First, it would allow us to test whether the effect of abstraction demands is an artefact of the methodological issues raised previously. Specifically, if the same child performs better on an inductive version of the Preschool Matrix Completion Task as compared to a deductive version, we can conclude more confidently that labels do interfere with children's ability to coordinate two dimensions simultaneously. Secondly, a within-subject design would allow us to determine whether we can use the abstraction effects to promote children's performance on concurrent cognitive flexibility tasks. For instance, if children who see an inductive version before a deductive version of the Preschool Matrix Completion Task do better on the latter version, but seeing a deductive version does not improve children's performance on an inductive version in a similar way, this would suggest that the inductive version could be used to enhance children's performance on concurrent cognitive flexibility tasks. Thus, interventions and curricula that promote concurrent cognitive flexibility could be devised based on such a study.

A third general limitation of this study, as I mentioned before, is that despite previous findings that at least some 4-year-olds can perform well on the Preschool Matrix Completion Task (Podjarny et al., in preparation), the 4-year-olds in this sample performed, as a group, at chance levels. It could be that the inclusion of size as a relevant dimension in some of the trials affected these children's performance, as discussed in

Chapter 4 and above. As I noted previously, this hypothesis should be tested directly in future research.

Despite these limitations, this study helps further our understanding of concurrent cognitive flexibility development. Based on the findings, it appears that inhibitory control may play an important role in concurrent cognitive flexibility development, as it does in consecutive cognitive flexibility development (see, e.g., Diamond, 2012; Kirkham et al, 2003). More work is required to examine this relation.

The findings from this study serve to emphasize the need for more work examining the specific conditions under which children are able to coordinate two dimensions concurrently. There is still much we do not know about when and how children become able to coordinate two dimensions concurrently. What we do know from this work is that careful task analysis and controls are required in order to understand and interpret children's performance on concurrent cognitive flexibility tasks.

One conclusion that can be drawn from this study is that there are some conditions under which children *can* coordinate two dimensions simultaneously. In contrast to previous research estimating that preschooler are unable to perform concurrent cognitive flexibility tasks (e.g., Halford, 1980; Halford et al., 1998; Inhelder & Piaget, 1964; Siegler & Svetina, 2002), this study demonstrated that task characteristics do affect children's performance on such tasks. Thus, it is not the case that younger children lack the capacity to consider two dimensions simultaneously (as suggested by Halford et al., 1998). It seems that previous research that used tasks that were too difficult or confusing for preschoolers had underestimated their abilities (see, e.g., Light & Nix, 1983; Perner, Stummer et al., 2002).

In the next chapter, the General Discussion, I shall discuss the findings of both Study 1 and Study 2 taken together, and how they contribute to the understanding of concurrent cognitive flexibility development during the preschool years.

Chapter 6: General Discussion

Imagine facing a problem to which you do not know the solution. For instance, imagine having a dataset you collected trying to answer a certain research question, but that now does not seem to answer this question. Various courses of action are available to you. You could abandon the endeavor altogether. Better yet, you could think about the data in other ways, and to try and figure out the story that the data tell you. In order to do so, you will rely on cognitive flexibility: the ability to think about something in more than one way (e.g., Cragg & Chevalier, 2012). Thus, this dissertation has itself been a real-life opportunity to solve problems in a new, creative way.

The goal of this work was to examine the early development of cognitive flexibility, with a focus on the emergence of concurrent cognitive flexibility. Whereas previous studies have placed the age in which this skill emerges around 7 years (e.g., Halford, 1980; Inhleder & Piaget, 1964; Siegler & Svetina, 2002), this work provides evidence that, given more age-appropriate conditions, even 3- and 4-year-olds show emerging concurrent cognitive flexibility skills. Moreover, it found that consecutive and concurrent cognitive flexibility are closely related skills.

Note that the finding that preschoolers are able to coordinate two and three dimensions concurrently (using the tasks I have developed) is inconsistent with findings from previous studies. Specifically, previous studies examining concurrent cognitive flexibility performance showed that children could not consider multiple dimensions simultaneously until they are closer to 7 years of age (e.g., Halford, 1980; Inhelder & Piaget, 1964; Parker et al., 1972; Siegler & Svetina, 2002). However, my findings are consistent with studies examining children's consecutive cognitive flexibility skills, which found that by the time they are 5 years old, children can switch from thinking about a stimulus along one dimension to thinking about it along a second dimension (e.g., e.g., Cragg & Chevalier, 2012; Garon et al., 2008; Jacques & Zelazo, 2001, 2005; Smidts et al., 2004; Zelazo, 2006). Thus, it appears that previous work examining concurrent cognitive flexibility had underestimated preschoolers' concurrent cognitive flexibility skills (see, e.g., Perner, Stummer, et al., 2002, for a similar argument).

One of the goals of this work was to establish an empirical differentiation between consecutive and concurrent cognitive flexibility skills, which, I argued at the outset, should be examined separately. The findings from Study 1 showed that there was no statistical support for a model that contained two latent cognitive flexibility factors (i.e., one consecutive and one concurrent). However, some of the tasks I used to measure consecutive and concurrent cognitive flexibility skills do correlate (see Table 3.5), and so there is reason to believe that consecutive and concurrent cognitive flexibility skills are related.

Despite consecutive and concurrent cognitive flexibility skills being related, the current work goes beyond just this linear correlation and provides preliminary suggestions as to (a) the nature of the relation between consecutive and concurrent cognitive flexibility skills in preschoolers; and (b) the factors that affect preschoolers' concurrent cognitive flexibility performance. These new findings can inform researchers when they decide which cognitive flexibility task to use for their investigations, as well as when they plan interventions and curricula to promote concurrent cognitive flexibility skills.

One interesting finding from the current work is that abstraction demands affect children's concurrent cognitive flexibility performance differently than they do their consecutive cognitive flexibility performance. In Study 1, I found an interaction in children's performance between the abstraction demands (whether the task was inductive or deductive) and the type of cognitive flexibility (concurrent or consecutive). Consistent with previous work (e.g., Doebel & Zelazo, 2013; Jacques & Zelazo, 2005), 3- and 4-year-olds found deductive (labeled) consecutive tasks easier than inductive (unlabeled) consecutive tasks. This pattern did not hold in concurrent cognitive flexibility tasks: the same children found the inductive task (Matrix Sort Task) easier than the deductive tasks (Preschool Matrix Completion Task and Multidimensional Card Selection Task). These results suggested that labeling the relevant dimensions hinders children's concurrent cognitive flexibility performance. However, because the tasks used were different it was not possible to fully determine the source of the difference in performance.

In Study 2, I partially replicated this finding using a more carefully controlled manipulation, and examined only concurrent cognitive flexibility performance. The results showed that 5-year-olds found the deductive version of the Preschool Matrix Completion Task more difficult than the inductive version of the same task, except when they had seen another matrix task first. In contrast, both 4- and 5-year-olds found the deductive version of the Matrix Sort Task easier than the inductive version of the same task, highlighting the complexity of the nature of the relation between abstraction and concurrent cognitive flexibility.

I have interpreted these findings in terms of the attentional inertia account (Diamond, 2006, 2012; Kirkham et al., 2003). According to this account, labels direct children's attention to a certain dimension when they are tasked with considering several dimensions of a single stimulus. In the context of consecutive cognitive flexibility, this attention-directing property of labels improves children's performance, as it helps them make a switch between the previously relevant dimension and the now-relevant dimension. In the context of concurrent cognitive flexibility, however, it appears that the attention-directing properties of labels work against the requirements of coordinating two dimensions in the task. Thus, the labels seem to interfere with the ability to consider several dimensions simultaneously, at least in some circumstances. This was related to the finding that children's performance was only affected on the task in which there is an answer that matches another item on the board on a single dimension. It seems, then, that the labels direct children's attention to a single dimension, and if an option that contains this single dimension is available, they are more likely to choose it. This interpretation also accounts for the lack of a difference between the inductive and deductive versions for the Matrix Sort task (as no such distractors exist).

This finding, and the current work in general, also hint at the role of concurrent cognitive flexibility within the structure of Executive Functions. From the findings in Study 1, we can conclude that concurrent cognitive flexibility is correlated with consecutive cognitive flexibility. However, the interaction between inductive task demands and cognitive flexibility type suggests that these skills are distinct in the sense that various factors differentially affect performance on consecutive, as compared with concurrent tasks. Moreover, inhibitory control (one of the other Executive Functions) seems to play an important role for both consecutive and concurrent cognitive flexibility skills, although it affects performance in different ways.

Another interesting issue raised from the current work involves the number of dimensions being coordinated. There are two ways to think about the number of dimensions being coordinated. Specifically, when examining cognitive flexibility performance, we need to consider both the number of dimensions being considered in every given trial as well as the number of dimensions that are relevant in the task in general. Note that I alluded to this issue in Chapter 2 when reviewing consecutive cognitive flexibility tasks. For instance, in the Dimensional Change Card Sort, only two dimensions are being varied. In the Modified Flexible Item Selection Task, two dimensions are being varied in every given trial, but there are three dimensions relevant in the task in general. Finally, in the Modified Object Classification Task for Children, the child is asked to consider the stimuli set along three dimensions. I noted before that, for example, Cragg and Chevalier's (2012) review included a reference to the stimulus valence, but not to the number of dimensions that the child was required to consider in each trial, and so their review describes both the stimuli in Flexible Item Selection Task and the Object Classification Task for Children as 'trivalent' (Cragg & Chevalier, 2012, p. 215).

The difference between the consecutive cognitive flexibility tasks and the concurrent cognitive flexibility tasks I used is that I did not have a task similar to the Dimensional Change Card Sort in terms of the number of dimensions relevant in the task in general. That is, I did not have a concurrent cognitive flexibility task in which the stimuli only varied along two dimensions: both the Preschool Matrix Completion Task and the Matrix Sort Task were similar to the Modified Flexible Item Selection Task in that they required coordinating two dimensions in every trial, but all three dimensions (colour, size, and shape) were relevant in the task in general. The Multidimensional Card Selection Task, in contrast, was similar to the Modified Object Classification Task for Children in that it required children to consider the stimuli along three dimensions in every trial.

Future investigations should take both ways of thinking about the number of relevant dimensions into account when selecting or designing tasks to measure cognitive flexibility in preschoolers. Note that while based on the relational complexity theory (e.g., Halford, 1980; Halford et al., 1998), as well as on my extrapolation on the Cognitive Complexity and Control Theory (Revised; Zelazo et al., 2003), we would expect children to have more difficulties when they are required to consider three, as compared with two, dimensions in a given trial. However, neither of these theories seem to predict that the number of relevant dimensions in the context of the task in general would affect children's performance on cognitive flexibility tasks. Note that while there is no direct evidence that the number of relevant dimensions in the task affects children's performance, this work provides some indirect support to this notion (see Chapter 5 for a more detailed discussion of how might future work test this hypothesis).

In general, then, the findings from this thesis suggest that an investigation of cognitive flexibility development should include measurement of both types of cognitive flexibility (concurrent and consecutive), of both types of tasks (inductive and deductive), and of both ways of thinking about the number of relevant dimensions (varied in every trial and varied in the context of the task). For instance, we might construct a battery of cognitive flexibility tasks that includes tasks that measure consecutive and concurrent cognitive flexibility skills. We would need to vary the abstraction demands (i.e., have both inductive and deductive tasks, preferably inductive and deductive versions for several tasks), and we would need to vary the number of dimensions children are asked to consider in each trial, as well as the number of relevant dimensions in the context of the task. This kind of battery, administered longitudinally to 3- to 8-year-olds would serve to document cognitive flexibility development in a more continuous way. It would allow us to examine the role that the three factors reviewed in this work play in cognitive flexibility development throughout early childhood. Further, it would enable researchers to examine whether there are changes in how well a structural equation model would best capture the data. Based on previous work (e.g., Lee et al., 2013), one would expect that with the youngest children, a single-factor model would best capture performance, with a dual-factor model (one for each type of cognitive flexibility) better capturing performance with the older children.

For the most part, my thesis findings are consistent with the attentional inertia account (e.g., Diamond, 2006, 2012; Kirkham et al., 2003) that claims that inhibitory control skills play a major role in children's cognitive flexibility performance. Two of the main findings can be most readily interpreted using the Attentional Inertia Account. The first is the finding that labels, while facilitating children's consecutive cognitive flexibility performance, interfere with their concurrent cognitive flexibility performance in tasks in which inhibitory control demands are higher (due to distractor items). The second is the finding that 3-year-olds' ability to coordinate three dimensions—consecutively and concurrently—is equivalent to their ability to coordinate two dimensions. Note that the finding that children found the deductive version of the Matrix Sort Task easier than the inductive version, while not necessarily consistent with the attentional inertia account, does not contradict it *per se* (see more detailed discussion in Chapter 5).

Nevertheless, some of the other findings—such as the Matrix Sort Task functioning as an overlearning opportunity for children solving the Preschool Matrix Completion Task in the deductive version—are more readily interpreted in the context of the Cognitive Complexity and Control Theory (Revised). As noted before, this work cannot provide a test between these two theories, as it was not designed to do so. However, it seems that both theories have merit and both are beneficial for understanding both concurrent and consecutive cognitive flexibility development during the preschool years.

Limitations and Future Directions

There are several general limitations to the current work (in addition to the study-specific limitations I discussed in previous chapters). First, all data was collected in a single city, and while efforts were made to include daycare centres and schools from all neighbourhoods in the city, the sample is likely not a fully representative sample of the general population. Thus, replications of the findings are required before the conclusions are generalized further.

Second, all the concurrent cognitive flexibility tasks I used were either adapted from previous work or developed for the purpose of the current work. While my work has provided an early introduction of these tasks, more work is required to examine the tasks' reliability to use in further research. For instance, the Matrix Sort Task was less reliable than the Preschool Matrix Completion Task, but this difference could be attributed to methodological issues (see more detailed discussion in Chapter 5).

Nevertheless, note that there were no tasks to measure concurrent cognitive flexibility skills that show any variability in preschoolers' performance—preschoolers showed very poor performance on all tasks used previously (e.g., Halford, 1980; Inhelder & Piaget, 1964; Parker et al., 1972). The tasks I have developed allow us to investigate concurrent cognitive flexibility development in preschoolers.

Future research should also examine the effects of other possible factors on children's concurrent cognitive flexibility performance. For instance, Diamond, Kirkham, and Amso (2002) found that forcing children to wait before providing an answer helped them overcome a prepotent response on the Day/Night Stroop task (which measures inhibitory control). If the critical factor playing a role in children's concurrent cognitive flexibility performance is the ability to direct their attention to both relevant dimensions, then a "stop-and-think" procedure should help them succeed on tasks such as the Preschool Matrix Completion Task. Understanding the factors that affect children's concurrent cognitive flexibility performance would allow us to understand how children become able to consider two (or more) dimensions simultaneously.

Another interesting avenue for future research is examining the differential predictive power of consecutive and concurrent cognitive flexibility on developmental outcomes. For instance, Perner et al. (2002) argue that concurrent, rather than consecutive, processes are critical for reasoning about others' mental states. Using the tasks I have developed to measure concurrent cognitive flexibility in preschoolers, future research can examine this question by investigating the relations between both consecutive and concurrent cognitive flexibility and early Theory of Mind (e.g., false belief reasoning). Recall that I noted that in the Executive Functions literature, despite the fact that inhibitory control and working memory are sometimes found to be indistinguishable using Structural Equation Modeling in young children (e.g., Lee et al., 2013), these two skills uniquely predict developmental outcomes such as academic achievements (see, e.g., Bull & Scerif, 2001; St. Clair-Thompson & Gathercole, 2006). Similarly, it could be that consecutive and concurrent cognitive flexibility skills, although correlated, may uniquely explain some developmental outcomes. For example, we know that in older children, performance on concurrent cognitive flexibility tasks is linked to reading proficiency (Cartwright et al., 2010; Colé et al., 2014) and analogical reasoning (see Siegler & Svetina, 2002). In contrast, performance on consecutive cognitive flexibility tasks predicts later performance on mathematical assessments (Coldren, 2013). Carefully examining the roles that consecutive and concurrent cognitive flexibility play in children's cognitive development will provide us with a better understanding of the different routes to successful developmental outcomes.

Final Conclusions

This work opens the door to investigating concurrent cognitive flexibility skills in 3- to 5-year-olds, a period of life in which major developments in other Executive Functions occur. Thus, a major contribution of this work is developing new tasks that can be now used to examine an area in preschoolers' cognitive development that has not yet been investigated.

In addition, this work has begun to document the kinds of considerations researchers should keep in mind when investigating concurrent cognitive flexibility development. It has highlighted the role that abstraction demands, as well as the number of dimensions to be considered, play in preschoolers' consecutive and concurrent cognitive flexibility performance. And, it has provided preliminary suggestions as to which factors could be investigated further.

Using the tasks I have developed, researchers can now examine a variety of research questions and to further our knowledge about cognitive flexibility in children. This knowledge, in turn, will help us further refine the measures, extend and develop theories to account for development, better identify children who have difficulties with concurrent cognitive flexibility, as well as inform research about the predictive power of cognitive flexibility in general (consecutive and concurrent cognitive flexibility in particular) on developmental outcomes.

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Appendices

Appendix A: Structural Equation Modeling Details

This appendix details the Structural Equation Modeling procedure, model specifications, and results I have used in Study 1. I begin with an overview of Structural Equation Modeling, followed by a description of the model specifications I used and a discussion of estimation issues and model fit indices. I then describe the results of the Structural Equation Modeling.

Structural Equation Modeling—Overview and Analysis Plan

Structural Equation Modeling is an advanced statistical technique that allows for the estimation of common variance between variables (Hoyle, 2012). In other words, Structural Equation Modeling allows researchers to investigate the relations between observed variables to create latent constructs and examine the relations between those latent variables. It is particularly useful for psychological research, in which variables of interest often cannot be measured directly. Cognitive flexibility (both concurrent and consecutive) is one example of a latent construct that cannot be measured directly, and this characteristic lends itself to using Structural Equation Modeling.

In Structural Equation Modeling the covariances between observed variables are examined, and common variance is extracted to create a latent variable (see Hoyle, 2012). Structural Equation Modeling is a confirmatory approach, and therefore can be used to support or refute a theory about the relations between latent variables. In the current study, I have used Structural Equation Modeling to examine the separability of cognitive flexibility into two related structures: concurrent cognitive flexibility and consecutive cognitive flexibility. In order to achieve this goal, I tested four models: the first two contained only cognitive flexibility tasks, with one model specifying all cognitive flexibility tasks as loading onto a single factor (see Figure A1), and the second specifying two related factors of cognitive flexibility (consecutive and concurrent cognitive flexibility, with the appropriate tasks loading on each; see Figure A2). In effect, the first two models reflected a confirmatory factor analysis rather than actual Structural Equation Modeling, because Structural Equation Modeling by definition also specifies causal relations between different latent variables. The latter two models contained, in addition to cognitive flexibility tasks, other variables as well. Specifically, I combined children's inhibitory control, working memory, receptive language, nonverbal IQ, and age in months into one "covariate" variable in order to test the separability of the two cognitive flexibility factors above and beyond these covariate variables (see, e.g., Muthén, 2002). These models specified either one or two factors of cognitive flexibility with the covariate variable as predicting cognitive flexibility variability. The question that was asked was not whether executive functions and other cognitive skills indeed predict cognitive flexibility performance, but whether this prediction is more useful with cognitive flexibility being specified as either one or two factors (i.e., an overall construct of cognitive flexibility, or two separable constructs of consecutive cognitive flexibility and concurrent cognitive flexibility).

I used a Weighted Least Square – Mean and Variance adjusted (WLSMV; Muthén, 1984) estimation. This estimation method is a Full Information Maximum Likelihood (FIML) method, which means that it uses the raw data as opposed to calculating correlations and fitting the model using these correlations (Lei & Wu, 2012). This method is recommended when estimating a model that includes categorical data, as it was found to perform better than other estimation methods that enable the use of categorical variables (see, e.g., Edwards, Wirth, Houts, & Xi, 2012; Lei & Wu, 2012).

For all models, four goodness-of-fit indices are reported (see Table A1). The Chi-Square test (Jöreskog, 1969) is the basic goodness-of-fit test. The Chi-Square fit test compares the null hypothesis – that the model specified by the researcher is true in the population – with the alternative hypothesis – that the model specified by the researcher is not true in the population. Significant χ^2 values indicate that the specified model does not fit the data. However, the Chi-Square test has many limitations, including, for instance, relying on the assumption that the observed variables have a multivariate normal distribution. Since several of the observed variables in this study are categorical, this assumption will not hold. Therefore, a significant Chi-Square fit index for the specified model may indicate that the model is false, but it may also (more likely) indicate that the assumptions are not met (see West et al., 2012 for a discussion). Because of these limitations, other indicators are also reported. The Root Mean Square Error of Approximation (RMSEA; Steiger & Lind, 1980) tests how badly the model fits the χ^2 distribution using the non-centrality parameter estimation. It penalizes for over-fitting the model (i.e., all things being equal, a more parsimonious model will perform better) and is a popular goodness-of-fit index (West et al., 2012). A value of less than .05 indicates a close fit, and the upper limit of the confidence interval (CI) should not exceed .08 (West et al., 2012). The RMSEA underestimates fit in sample sizes of less than 200 (which is the case in the current project). The Comparative Fit Index (CFI; Bentler, 1990) is another popular goodness-of-fit index, which compares the specified model to an independence model (a model in which there are no correlations between the observed variables). The Tucker-Lewis Index (TLI; Tucker & Lewis, 1973) is also popular, and was originally proposed for exploratory factor analyses. The TLI also compares the specified model with an independence model, penalizing for model complexity. For both the TLI and the CFI, a value of above .95 indicates a good fit for the specified model.

Results

The analyses were conducted using Mplus version 7.3 for mac. Comparing the measurement model of cognitive flexibility as either a one-factor (Figure A1) or a two-factor solution with consecutive and concurrent cognitive flexibility as separate, but related, factors (Figure A2), it is clear that the two models are fairly comparable (see Table A1). Note that the Figures present non-standardized parameter estimates. Tables A2 and A3 detail the tetrachoric correlations and the residuals for the first and second model, respectively. Both of them, however, do not fit the data well. Both RMSEA indices, for instance, were close to 0.2, where the recommendation is for them to be lower than 0.05. Moreover, both the Modified Object Classification Task for Children and the Matrix Sort Task showed fairly poor loadings: the loadings were -.44 and .19, respectively, onto the single-factor and -.32 and .24, respectively, onto the two-factor solution (see Figures A1 and A2). Note that while the loading for the Modified Object Classification Task for Children in the first model was just significant, $p = .047$, all the other loadings were not significant, $ps > .078$ (see Brown & Moore, 2012, for a discussion). Recall that both these tasks are inductive tasks; however, so was the Flexible Item Selection Task, which served as a scaling indicator because it had the highest loading onto the latent factors. It is possible that the variability associated with the type of task (i.e., inductive vs. deductive) overlapped with the variability associated with the type of cognitive flexibility skill (i.e., consecutive vs. concurrent), causing the entire model to provide a poor fit. I did not have enough indicators to separate out these four factors using a Structural Equation Modeling analysis, but see Chapter 4 for a discussion on the relation between cognitive flexibility type and task type.

When comparing the two models, because the single factor model is more parsimonious, there is no justification to separate consecutive from concurrent cognitive flexibility in preschoolers, at least from a structural analysis point of view. Note as well that the correlation between consecutive and concurrent cognitive flexibility latent factors was fairly high (r = .70), indicating that the two constructs are correlated. I examined the same models with a covariate variable that included inhibitory control, working memory, age, language, and nonverbal intelligence (Z scores calculated using the entire sample were used for all variables in order to level the scale). Both of these models did not provide a valid estimation, because the covariate latent variable was highly correlated with the latent cognitive flexibility factor in the single-factor solution and to the consecutive cognitive flexibility factor in the two-factor solution (both rs > 1). This high correlation suggests that perhaps separating cognitive constructs is problematic with this age group (see, e.g., Lee et al., 2013; Wiebe et al., 2008).

Table A1

Goodness-of-fit Indices and Model Comparison

Model	χ^2	df	p-value	RMSEA	RMSEA CI (lower-upper)	CFI	TLI
1. One cognitive flexibility factor	100.88	18	.00	.19	.16-.23	0	-0.52
2. Two cognitive flexibility factors	95.44	16	.00	.20	.16-.24	0	-0.64

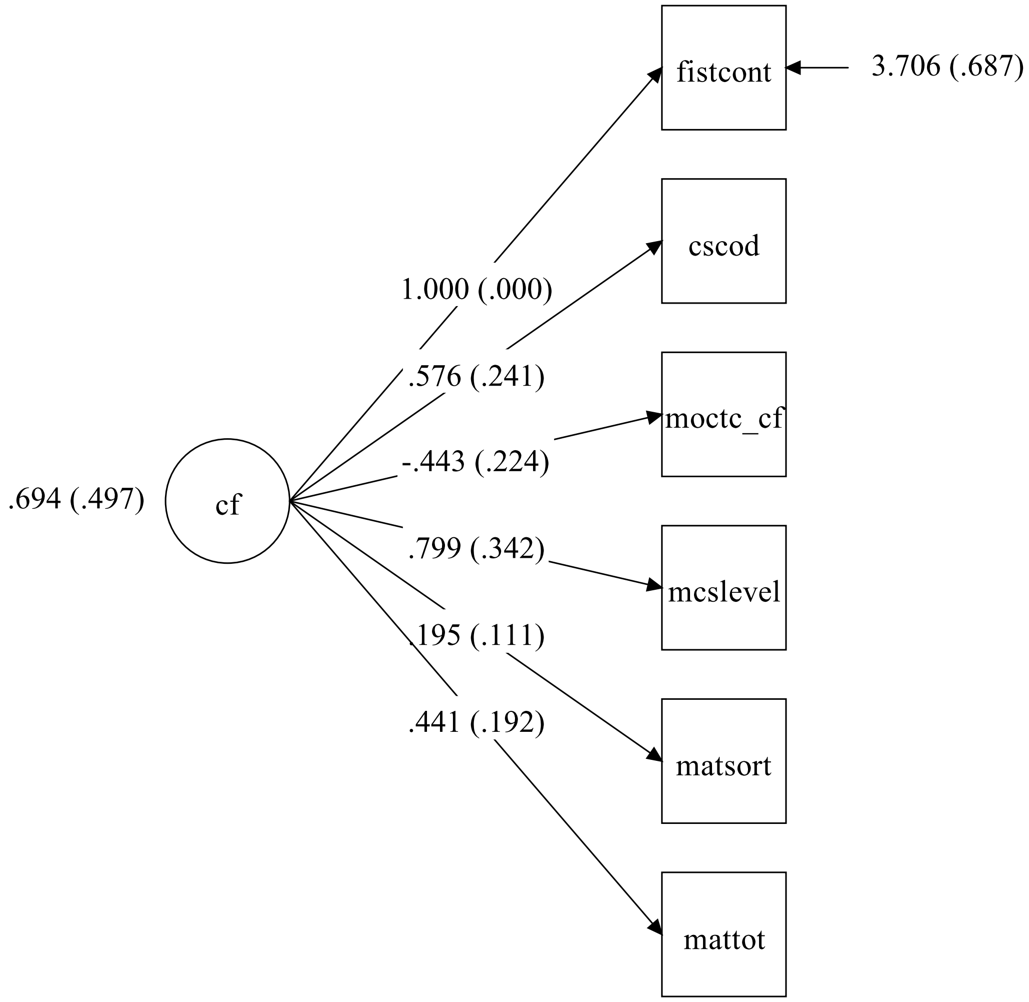


Figure A1 Cognitive flexibility as a single factor. Non-standardized loadings are reported. cf = cognitive flexibility; fistcont = Modified Flexible Item Selection Task contingency score; cscod = Dimensional Change Card Sort pass/fail score; moctc_cf = Modified Object Classification Task for Children flexibility score; mcslevel = Multidimensional Card Selection Task flexibility score; matsort = Matrix Sort Task score; mattot = Preschool Matrix Completion Task score.

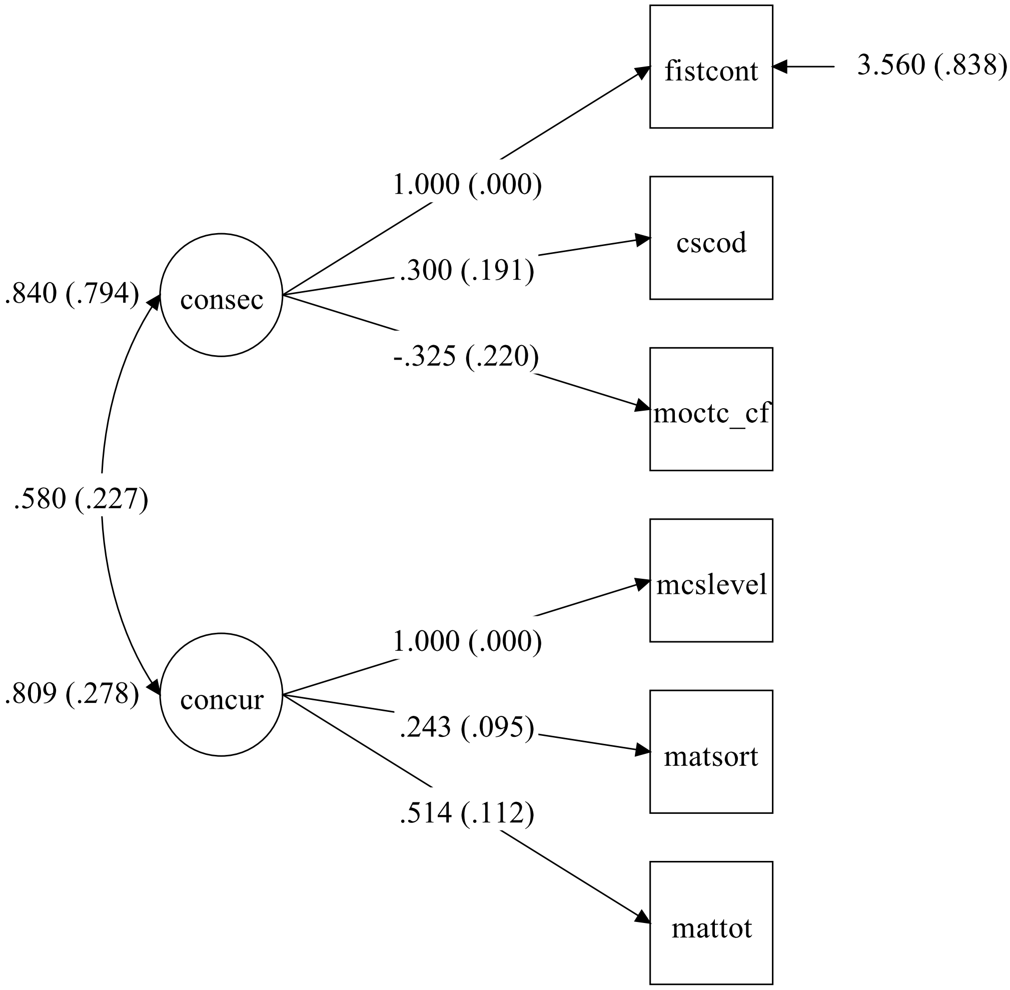


Figure A2 Cognitive flexibility as two factors. Non-standardized parameters are reported. cf = cognitive flexibility; fistcont = Modified Flexible Item Selection Task contingency score; cscod = Dimensional Change Card Sort pass/fail score; moctc_cf = Modified Object Classification Task for Children flexibility score; mcslevel = Multidimensional Card Selection Task flexibility score; matsort = Matrix Sort Task score; mattot = Preschool Matrix Completion Task score.

Table A2

Tetrachoric Correlations and Residuals For Model 1

	DCCS	MFIST	MOCTC	PMC	MST	MCS
DCCS	-	0.400	-0.177	0.177	0.078	0.320
MFIST	0.270	4.400	-0.308	0.307	0.135	0.555
MOCTC	0.349	0.561	-	-0.136	-0.060	-0.246
PMC	0.200	-0.098	0.315	-	0.060	0.245
MST	0.165	0.334	0.027	0.239	-	0.108
MCS	0.069	-0.077	0.253	0.103	0.077	-

Note. Tetrachoric correlations presented above the diagonal, residuals below. The diagonal contains the variance if applicable. DCCS = Dimensional Change Card Sort; MFIST = Modified Flexible Item Selection Task; MOCTC = Modified Object Classification Task for Children; PMC = Preschool Matrix Completion Task; MST = Matrix Sort Task; MCS = Multidimensional Card Selection Task.

Table A3

Tetrachoric Correlations and Residuals For Model 2

	DCCS	MFIST	MOCTC	PMC	MST	MCS
DCCS	-	0.252	-0.082	0.089	0.042	0.174
MFIST	0.419	4.400	-0.273	0.298	0.141	0.580
MOCTC	0.254	0.526	-	-0.097	-0.046	-0.189
PMC	0.287	-0.089	0.276	-	0.101	0.416
MST	0.201	0.328	0.013	0.197	-	0.197
MCS	0.215	-0.102	0.196	0.068	-0.012	-

Note. Tetrachoric correlations presented above the diagonal, residuals below. The diagonal contains the variance if applicable. DCCS = Dimensional Change Card Sort; MFIST = Modified Flexible Item Selection Task; MOCTC = Modified Object Classification Task for Children; PMC = Preschool Matrix Completion Task; MST = Matrix Sort Task; MCS = Multidimensional Card Selection Task.

Appendix B: Dimensional Change Card Sort Protocol

Standard DCCS – Boats and Rabbits

Present boxes. Show target cards (one at a time) while placing on boxes and saying

Here is a blue boat and here is a red rabbit. This one is blue, and this one is red.

We are going to play a game. This is the colour game. The colour game is different from the shape game. All the blue ones go in this box *(pointing)*, **and all the red ones go in that box** *(pointing)*. **We don't put any blue ones in that box** *(pointing again)*. **No way. We put all the blue ones over here** *(pointing)* **and only red ones go over there** *(pointing)*. **This is the colour game.**

Demo Sort: **Here is a blue one. This one goes here because it's blue.**
Child Sorts: **Here is a red one. Where does this one go?**

Feedback: **Very good** *or* **No, this one's red, so it goes over here.**

Okay, now I'm going to show you some blue ones and red ones.

Show preswitch cards, one at a time:

If it's a blue one, then it goes here. If it's a red one, then it goes there.

Show the card:	**It's a ____ ____ (blue/red one).**	ACCURACY (V or X)
Give child the card:	**Where does this go?**	☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐
No Feedback:	**Let's do another one!**	

Okay, now we're going to switch, so I'm going to put my switch cards in now *(put switch cards in)*. **We are not going to play the colour game anymore. We are going to play the shape game. All the boats go in this box** *(pointing)*, **and all the rabbits go in that box** *(pointing)*. **We don't put any boats in that box** *(pointing again)*. **No way. We put all the boats over here** *(point)* **and only rabbits go over there** *(pointing)*. **This is the shape game.**

Show 8 post-switch cards and for each:

If it's a boat, then it goes here. If it's a rabbit, it goes there.

Show the card:	**It's a ____ ____ (boat/rabbit).**	ACCURACY (V OR X)
Give child the card:	**Where does this go?**	☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐
No Feedback:	**Okay, let's do another one!**	

Children cannot re-sort once card is in box.

Appendix C: Modified Flexible Item Selection Task Protocol

Favourite Game: Checking Children Can Point To Two Out Of Three Pictures

Flexible Item Selection Task – Favourites

(Open to blank sheet)

Now you and I are going to pick some of our favourite pictures together. I'm going to pick my favourite pictures first, and then it will be your turn. Okay?

(Turn to demo trial)

See, here's a picture *(point)*, **here's another picture** *(point),* **and here's another picture** *(point)*. **I'm going to pick my two favourite pictures, so I'm going to point to this picture here** *(point to 1)* **and to this picture here** *(point to 3)* **because these are my two favourite pictures** *(point back and forth)*.

I'm not going to point to the other picture, because it's not one of my favourites.

I'm only going to point to these two *(pointing back and forth)* **because these two pictures are my favourite pictures.**

For each item selected, enter corresponding number (1 = Left, 2 = Center, 3 = Right)

1. Now it's your turn. Can you point to your two favourite pictures?

Child Selects: _____ _____ 2nd try: _____ _____

If child selects two pictures, feedback:

So these are your two favourite pictures *(pointing)*? **Good job! You didn't point to the other picture because it's not one of your favourites, is it? No! So you only pointed to your two favourite pictures** *(pointing)*, **good for you!**

If child selects only one picture, prompt:

Remember to point to TWO of your favourite pictures. You pointed to this one *(point to picture child indicated)* **because that is one of your favourite pictures, now point to your other favourite picture.**

If child selects all three pictures, correct:

Remember to only point to your TWO favourite pictures. Can you try again? Only point to TWO of your favourite pictures.

2. Now it's your turn again. Can you point to your two favourite pictures here?

Child Selects: _____ _____ 2nd try: _____ _____

If child selects two pictures, feedback:

So these are your two favourite pictures *(pointing)***? Good job! You didn't point to the other picture because it's not one of your favourites, is it? No! So you only pointed to your two favourite pictures** *(pointing)***, good for you!**

If child selects only one picture, prompt:

Remember to point to TWO of your favourite pictures. You pointed to this one *(point to picture child indicated)* **because that is one of your favourite pictures, now point to your other favourite picture.**

If child selects all three pictures, correct:

Remember to only point to your TWO favourite pictures. Can you try again? Only point to TWO of your favourite pictures.

3. Let's try one more. Can you point to your two favourite pictures here?

Child Selects: _____ _____ 2nd try: _____ _____

If child selects two pictures, feedback:

So these are your two favourite pictures *(pointing)***? Good job! You didn't point to the other picture because it's not one of your favourites, is it? No! So you only pointed to your two favourite pictures** *(pointing)***, good for you!**

If child selects only one picture, prompt:

Remember to point to TWO of your favourite pictures. You pointed to this one *(point to picture child indicated)* **because that is one of your favourite pictures, now point to your other favourite picture.**

If child selects all three pictures, correct:

Remember to only point to your TWO favourite pictures. Can you try again? Only point to TWO of your favourite pictures.

Modified Flexible Item Selection Task Test Trials

Flexible Item Selection Task
Test Trials

(Starting on blank page before test trials)

Now you and I are going to play a different pictures game. We're going to pick some more pictures together, but we are going to pick them in a different way. I'm going to pick some pictures first, just to show you how we play this new game, and then it will be your turn. Okay? *(turn to demo page)*

Demonstration Trial:

Selection 1:

I'm going to pick two pictures that go together in one way. So I'm going to point to this picture here *(point to 1)* **and to this picture here** *(point to 2)***, because these two pictures** *(pointing)* **go together in one way. The other picture doesn't go with these two pictures here. No way! These two pictures go together in one way** *(pointing)***.**

Child Labels: ____________

Selection 2:

Now, do you know what I'm going to do? I'm going to pick two pictures that go together, but in another way. So I'm going to point to this picture here *(point to 2)* **and to this picture here** *(point to 3)***, because these two pictures** *(pointing)* **go together in another way. The other picture doesn't go with these two pictures here. No way! These two pictures go together** *(pointing)***, but in another way.**

Child Labels: ____________

Summary:

So these two pictures *[point to 1 and 2]* **go together in one way and these two pictures go together** *[point to 2 and 3]***, but in another way.**

<u>Feedback for Practice Trials:</u>

Child Selects Matching Pair:

> **You know what? You're right! These two pictures** *(pointing)* **go together in one way. The other picture doesn't go with these two pictures here. No way! So these two pictures** *(pointing)* **go together in one way.**

Child Selects incorrect pair, no items, one item, or all three items:

> **Good try, but you know what? These two pictures go together in one way** *(pointing)***. The other picture doesn't go with these two pictures here. No way! These two pictures go together in one way** *(pointing)***.**
>
> **Now can you point to two pictures that go together, but in another way?**

<u>Practice Trial 1:</u>

Now it's your turn! Can you point to two pictures that go together in one way?

Selection 1: _____ _____ Child Labels: _______________

Selection 2: _____ _____ Child Labels: _______________

<u>Summary:</u>

So these two pictures *[selection 1]* **go together in one way and these two pictures go together** *[selection 2]***, but in another way.**

Great job! Let's do another one!

<u>Practice Trial 2:</u>

Now it's your turn to pick some pictures again! Can you point to two pictures that go together in one way?

Selection 1: _____ _____ Child Labels: _________________________

Selection 2: _____ _____ Child Labels: _________________________

<u>Summary:</u>

So these two pictures *[selection 1]* **go together in one way and these two pictures go together** *[selection 2]***, but in another way.**

<u>Test Trials</u>

I think you know how to play my game now. So we can go a little bit faster.

No Feedback, general praise only. For each:

Show me two pictures that go together in one way, *then*
Now, show me two pictures that go together, but in another way:

1.1	_____ _____	label: _______________	**5.1**	_____ _____	label: _______________
1.2	_____ _____	label: _______________	**5.2**	_____ _____	label: _______________
2.1	_____ _____	label: _______________	**6.1**	_____ _____	label: _______________
2.2	_____ _____	label: _______________	**6.2**	_____ _____	label: _______________
3.1	_____ _____	label: _______________	**7.1**	_____ _____	label: _______________
3.2	_____ _____	label: _______________	**7.2**	_____ _____	label: _______________
4.1	_____ _____	label: _______________	**8.1**	_____ _____	label: _______________
4.2	_____ _____	label: _______________	**8.2**	_____ _____	label: _______________

Children are allowed to self correct.

If child labels, record (e.g. “colour” or “shape” or “size”) and mark if correct with a ✓ or ×

Appendix D: Modified Object Classification Task for Children Protocol

Introduction Trial

Modified Object Classification Task for Children (M-OCTC)
Introduction Trial

(Table is empty)

Now you and I are going to play with some cards. Okay? *(take out intro cards set 1, show first pair)*
See, here I have a banana and a rabbit. *(show second pair)*
See, these cards are the same as the ones you have there. The cards that are the same go together. Can you put the cards that go together on this side of the table *(point to one side of the table)***, and the other two that go together on that side of the table** *(point to the other side of the table)***?**

Feedback for Introduction Trial:

Child Sorts correctly:

You know what? You're right! These two cards *(pointing)* **go together, and those two cards go together** *(pointing)***.**

Child Sorts incorrectly:

Good try, but you know what? These two cards go together *(sort)***, and these two cards go together** *(sort)***.**
Let's try it with some more cards.

Repeat with Intro cards set 2 only if child sorted the first pair incorrectly
For intro cards 2: **here I have a sheep and glasses**.

**** If Child fails in both introduction trials, terminate task. ****

Demonstration Trial

Demo Trial

Now let's look at some other cards.
Look, I have six cards here, see? *(show all six cards)*
I'm going to make two groups with these pictures. Something will be the same about the pictures in each group. Look.

Sort cards into two groups.
See? All these things *(point)* **are** *(label dimension)* **and all these things** *(point)* **are** *(label dimension)*.

But you know what? I can sort these cards in another way. Something else will be the same about the pictures in each group. Look.

Sort cards into two groups.
See? All these things *(point)* **are** *(label dimension)* **and all these things** *(point)* **are** *(label dimension)*.

And you know, there is another way I can sort these cards. Something else will be the same about the pictures in each group. Look.

Sort cards into two groups.
See? All these things *(point)* **are** *(label dimension)* **and all these things** *(point)* **are** *(label dimension)*.

See? We can sort these pictures in three different ways. Now it's your turn!

Test Trials

Test Trials

Always begin trial with CG.

<u>Sort 1:</u>
<u>Category Generation (CG)</u>

Okay, let's look at some other cards now.
Look, I have six cards here, see? *(take out 6 cards set, put all cards in neutral state)*.
Can you make two groups for me? Something has to be the same about the pictures in each group. Can you put one group on this side of the table and the other group on that side?

Can you tell me what is the same about these pictures? And what is the same about these pictures?

Child sorts correctly: Proceed to Sort 2, CG

Child sorts incorrectly:

<u>Category Identification (CI)</u>

OK, let me show you. *Sort cards into two groups*. ***Indicate dimension on scoring sheet!***
See these two groups of cards? Can you tell me what is the same about these pictures? And what is the same about these pictures?

Child Labels correctly: Proceed to Sort 2, CG

Child Labels incorrectly:

<u>Instructed Sort (IS)</u>

Let's try something else. I'll put all the cards back together *(put cards back to neutral state)*.

Can you put all the *(label dimension, e.g., blue)* **ones on this side of the table** *(<u>opposite sides of CI</u>)* **and all the** *(label dimension, e.g., red)* **ones on that side of the table?** ***Indicate dimension on scoring sheet!***

Proceed to Sort 2, CG.

<u>Sort 2:</u>
<u>Category Generation (CG)</u>

OK, I'm going to put the cards back now *(put all cards back to neutral state)*. **Can you make two groups for me again? But now, something else has to be the same about the pictures. Remember, last time you put all the** *(label, e.g., red ones)* **together, and all the** *(label, e.g., blue ones)* **together. Is there another way you can make two groups?**

Can you tell me what is the same about these pictures? And what is the same about these pictures?

Child sorts correctly: Proceed to Sort 3, CG

Child sorts incorrectly:

<u>Category Identification (CI)</u>

OK, let me show you. *Sort cards into two groups. **Indicate dimension on scoring sheet!** **make sure to switch***

See these two groups of cards? Can you tell me what is the same about these pictures? And what is the same about these pictures?

Child Labels correctly: Proceed to Sort 3, CG

Child Labels incorrectly:

<u>Instructed Sort (IS)</u>

Let's try something else. I'll put all the cards back together *(put cards back to neutral state).*

Can you put all the *(label dimension)* **ones on this side of the table** *(<u>opposite sides of CI</u>)* **and all the** *(label dimension)* **ones on that side of the table?** ***Indicate dimension on scoring sheet!***

Proceed to Sort 3, CG

Sort 3:
Category Generation (CG)

OK, I'm going to put the cards back now *(put cards back to neutral state)*. **Can you make two groups for me again? But now, something else has to be the same about the pictures. Remember, you already put all the** *(label first dimension, e.g., red ones)* **together, and all the** *(label first dimension, e.g., blue ones)* **together, and you already put all the** *(label second dimension, e.g., stars)* **together and all the** *(label second dimension, e.g., triangles)* **together. Is there another way you can make two groups?**

Can you tell me what is the same about these pictures? And what is the same about these pictures?

Child sorts correctly: Proceed to next Trial.

Child sorts incorrectly:

Category Identification (CI)

OK, let me show you. *Sort cards into two groups*. ***Indicate dimension on scoring sheet!** **make sure to switch***
See these two groups of cards? Can you tell me what is the same about these pictures? And what is the same about these pictures?

Child Labels correctly: Proceed to next Trial.

Child Labels incorrectly:

Instructed Sort (IS)

Let's try something else. I'll put all the cards back together *(put cards back to neutral state)*.

Can you put all the *(label dimensions, e.g., blue)* **ones on this side of the table** *(opposite sides of CI)* **and all the** *(label dimensions, e.g., red)* **ones on that side of the table?** ***Indicate dimension on scoring sheet!***

Proceed to next Trial.

Appendix E: Preschool Matrix Completion Task Protocol

Practice Trial

Matrix Completion Task
Demo Trial

Now you and I are going to play a different game. Here's our game board *(take out board)*. **The game board shows us where different pictures belong.**

- **See, here's a small one** *(point to small triangle)*. **It tells us that only small ones go here** (*gesture up and down right-hand column*).
- **And here's a big one** *(point to big triangle)*. **It tells us that only big ones go here** (*gesture up and down left-hand column*).
- **See the book on this side** *(point to book)*? **It tells us that only books go here** (*gesture along top row*).
- **And see the balloon** *(point to balloon)*? **It tells us that only balloons go here** (*gesture along bottom row*).

Now, here I have a small book. So, it belongs here (*place small book*), **because it's a book, *and* it's small. See, here I have a big book. It belongs here** (*place big book*), **because it's a book *and* it's big. And here I have a small balloon. It belongs over here** (*place small balloon*) **because it's a balloon *and* it's small.**

Now, there's only one spot left. Can you tell me which of these pictures (*show answers*) **belongs over here?** (*Point to empty cell*).

Child answers: *Correct* *Incorrect*

Feedback
Correct: **that's right! The big balloon belongs here because it's a balloon *and* it's big. Good job!** *Incorrect:* **good try, but the big balloon belongs here. You see, it belongs in here** *(place big balloon)* **because it's a balloon *and* it's big**.

Source: Siegler & Svetina (2002). Version 2.

Test Trials

Test Trials

Now, I have some more boards for you. They've already been started, but I need your help to finish them, OK?

For each trial:

Show board and answers
Can you tell me which one of these pictures (*show answers with vague motion*) belongs over here? (*Point to empty cell*).

Circle the answer item the child selects

	1		2		3
4		5		6	

Label: ______________________________
____

	1		2		3
4		5		6	

Label: ______________________________
____

	1		2		3
4		5		6	

Label: ______________________________
____

	1		2		3
4		5		6	

Label: ______________________________
____

	1		2		3
4		5		6	

Label: ______________________________
____

Children are allowed to self correct.

If child labels, record and mark if correct with a ✓ or ×

Source: Siegler & Svetina (2002). Version 2.

Appendix F: Matrix Sort Task Protocol

Matrix Sort Task
Demo Trial

Now let's look at some other cards.
I have four cards here, see? *(show all four cards)*
I'm going to put them on this game board.

Put cards on game board:

Small book	*Small balloon*
Big book	*Big balloon*

See? All the books are on this side, and all the balloons are on that side. And look at it this way, all the small ones are on the top, and all the big ones are on the bottom.
OK, now it's your turn!

Test Trials

Clear board, spread out cards in a row (see below for order).
Can you put these cards on the game board for me? Remember, the cards on this side *(point to first column)* **have to go together, and the cards on this side** *(point to second column)* **have to go together too. But also, the cards on the top** *(point to first row)* **have to go together, and the cards on the bottom** *(point to second row)* **have to go together.**
If kid stares at you blankly: **like we did with the first game board, remember?**

Record child's final answer in the tables below
After sorting: **Can you tell me what is the same about these cards? And what is the same about these cards?**

Trial 1: yellow car, yellow book, green book, green car

Trial 2: Big shoe, little shoe, little cup, big cup

Trial 3: Big yellow, big red, small red, small yellow

Source: Cartwright, Marshall, Dandy, & Isaac (2010). Version 1 (but see "Progressive Matrix Task")

Appendix G: Multidimensional Card Selection Task Protocol

Introduction Trial: Checking Children Can Answer ‘No’

Multidimensional Card Selection Task
Introduction Trial

Take out demo array.

Look at all these cards. Can you put all the flowers over here?

Repeat:
Are there any more?
If yes:
Correct: that’s right, let’s put it over here.
Incorrect: oh, you know what? There are no more flowers here!
If no:
Correct: that’s right, there are no more flowers here!
Incorrect: oh, look carefully. Can you find any more?

Good job. Now we’re going to look at some more cards, and I’ll ask you if there are anymore? and sometimes there will be, and you can say yes, and sometimes there won’t be, and you can say no. OK?

Question #	Child’s answer	Correct?
1 (put the flower here)	Yes no	
2 (any more?)	Yes no	
3 (any more?)	Yes no	
4 (any more?)	Yes no	

Working Memory Baseline Trial

Memory Control

Multidimensional Card Selection Task
Test Trial

Take out Lucy.
This is my friend, Lucy. Lucy likes hearts. *(Take out set of cards).* **Now, I want you to look carefully at all these cards. Can you put all the hearts by Lucy? Are there any more hearts?** *(Keep asking until the child says no).*

If no is incorrect: **let's take one more look. Are there any more hearts here?**

Child picks cards number: ____

Now Lucy is going to go home, so let's put all her cards back. *Put Lucy away. Take out Mark, put all the cards back in their place.*
This is my friend, Mark. Mark likes hearts and stars. Now, I want you to look carefully at all these cards. Can you put all the hearts and the stars by Mark? Are there any more hearts or stars here? *(Keep asking until the child says no).*

If no is incorrect: **let's take one more look. Are there any more hearts or stars here?**

Child picks cards number: ____

Now Mark is going to go home, so let's put all his cards back. *Put Mark away. Take out Sarah, put all the cards back in their place.*
This is my friend, Sarah. Sarah likes hearts, stars, and circles. Now, I want you to look carefully at all these cards. Can you put all the hearts, stars, and circles by Sarah? Are there any more hearts, stars, or circles here? *(Keep asking until the child says no).*

If no is incorrect: **let's take one more look. Are there any more hearts, stars, or circles here?**

Child picks cards number: ____

Test Trials

Cog flex color size shape

Multidimensional Card Selection Task
Test Trial

Take out Julie.
This is my friend, Julie. *(Take out set of cards).* **Julie likes blue shapes. Now, I want you to look carefully at all these cards. Can you show me a blue shape? Can you put it over here by Julie? Are there any more blue shapes?** *(Keep asking until the child says no).*

If no is incorrect: **let's take one more look. Are there any more blue shapes here?**

Child picks cards number: ____

Now Julie is going to go home, so lets put all her cards back. *Put Julie away. Take out Chris, put all the cards back in their place.*
This is my friend, Chris. Chris likes small green shapes. Now, I want you to look carefully at all these cards. Can you show me a small green shape? Can you put it over here by Chris? Are there any more small green shapes? *(Keep asking until the child says no).*

If no is incorrect: **let's take one more look. Are there any more small green shapes here?**

Child picks cards number: ____

Now Chris is going to go home, so lets put all his cards back. *Put Chris away. Take out Ann, put all the cards back in their place.*
This is my friend, Ann. Ann likes big yellow triangles. Now, I want you to look carefully at all these cards. Can you show me a big yellow triangle? Can you put it over here by Ann? Are there any more big yellow triangles? *(Keep asking until the child says no).*

If no is incorrect: **let's take one more look. Are there any more big yellow triangles here?**

Child picks cards number: ____

Multidimensional Card Selection Task
Test Trial

Take out Kate.
This is my friend, Kate. *(Take out set of cards)*. **Kate likes hearts. Now, I want you to look carefully at all these cards. Can you show me a heart? Can you put it over here by Kate? Are there any more hearts?** *(Keep asking until the child says no)*.

If no is incorrect: **let's take one more look. Are there any more hearts here?**

Child picks cards number: ________________________________

Now Kate is going to go home, so lets put all her cards back. *Put away Kate*. *Take out Tommy, put all the cards back in their place*.
This is my friend, Tommy. Tommy likes yellow triangles. Now, I want you to look carefully at all these cards. Can you show me a yellow triangle? Can you put it over here by Tommy? Are there any more yellow triangles? *(Keep asking until the child says no)*.

If no is incorrect: **let's take one more look. Are there any more yellow triangles here?**

Child picks cards number: ________________________________

Now Tommy is going to go home, so lets put all his cards back. *Put Tommy away*. *Take out Emily, put all the cards back in their place*.
This is my friend, Emily. Emily likes small red circles. Now, I want you to look carefully at all these cards. Can you show me a small red circle? Can you put it over here by Emily? Are there any more small red circles? *(Keep asking until the child says no)*.

If no is incorrect: **let's take one more look. Are there any more small red circles here?**

Child picks cards number: ________________________________

Cog flex size shape color

Multidimensional Card Selection Task
Test Trial

Take out Sally.
This is my friend, Sally. *(Take out set of cards)*. **Sally likes big shapes. Now, I want you to look carefully at all these cards. Can you show me a big shape? Can you put it over here by Sally? Are there any more big shapes?** *(Keep asking until the child says no)*.

If no is incorrect: **let's take one more look. Are there any more big shapes here?**

Child picks cards number: ____

Now Sally is going to go home, so lets put all her cards back. *Put away Sally*. *Take out Ben, put all the cards back in their place*.
This is my friend, Ben. *(Take out set of cards)*. **Ben likes small stars. Now, I want you to look carefully at all these cards. Can you show me a small star? Can you put it over here by Ben? Are there any more small stars?** *(Keep asking until the child says no)*.

If no is incorrect: **let's take one more look. Are there any more small stars here?**

Child picks cards number: ____

Now Ben is going to go home, so lets put all his cards back. *Put Ben away*. *Take out Claire, put all the cards back in their place*.
This is my friend, Claire. *(Take out set of cards)*. **Claire likes big blue hearts. Now, I want you to look carefully at all these cards. Can you show me a big blue heart? Can you put it over here by Claire? Are there any more big blue hearts?** *(Keep asking until the child says no)*.

If no is incorrect: **let's take one more look. Are there any more big blue hearts here?**

Child picks cards number: ____

Appendix H: Sample Characters For Multidimensional Card Selection Task

Appendix I: Self-Ordered Pointing Task Protocol

Practice Trials

Self-Ordered Pointing

(Before opening the binder)

Now you and I are going to play a different pictures game. We're going to look at some pictures together, and I want you point to each picture just one time. Okay? *(Open practice trial 1)*

<u>Practice Trial 1:</u>

Okay, point to one picture on this page.

Child selects: Dog Rabbit
Good job *Turn page.*

Now point to one picture that you didn't point to before.
Child selects: Dog Rabbit

If correct: **Good job**
If incorrect: **Oh, good try, but you already pointed to this picture before. Remember, in this game you point to a picture that you didn't point to before. Can you do that now? Good job**
Let's try another one. *Turn to practice trial 2.*

<u>Practice Trial 2:</u>

Okay, point to a picture on this page.

Child selects: Car Backpack
Good job *Turn page.*

Now point to a picture that you didn't point to before.
Child selects: Car Backpack

If correct: **Good job**
If incorrect: **Oh, good try, but you already pointed to this picture before. Remember, in this game you point to a picture that you didn't point to before. Can you do that now? Good job**

Now we're going to look at a bunch of pictures. Each time I turn the page, I want you to point to a picture you didn't point to before.

Source: Hongwanishkul, Happaney, Lee, & Zelazo (2005). August 16, 2012 – Version 1.

Test Trials

Turn to test trials. No feedback from here on. Number each picture the child points to in the "first point" column or in the "second point" column if child already pointed to the picture before. Stop task after the child made two errors (second point) at the same level.

For first item in each set: **point to a picture on this page.**
For second item: **now point to a picture that you didn't point to before.**
For third item and up: **now point to another picture that you didn't point to before.**

	First point	Second point		First point	Second point
1.Airplane			**6. Book**		
Gift			**Bike**		
Cow			**Glasses**		
2. Turtle			**House**		
Apple			**Bird**		
Hand			**7. TV**		
3. Tiger			**Horse**		
Elephant			**Butterfly**		
Chair			**Bus**		
Cake			**Banana**		
4. Ball			**Spoon**		
Flower			**8. Bee**		
Shell			**Hat**		
Pencil			**Train**		
5. Sun			**Crayons**		
Balloon			**Barn**		
Cup			**Fish**		
Carrot					
Cat					

See more trials in additional page.

Source: Hongwanishkul, Happaney, Lee, & Zelazo (2005). August 16, 2012 – Version 1.

	First point	**Second point**			**First point**	**Second point**
9. Lion				**11. Phone**		
Fire truck				**Feather**		
Ladder				**Pillow**		
Scissors				**Button**		
Bed				**Lemon**		
Leaf				**Sailboat**		
Wagon				**Penguin**		
10. Chicken				**Tree**		
Dragonfly				**12. Pot**		
Pinwheel				**Grapes**		
Tooth Brush				**Hair Brush**		
Key				**Dinosaur**		
Tambourine				**Jug**		
Tractor				**Strawberry**		
				Ring		
				Umbrella		

Source: Hongwanishkul, Happaney, Lee, & Zelazo (2005). August 16, 2012 – Version 1.

Appendix J: Black/White Stroop Task Protocol

Black/White Stroop

Now we're going to play a different game!

Show black.

This card is black, right? When you see this card, I don't want you to say 'black'. No, I want you to say 'white'.

Remove black; show white.

This card is white, right? When you see this card, I don't want you to say 'white'. No, I want you to say 'black'.

Training:

Show white. If hesitation - **What do you say for this one?**

[W] [B] (Good.)

number of training trials

Show black. If hesitation - **What do you say for this one?**

[W] (Good.) [B]

If wrong or no response on either trial, repeat rules and training. Max of three training trials – always continue with test trials.

Testing - No feedback:

Circle or write in child's response, if not black/white:

1	W	B	________
2	W	B	________
3	W	B	________
4	W	B	________
5	W	B	________
6	W	B	________
7	W	B	________

8	W	B	________
9	W	B	________
10	W	B	________
11	W	B	________
12	W	B	________
13	W	B	________
14	W	B	________

15	W	B	________
16	W	B	________
17	W	B	________
18	W	B	________
19	W	B	________
20	W	B	________
21	W	B	________

No self-correct : Record *first complete* response

e.g. : If child says 'Black – no white' code as 'black.' If child says 'Bl--White' code as 'white'.

Appendix K: Normality Indicators And Plots For Study 1

This appendix includes the skewness and kurtosis values, K-S normality test information for the continuous variables used in Study 1 (see Table K1), except for the standardized tests (i.e., age in months, the Modified Flexible Item Selection Task, Black/White, and Self-Ordered Pointing Task). In addition, the appendix includes plots (histograms and Q-Q plots) for all variables used in Study 1. Specifically, these variables include:

1. Age in months;
2. Dimensional Change Card Sort score (total number of trials solved correctly);
3. Modified Flexible Item Selection Task contingency score;
4. Modified Object Classification Task for Children flexibility score;
5. Preschool Matrix Completion Task score (total number of trials solved correctly);
6. Matrix Sort Task score (total number of trials solved correctly);
7. Multidimensional Card Selection Task flexibility score;
8. Self-Ordered Pointing Task score (total number of trials solved correctly);
9. Black/White score (total number of trials solved correctly);

Normality Indicators

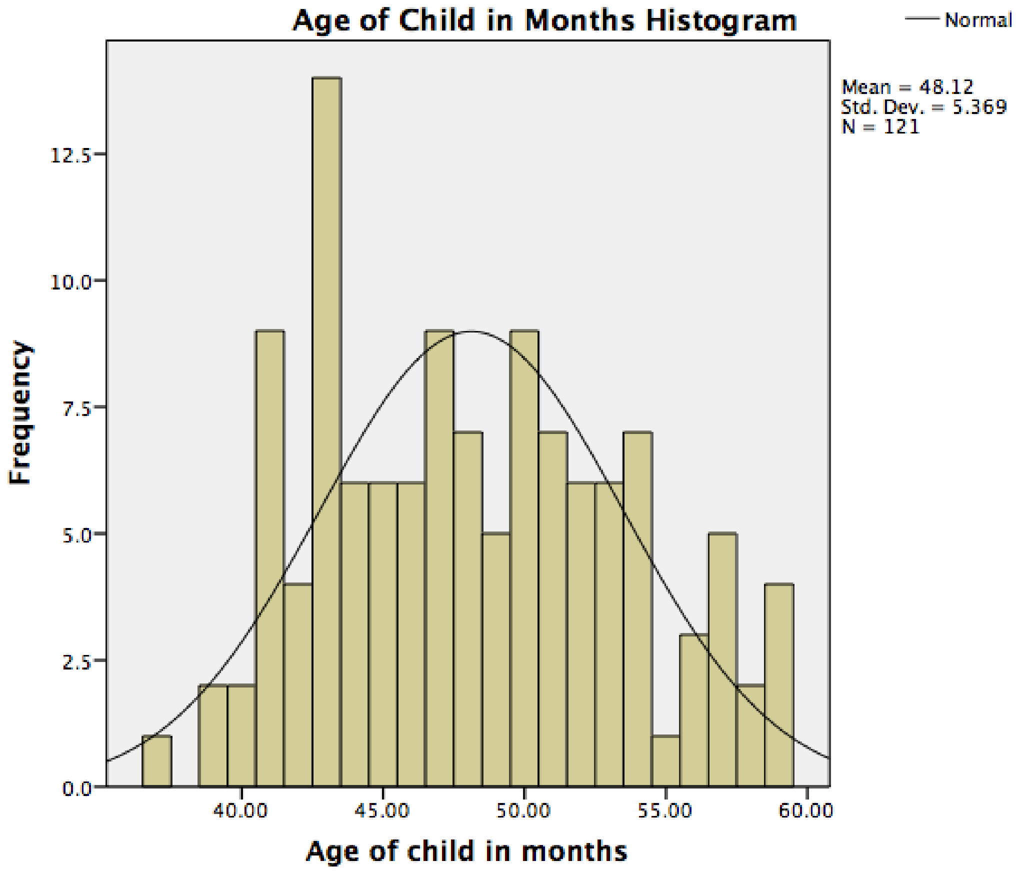
Table K1

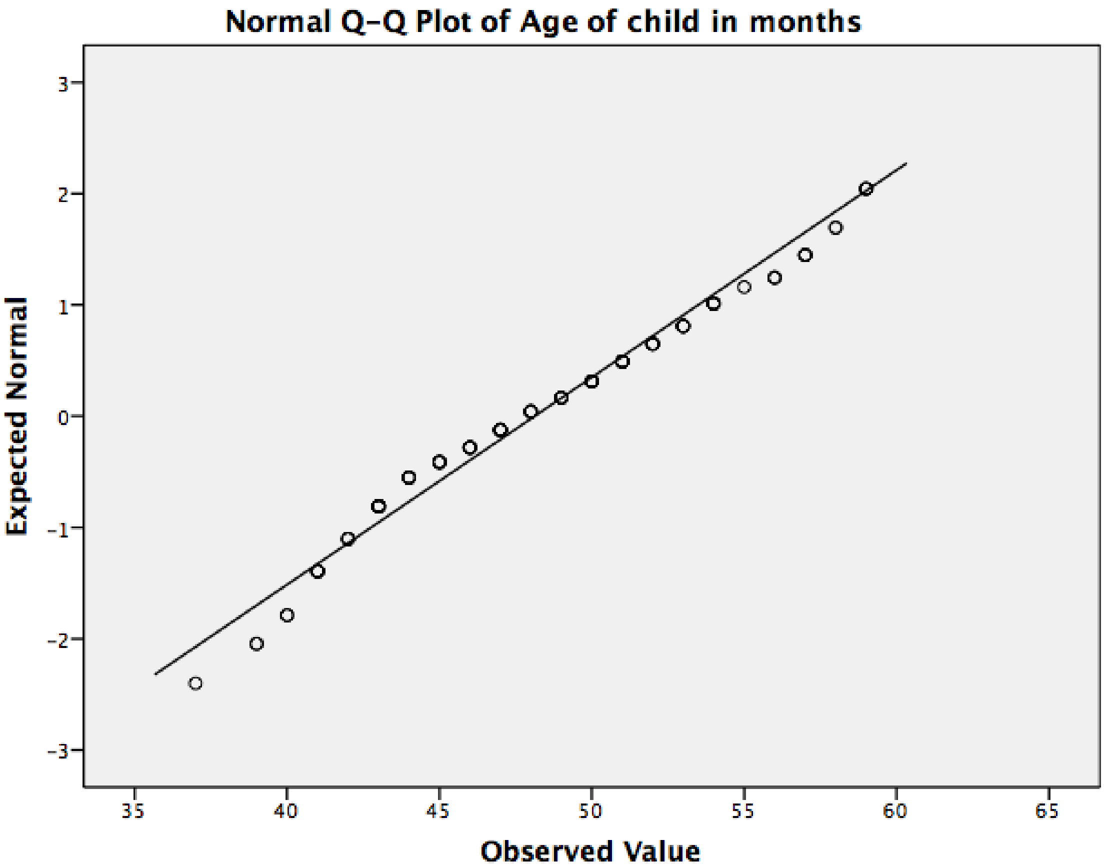
Normality Indicators for Study 1 Continuous Variables

Score	Skewness Score (SD)	Skewness Z-Score	Kurtosis Score (SD)	Kurtosis Z-Score	K-S Statistic (df)	K-S p-value
Age (in months)	0.24 (.22)	1.09	-0.84 (.44)	-1.09	.09 (121)	.01
MFIST	-0.78 (.22)	-3.54	-0.22 (.44)	-0.50	.19 (120)	.00
B/W	-0.54 (.22)	2.45	-1.05 (.44)	2.39	.16 (118)	.00
SOP	0.17 (.22)	0.77	-0.75 (.44)	1.70	.09 (120)	.01

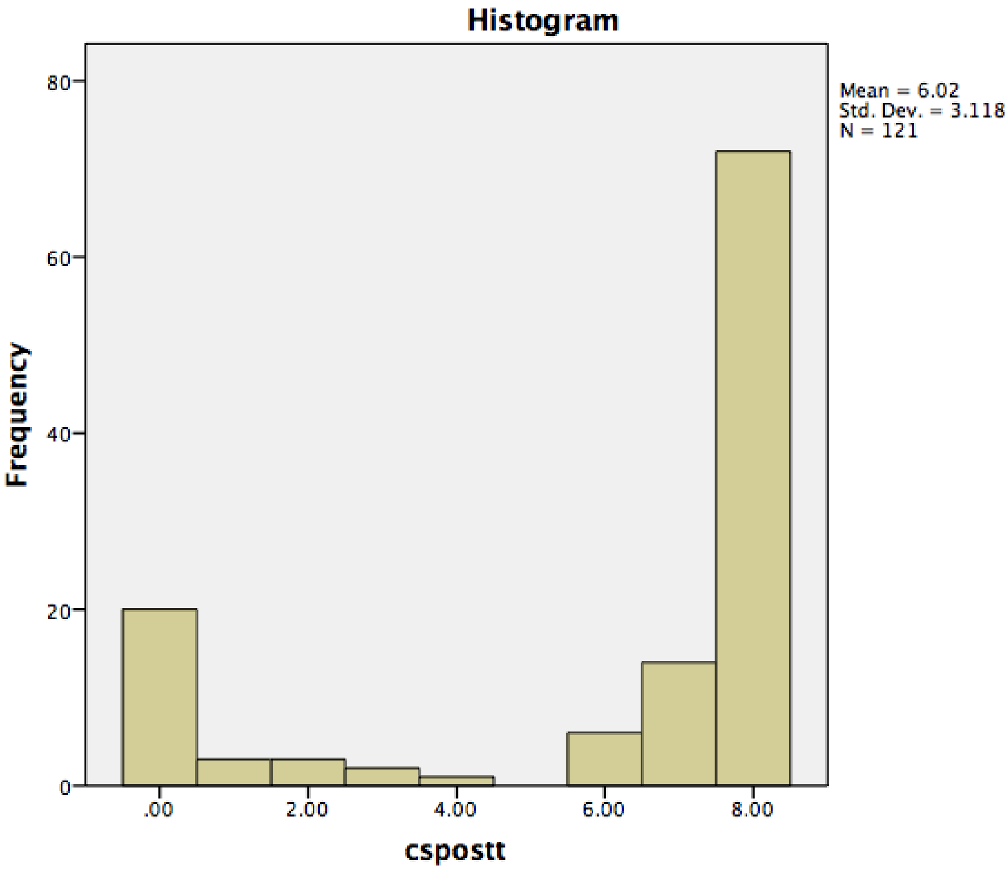
Note. MFIST = Modified Flexible Item Selection Task; B/W = Black/White; SOP = Self-Ordered Pointing Task.

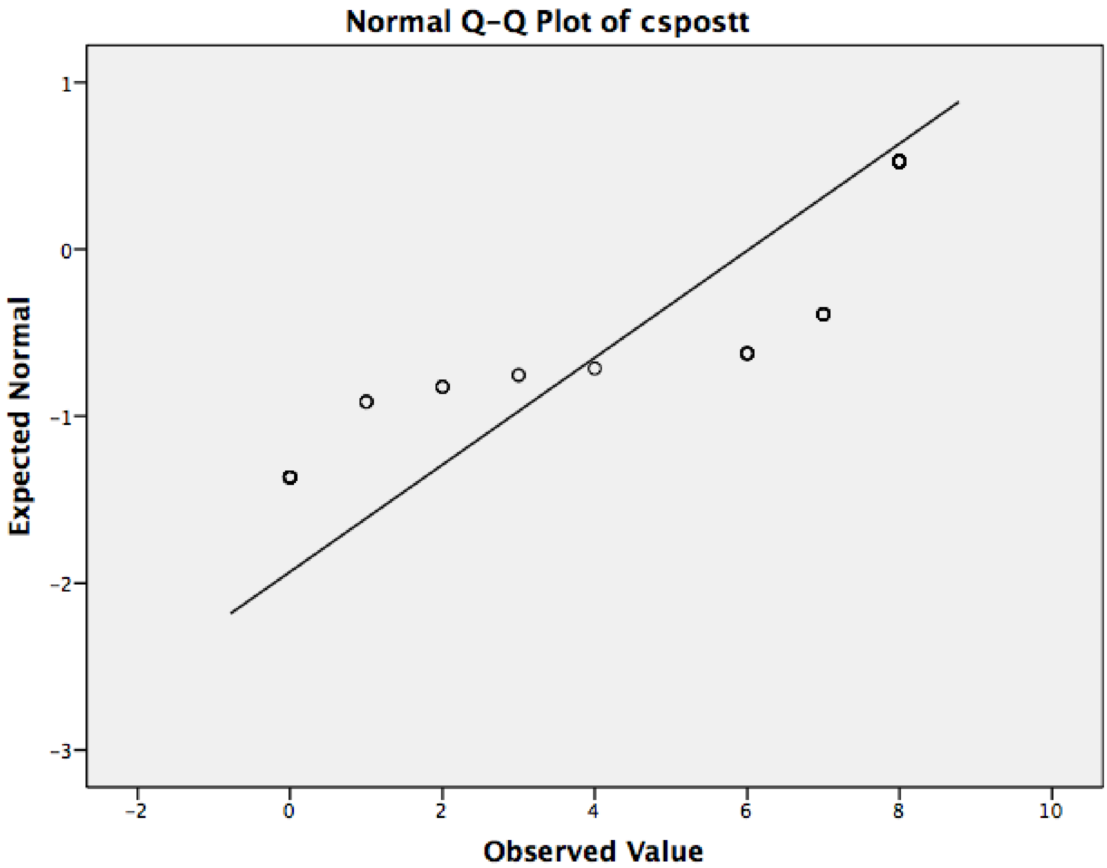
Age In Months



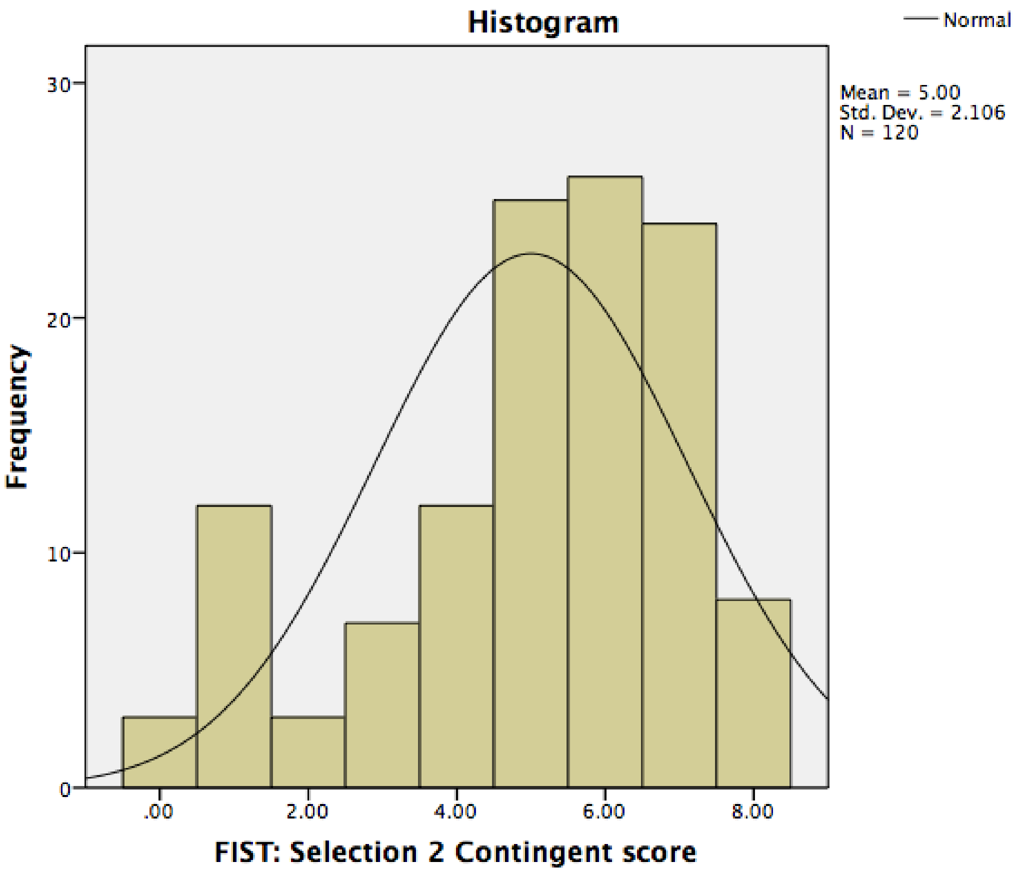

Normal Q-Q Plot of Age of child in months
Expected Normal
3
2
1
0
-1
-2
-3
35
40
45
50
55
60
65
Observed Value

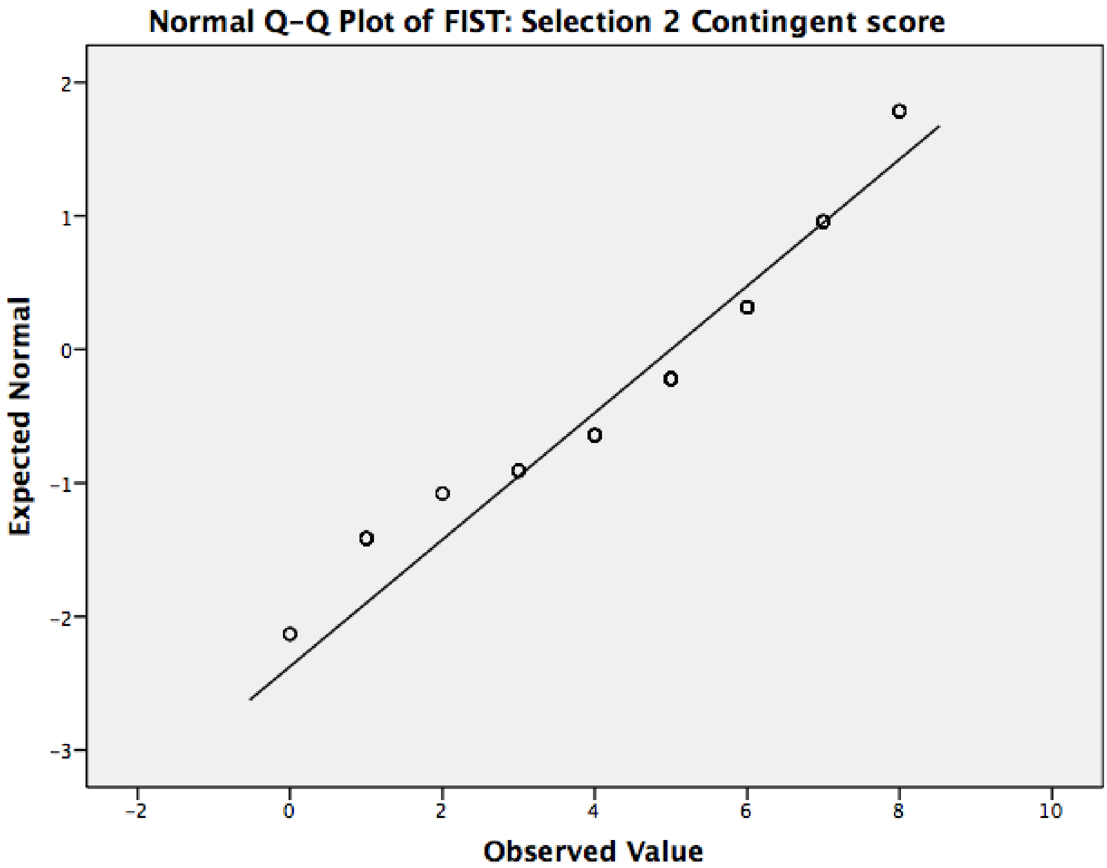
Dimensional Change Card Sort score



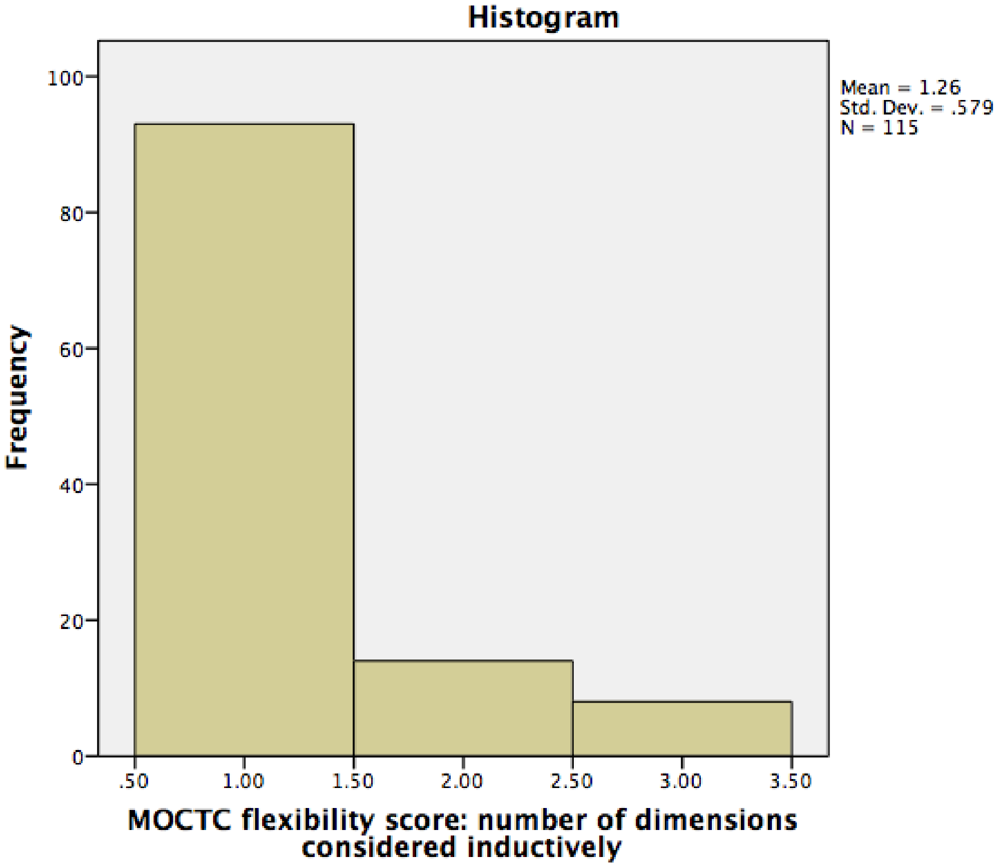

Normal Q-Q Plot of cspostt
Expected Normal
1
0
-1
-2
-3
-2
0
2
4
6
8
10
Observed Value

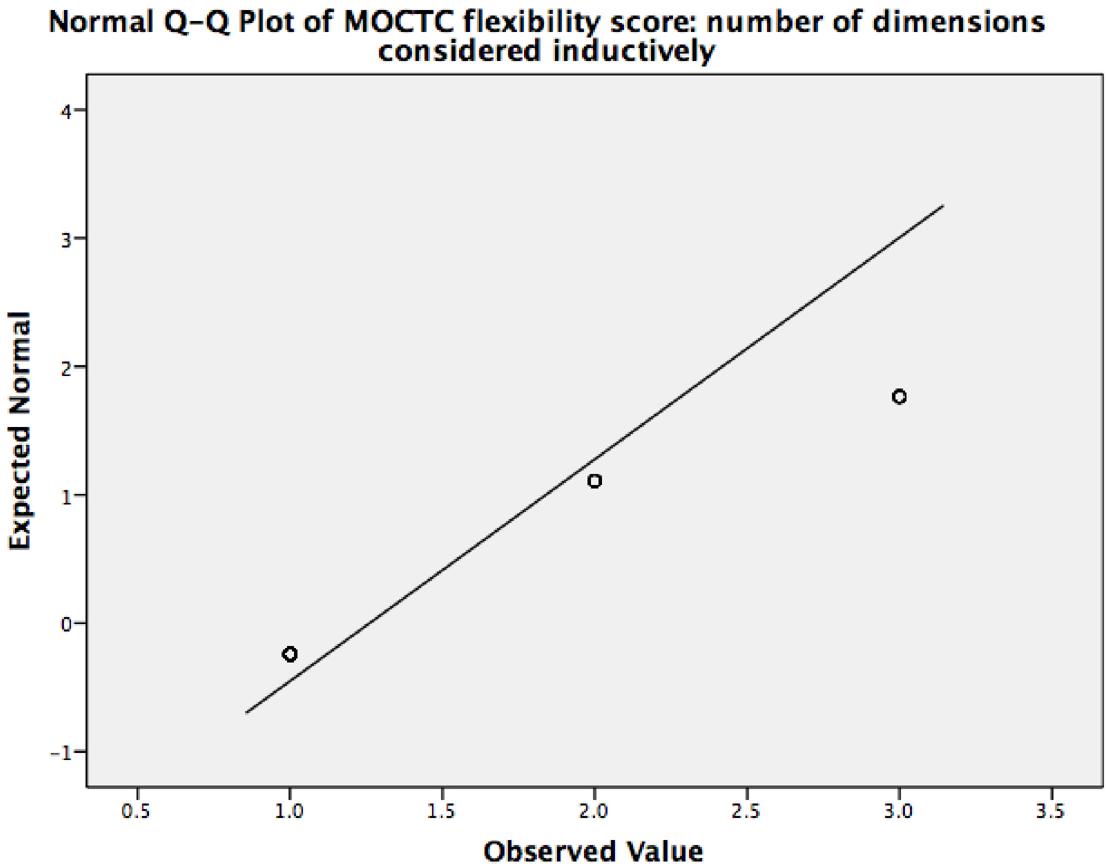
Modified Flexible Item Selection Task



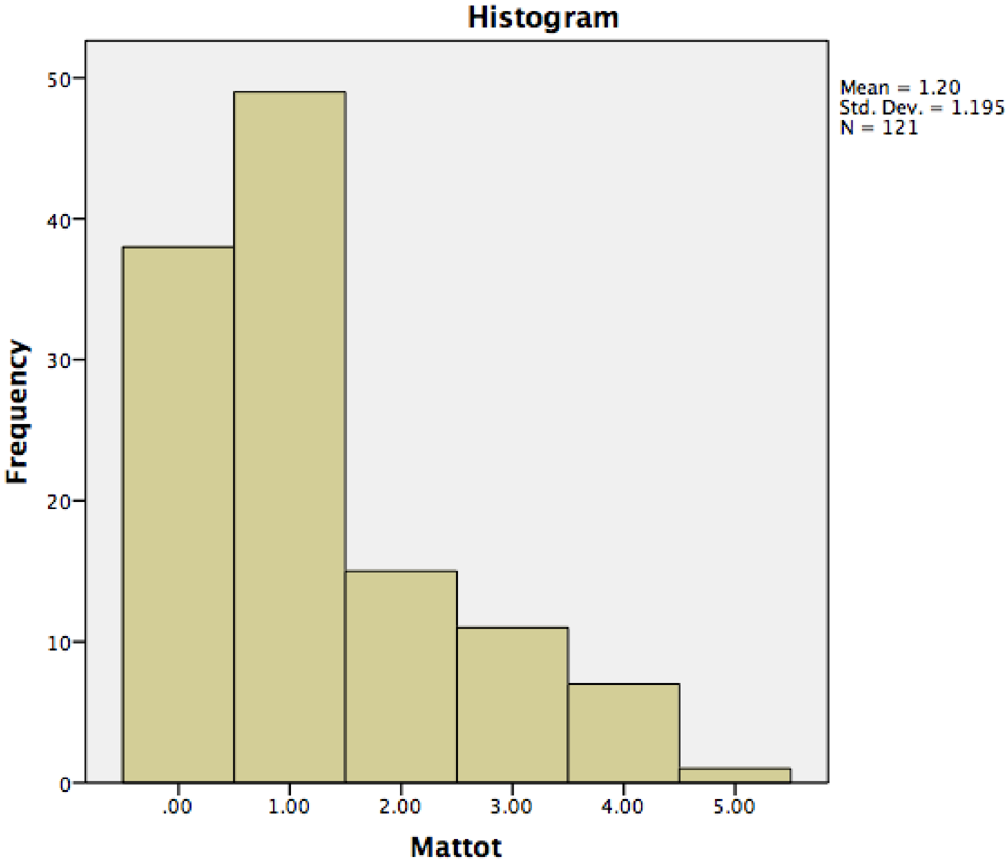

Normal Q-Q Plot of FIST: Selection 2 Contingent score
Expected Normal
Observed Value
2
1
0
-1
-2
-3
-2
0
2
4
6
8
10

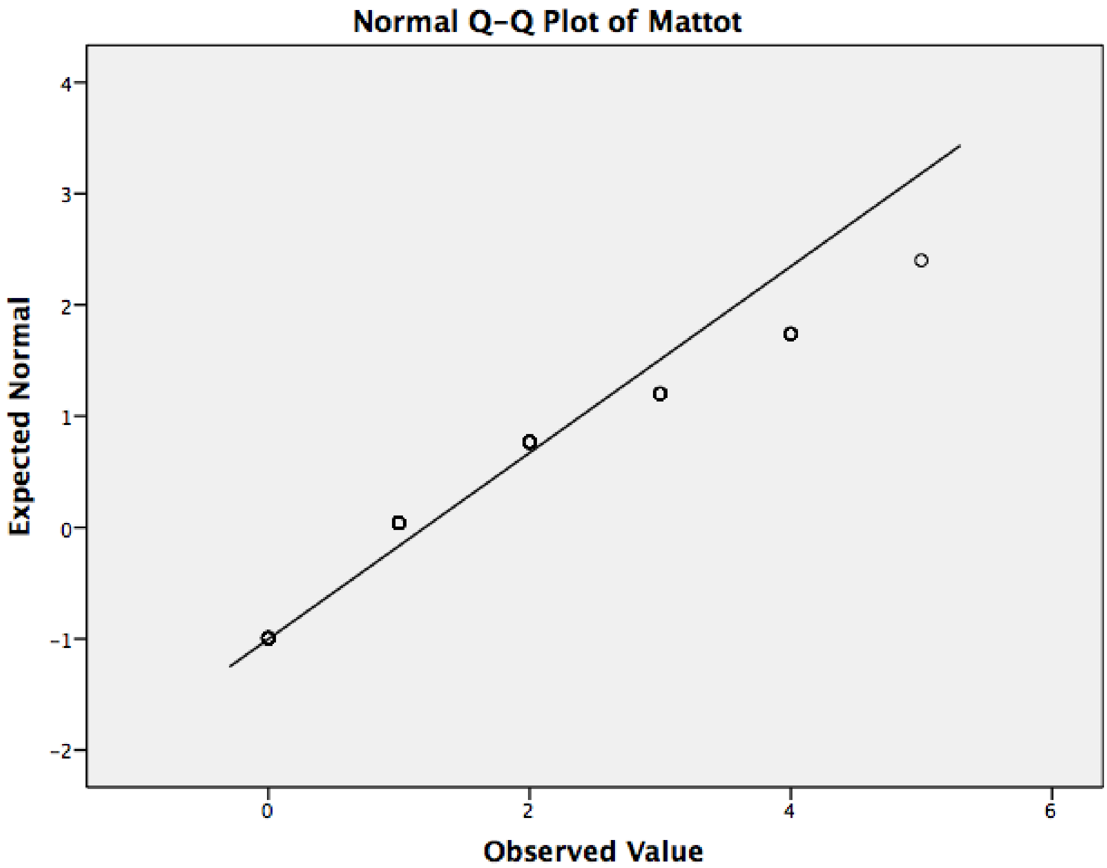
Modified Object Classification Task for Children



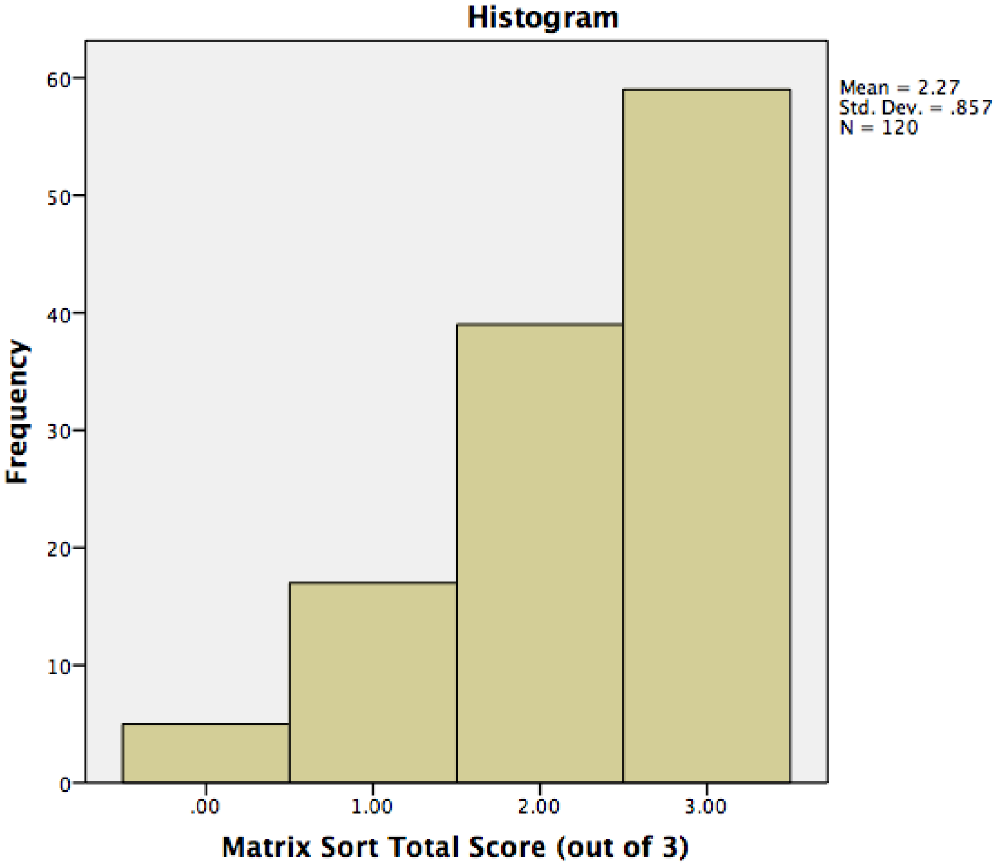

Normal Q-Q Plot of MOCTC flexibility score: number of dimensions considered inductively
Expected Normal
4
3
2
1
0
-1
0.5
1.0
1.5
2.0
2.5
3.0
3.5
Observed Value

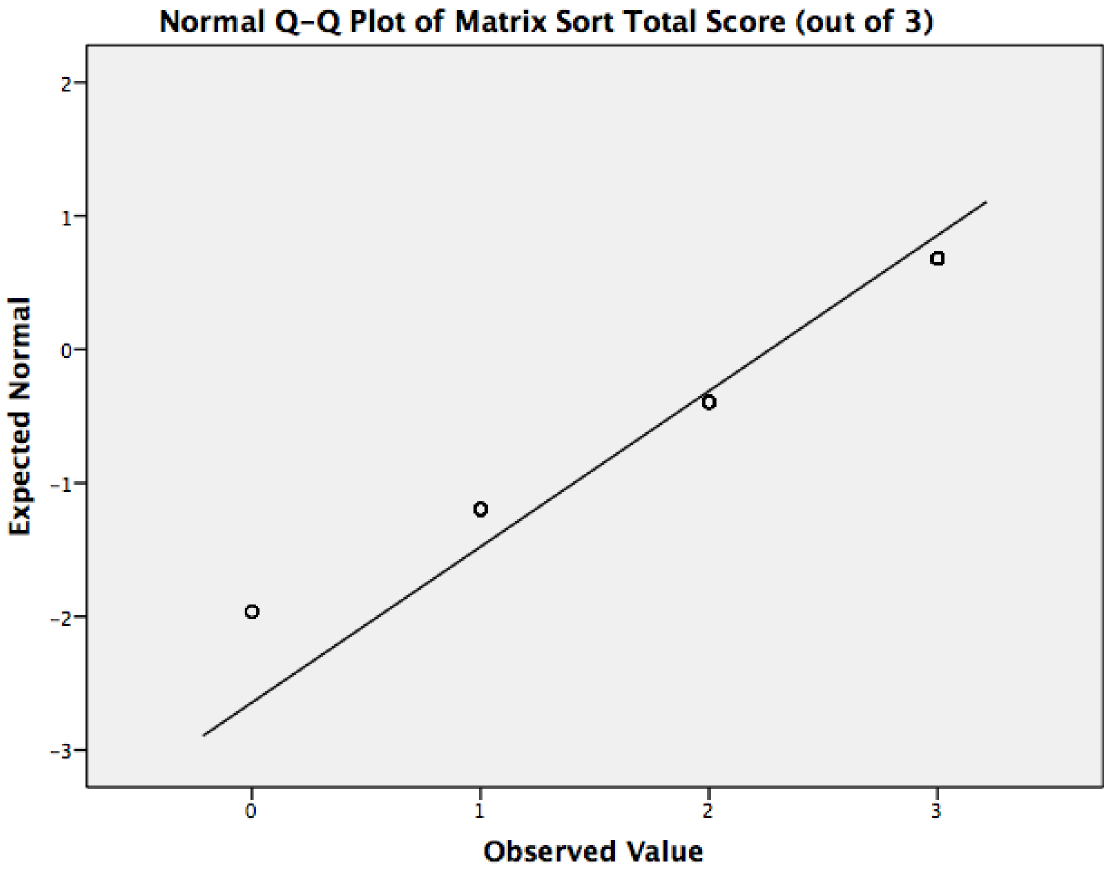
Preschool Matrix Completion Task



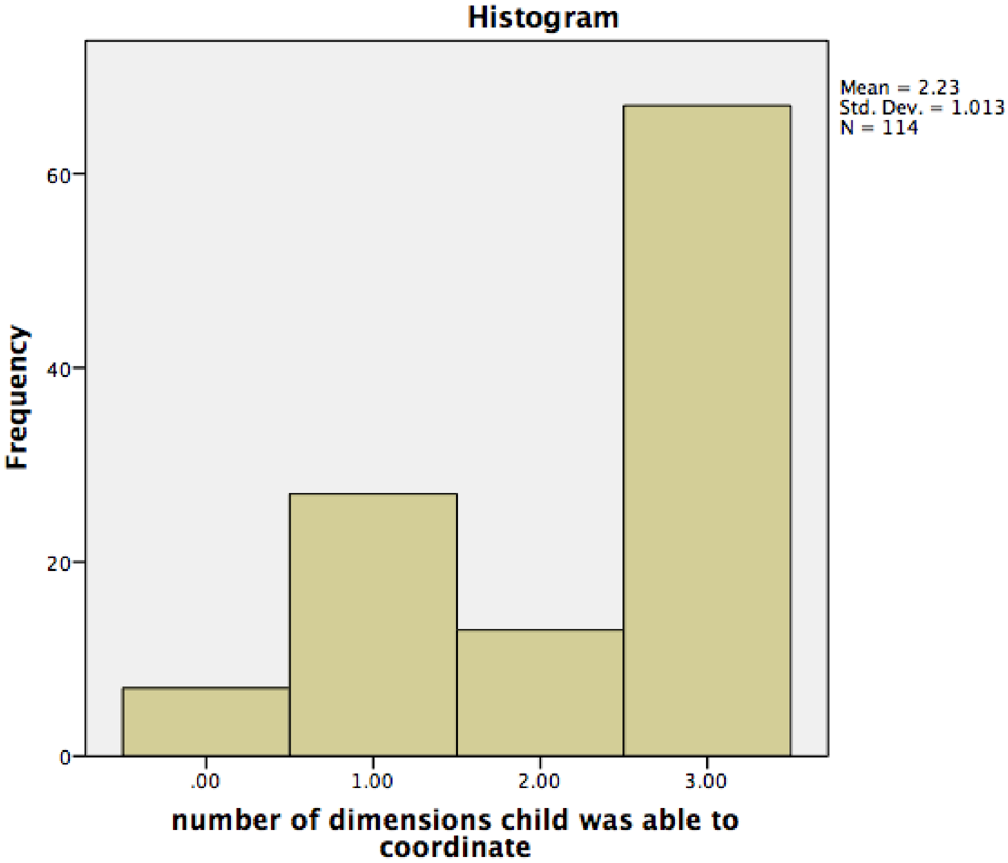

Normal Q-Q Plot of Mattot
Expected Normal
Observed Value
4
3
2
1
0
-1
-2
0
2
4
6

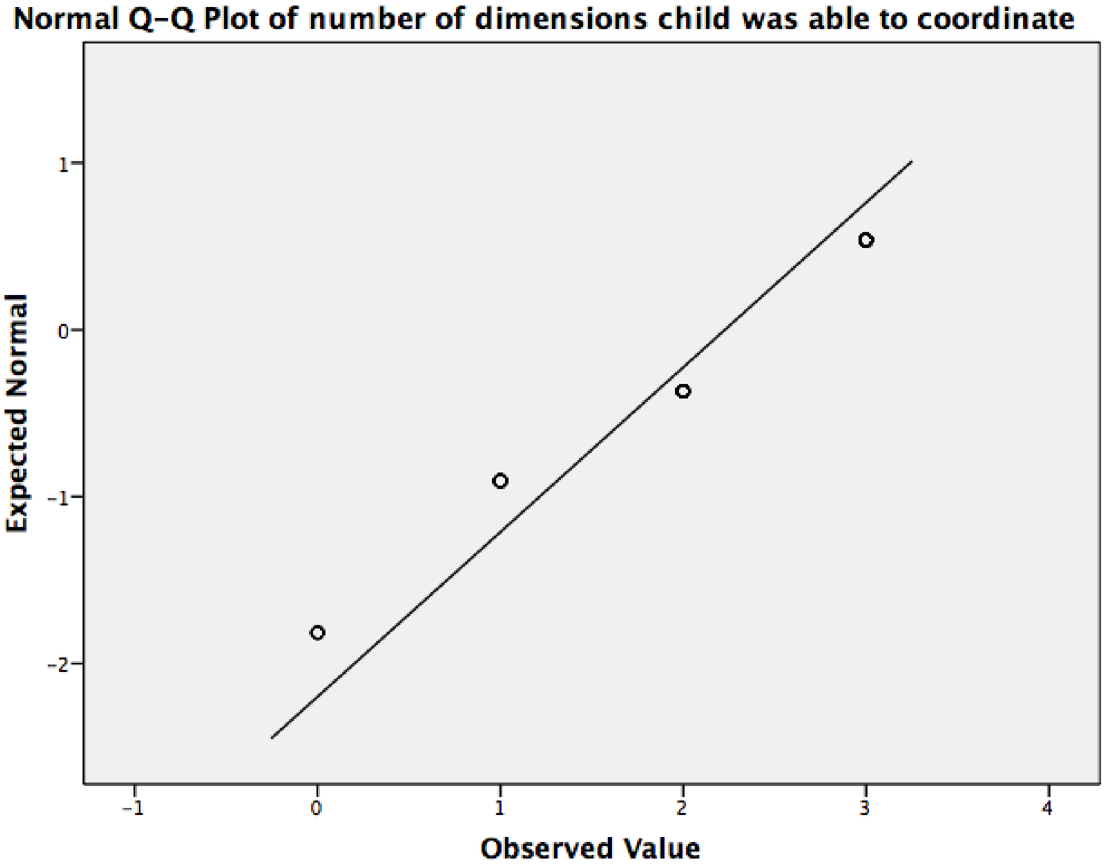
Matrix Sort Task



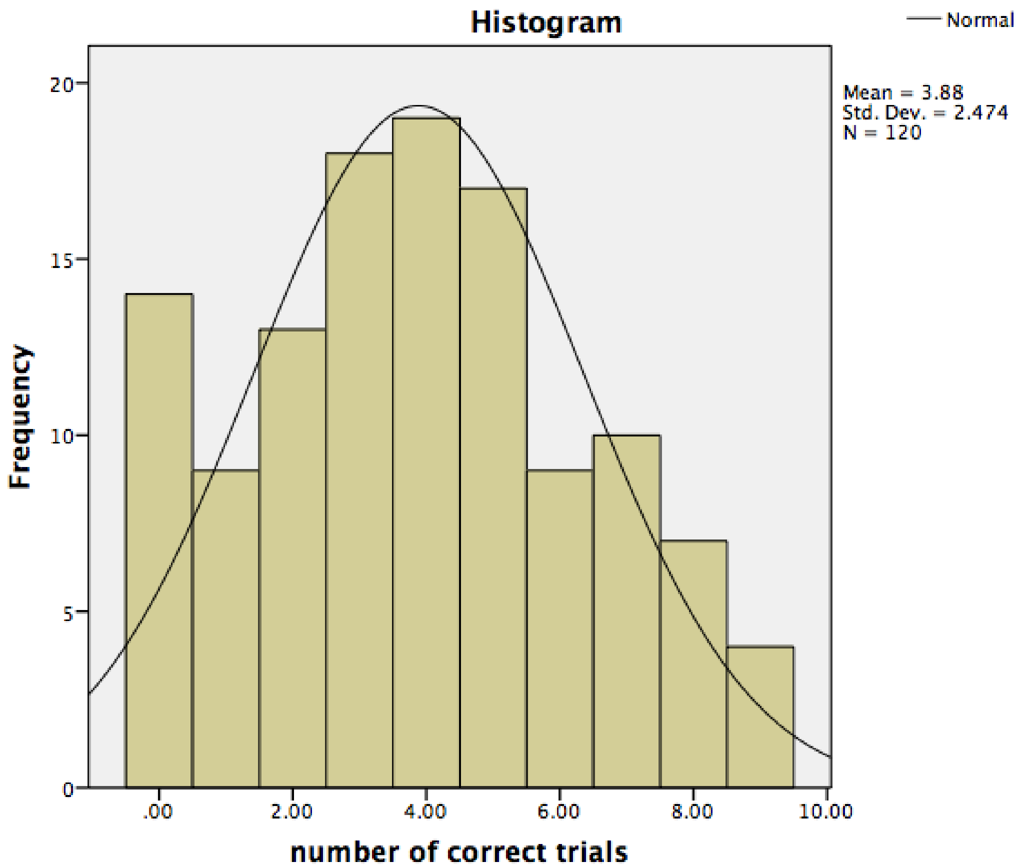

Normal Q-Q Plot of Matrix Sort Total Score (out of 3)
Expected Normal
Observed Value
2
1
0
-1
-2
-3
0
1
2
3

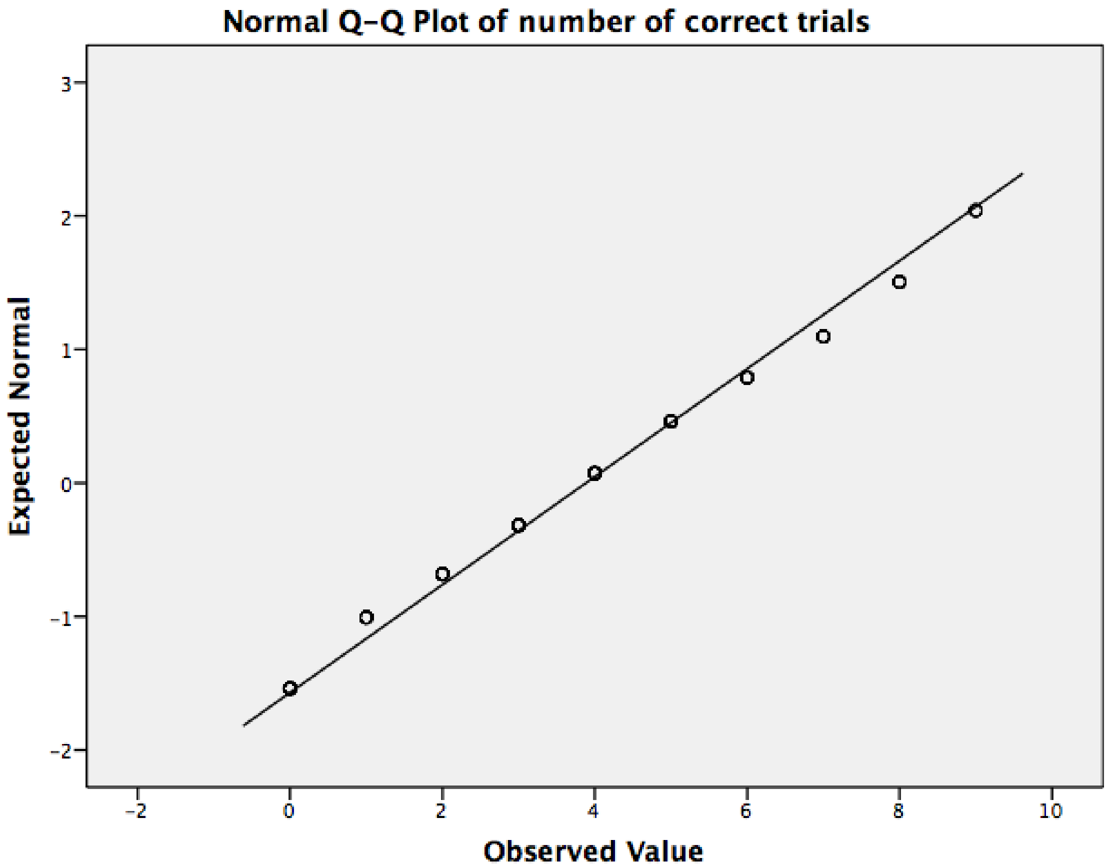
Multidimensional Card Selection Task



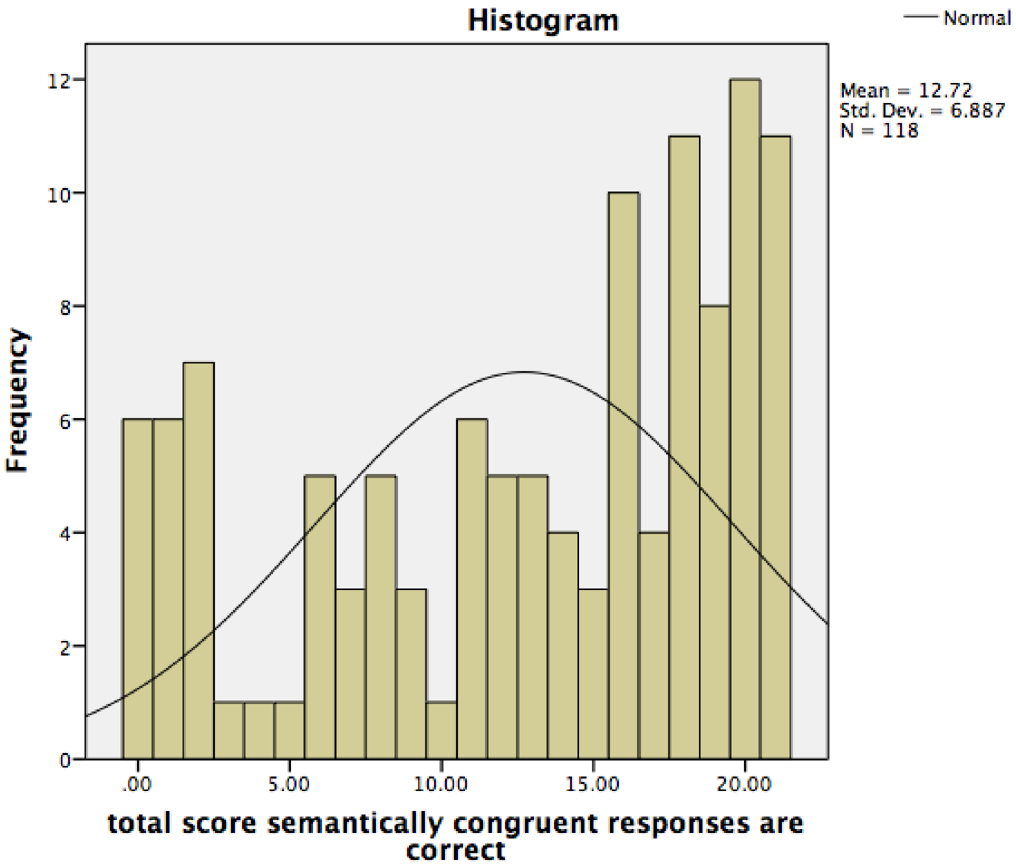

Normal Q-Q Plot of number of dimensions child was able to coordinate
Expected Normal
Observed Value
1
0
-1
-2
-1
0
1
2
3
4

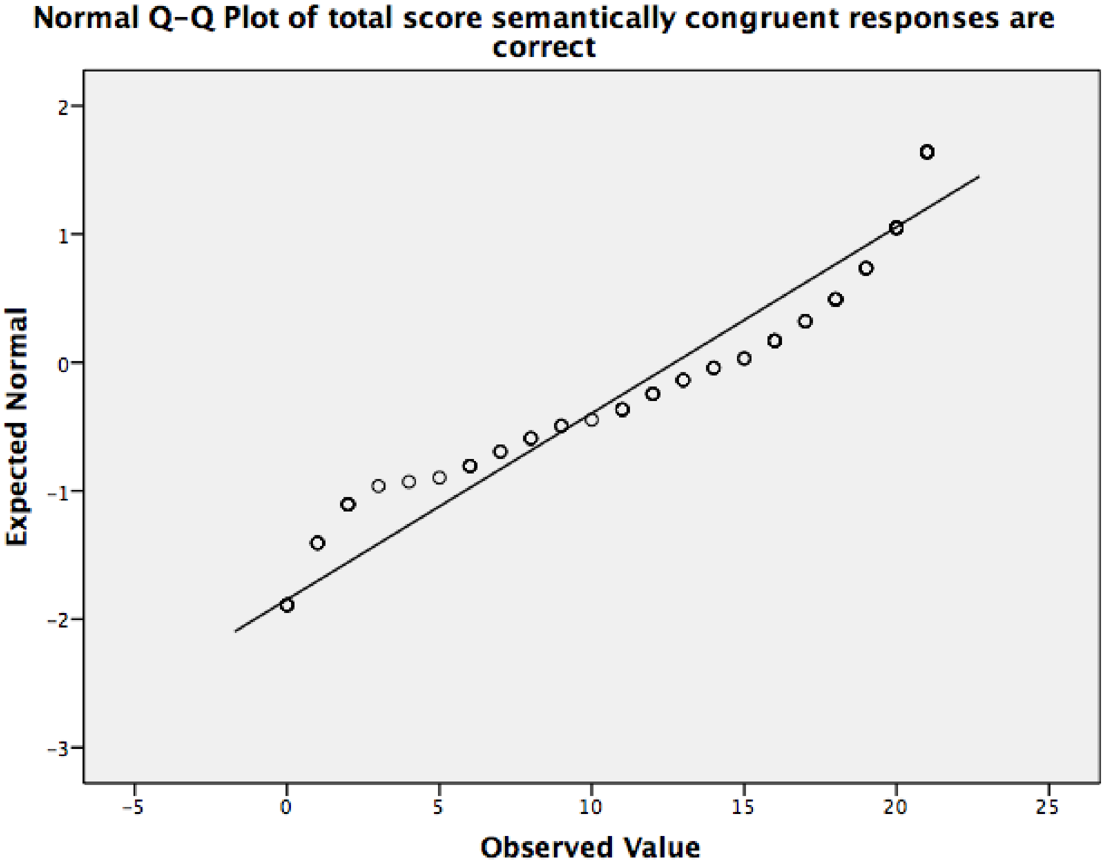
Self-Ordered Pointing Task




Normal Q-Q Plot of number of correct trials
Expected Normal
Observed Value
3
2
1
0
-1
-2
-2
0
2
4
6
8
10

Black/White Stroop-Like Task




Normal Q-Q Plot of total score semantically congruent responses are correct
Expected Normal
Observed Value
2
1
0
-1
-2
-3
-5
0
5
10
15
20
25

Appendix L: Study 2 Preschool Matrix Completion Task Protocols

Deductive Version, One Dimension Varied On The Practice Trial

VERSION B

Matrix Completion Task
Demo Trial

Now you and I are going to play a different game. Here's our game board *(take out board)*.

- **See, this is small** *(point to small)*. **It tells us that the small ones go here** (*gesture up and down right-hand column*).
- **And this is big** *(point to big)*. **It tells us that the big ones go here** (*gesture up and down left-hand column*).
- **See this? This is a book** *(point to top book)*. **It tells us that the books go here** (*gesture along top row*).
- **And this is a book** *(point to bottom book)*? **It tells us that the books go here** (*gesture along bottom row)*.

Look, there is one missing (*Point to empty cell*). **Can you tell me which of these pictures** *(show answers)* **belongs here?** (*Point to empty cell*).

Child answers: *Correct* *Incorrect*

Feedback *Correct:* **that's right! The big book belongs here because it's a book *and* it's big** *(point to appropriate labels – book and big)*. **Good job!** *Incorrect:* **good try, but the big book belongs here. You see, it belongs in here** *(place big book)* **because it's a book *and* it's big** *(point to appropriate labels – book and big).*

Source: Siegler & Svetina (2002). Version 3.

VERSION B

Test Trials

Now, I have some more boards for you. They've already been started, but I need your help to finish them, OK?

For each trial:

Show board and answers
Remember, the *(point to top left, label)* **tells us all the** *(label)* **go on this side** *(motion along left column)***, and the** *(point to top right, label)* **tells us all the** *(label)* **go here** *(motion to right column)***. Also the** *(point to side top, label)* **tells us all the** *(label)* **go on top** *(motion along top row)***, and the** *(point to side bottom, label)* **tells us all the** *(label)* **go on the bottom** *(motion along bottom row)***.**
Can you tell me which one of these pictures (*show answers with vague motion*) **belongs here?** (*Point to empty cell*).

Circle the answer item the child selects

Trial 1		1		2		3	Label:
	4		5		6		
Trial 2		1		2		3	Label:
	4		5		6		
Trial 3		1		2		3	Label:
	4		5		6		
Trial 4		1		2		3	Label:
	4		5		6		
Trial 5		1		2		3	Label:
	4		5		6		
Trial 6		1		2		3	Label:
	4		5		6		

Children are allowed to self correct.

If child labels, record and mark if correct with a ✓ or ×

Source: Siegler & Svetina (2002). Version 3.

Deductive Version, Two Dimensions Varied On The Practice Trial

VERSION A

Matrix Completion Task
Demo Trial

Now you and I are going to play a different game. Here's our game board *(take out board)*.

- **See, this is small** *(point to small)*. **It tells us that the small ones go here** *(gesture up and down right-hand column)*.
- **And this is big** *(point to big)*. **It tells us that the big ones go here** (*gesture up and down left-hand column*).
- **See this? This is a book** *(point to book)*. **It tells us that the books go here** (*gesture along top row*).
- **And this is a balloon** *(point to balloon)***? It tells us that the balloons go here** (*gesture along bottom row)*.

Look, there is one missing (*Point to empty cell*). **Can you tell me which of these pictures** *(show answers)* **belongs here?** (*Point to empty cell*).

Child answers: *Correct* *Incorrect*

Feedback *Correct:* **that's right! The big balloon belongs here because it's a balloon *and* it's big** *(point to appropriate labels – balloon and big)*. **Good job!** *Incorrect:* **good try, but the big balloon belongs here** *(place big balloon)*. **You see, it belongs in here because it's a balloon *and* it's big** *(point to appropriate labels – balloon and big)*.

Source: Siegler & Svetina (2002). Version 3.

VERSION A

Test Trials

Now, I have some more boards for you. They've already been started, but I need your help to finish them, OK?

For each trial:

Show board and answers
Remember, the *(point to top left, label)* **tells us all the** *(label)* **go on this side** *(motion along left column)***, and the** *(point to top right, label)* **tells us all the** *(label)* **go here** *(motion to right column)***. Also the** *(point to side top, label)* **tells us all the** *(label)* **go on top** *(motion along top row)***, and the** *(point to side bottom, label)* **tells us all the** *(label)* **go on the bottom** *(motion along bottom row)***.**
Can you tell me which one of these pictures (*show answers with vague motion*) **belongs here?** (*Point to empty cell*).

Circle the answer item the child selects

Trial 1		1		2		3	Label: ________
	4		5		6		
Trial 2		1		2		3	Label: ________
	4		5		6		
Trial 3		1		2		3	Label: ________
	4		5		6		
Trial 4		1		2		3	Label: ________
	4		5		6		
Trial 5		1		2		3	Label: ________
	4		5		6		
Trial 6		1		2		3	Label: ________
	4		5		6		

Children are allowed to self correct.

If child labels, record and mark if correct with a ✓ or ×

Source: Siegler & Svetina (2002). Version 3.

Inductive Version, One Dimension Varied On The Practice Trial

VERSION D

Matrix Completion Task
Demo Trial

Now you and I are going to play a different game. Here's our game board *(take out board)*.

In this game, the ones on this side go together (*gesture up and down right-hand column*) **and the ones on that side go together** *(gesture up and down left-hand column)*, **but also the ones up here go together** *(gesture along top row)* **and the ones down here go together** *(gesture along bottom row)*.

Look, there is one missing (*Point to empty cell*). **Can you tell me which of these pictures** (*show answers*) **belongs here?** (*Point to empty cell*).

Child answers: *Correct* *Incorrect*

Feedback *Correct:* **that's right! This one belongs here because it goes with this one *and* with this one** *(point to appropriate items – top and side)*. **Good job!** *Incorrect:* **good try, but this one belongs here** *(place big book)* **because it goes with this one *and* with this one** *(point to appropriate items – top and side).*

Source: Siegler & Svetina (2002). Version 3.

VERSION D

Test Trials

Now, I have some more boards for you. They've already been started, but I need your help to finish them, OK?

For each trial:

Show board and answers
Remember, the ones on this side have to go together *(motion along left column)*, **and the ones on that side have to go together** *(motion to right column)*. **And also the ones up here have to go together** *(motion along top row)*, **and the ones down here have to go together** *(motion along bottom row)*.

Can you tell me which one of these pictures (*show answers with vague motion*) **belongs here?** (*Point to empty cell*).

Circle the answer item the child selects

Trial 1		1		2		3	Label:
	4		5		6		
Trial 2		1		2		3	Label:
	4		5		6		
Trial 3		1		2		3	Label:
	4		5		6		
Trial 4		1		2		3	Label:
	4		5		6		
Trial 5		1		2		3	Label:
	4		5		6		
Trial 6		1		2		3	Label:
	4		5		6		

Children are allowed to self correct.

If child labels, record and mark if correct with a ✓ or ×

Source: Siegler & Svetina (2002). Version 3.

Inductive Version, Two Dimensions Varied On the Practice Trial

VERSION C

Matrix Completion Task
Demo Trial

Now you and I are going to play a different game. Here's our game board *(take out board)*.

In this game, the ones on this side go together (*gesture up and down right-hand column*) **and the ones on that side go together** *(gesture up and down left-hand column)*, **but also the ones up here go together** *(gesture along top row)* **and the ones down here go together** *(gesture along bottom row)*.

Look, there is one missing (*Point to empty cell*)**. Can you tell me which of these pictures** (*show answers*) **belongs here?** (*Point to empty cell*).

Child answers: *Correct* *Incorrect*

Feedback *Correct:* **that's right! This one belongs here because it goes with this one *and* with this one** *(point to appropriate items – top and side)*. **Good job!** *Incorrect:* **good try, but this one belongs here** *(place big balloon)* **because it goes with this one *and* with this one** *(point to appropriate items – top and side).*

Source: Siegler & Svetina (2002). Version 3.

VERSION C

Test Trials

Now, I have some more boards for you. They've already been started, but I need your help to finish them, OK?

For each trial:

> *Show board and answers*
> **Remember, the ones on this side have to go together** *(motion along left column)*, **and the ones on that side have to go together** *(motion to right column)*. **And also the ones up here have to go together** *(motion along top row)*, **and the ones down here have to go together** *(motion along bottom row)*.
>
> **Can you tell me which one of these pictures** (*show answers with vague motion*) **belongs here?** (*Point to empty cell*).

Circle the answer item the child selects

Trial 1		1		2		3	Label:
	4		5		6		
Trial 2		1		2		3	Label:
	4		5		6		
Trial 3		1		2		3	Label:
	4		5		6		
Trial 4		1		2		3	Label:
	4		5		6		
Trial 5		1		2		3	Label:
	4		5		6		
Trial 6		1		2		3	Label:
	4		5		6		

Children are allowed to self correct.

If child labels, record and mark if correct with a ✓ or ×

Source: Siegler & Svetina (2002). Version 3.

Appendix M: Study 2 Matrix Sort Task Protocols

Deductive Version, One Dimension Varied On The Practice Trial

VERSION B

Matrix Sort Task
Demo Trial

Now you and I are going to play a different game. Here's our game board *(take out board)*.

- **See, this is blue** *(point to blue)*. **It tells us that the blue ones go on this side** (*gesture up and down right-hand column*).
- **And this is red** *(point to train)*. **It tells us that the red ones go on that side** (*gesture up and down left-hand column*).
- **See this? This is a plane** *(point to book)*. **It tells us that the planes go on the top** (*gesture along top row*).
- **And this is a plane** *(point to balloon)*. **It tells us that the planes go on the bottom** (*gesture along bottom row*).

I have four cards here, see? *(show all four cards)*
I'm going to put them on this game board.

Put cards on game board:

Blue plane	*Red plane*
Blue plane	*Red plane*

See? The blue ones go together (*gesture up and down right-hand column*)**, and the red ones go together** (*gesture up and down left-hand column*)**. And look at it this way, the planes go together** *(gesture along top row*)**, and the planes go together** (*gesture along bottom row)*.

OK, now it's your turn! (See test trials on following page)

Source: Cartwright, Marshall, Dandy, & Isaac (2010). Version 2

VERSION B

Test Trials

Clear board, spread out cards in a row (see below for order).
Can you put these cards on the game board for me? Remember, the *(point to top left, label)* **tells us all the** *(label)* **go on this side** *(motion along left column)*, **and the** *(point to top right, label)* **tells us all the** *(label)* **go here** *(motion to right column)*. **Also the** *(point to side top, label)* **tells us all the** *(label)* **go on top** *(motion along top row)*, **and the** *(point to side bottom, label)* **tells us all the** *(label)* **go on the bottom** *(motion along bottom row)*.

Record child's final answer in the tables below

Trial 1: Big yellow, big red, small red, small yellow		
Trial 2: Yellow car, yellow fish, green fish, green car		
Trial 3: Small balloon, small book, big book, big balloon		
Trial 4: Big blue, small blue, small red, big red		
Trial 5: Big cup, big mitts, small mitts, small cup		
Trial 6: Red bird, yellow bird, yellow train, red train		

Source: Cartwright, Marshall, Dandy, & Isaac (2010). Version 2

Deductive Version, Two Dimensions Varied On The Practice Trial

VERSION A

Matrix Sort Task
Demo Trial

Now you and I are going to play a different game. Here's our game board *(take out board)*. **The game board shows us where different pictures belong.**

- **See, this is blue** *(point to blue)*. **It tells us that the blue ones go on this side** (*gesture up and down right-hand column*).
- **And this is red** *(point to train)*. **It tells us that the red ones go on that side** (*gesture up and down left-hand column*).
- **See this? This is a plane** *(point to book)***? It tells us that the planes go on the top** (*gesture along top row*).
- **And these are mitts** *(point to balloon)*. **They tell us that the mitts go on the bottom** (*gesture along bottom row*)**.**

I have four cards here, see? *(show all four cards)*
I'm going to put them on this game board.

Put cards on game board:

Blue plane	*Red plane*
Blue mitts	*Red mitts*

See? The blue ones go together (*gesture up and down right-hand column*)**, and the red ones go together** (*gesture up and down left-hand column*)**. And look at it this way, the planes go together** *(gesture along top row*)**, and the mitts go together** (*gesture along bottom row)***.**

OK, now it's your turn! (See test trials on following page)

Source: Cartwright, Marshall, Dandy, & Isaac (2010). Version 2

VERSION A

Test Trials

Clear board, spread out cards in a row (see below for order).
Can you put these cards on the game board for me? Remember, the *(point to top left, label)* **tells us all the** *(label)* **go on this side** *(motion along left column)***, and the** *(point to top right, label)* **tells us all the** *(label)* **go here** *(motion to right column)***. Also the** *(point to side top, label)* **tells us all the** *(label)* **go on top** *(motion along top row)***, and the** *(point to side bottom, label)* **tells us all the** *(label)* **go on the bottom** *(motion along bottom row)***.**

Record child's final answer in the tables below

Trial 1: Big yellow, big red, small red, small yellow		
Trial 2: Yellow car, yellow fish, green fish, green car		
Trial 3: Small balloon, small book, big book, big balloon		
Trial 4: Big blue, small blue, small red, big red		
Trial 5: Big cup, big mitts, small mitts, small cup		
Trial 6: Red bird, yellow bird, yellow train, red train		

Source: Cartwright, Marshall, Dandy, & Isaac (2010). Version 2

Inductive Version, One Dimension Varied On The Practice Trial

VERSION D

Matrix Sort Task
Demo Trial

Now you and I are going to play a different game. Here's our game board *(take out board)*.

In this game we have to put all the cards on the board. The cards on this side (*gesture up and down right-hand column*) **have to go together, the cards on that side** (*gesture up and down left-hand column*) **have to go together, and also the cards on the top** *(gesture along top row*) **have to go together, and the cards on the bottom have to go together** (*gesture along bottom row)***.**

I have four cards here, see? *(show all four cards)*
I'm going to put them on this game board.

Put cards on game board:

Blue plane	*Red plane*
Blue plane	*Red plane*

See? The ones on this side (*gesture up and down right-hand column*) **go together, and the ones on that side** (*gesture up and down left-hand column*) **go together. And look at it this way, the ones on the top** *(gesture along top row*) **go together, and the ones on the bottom** (*gesture along bottom row)* **go together.**

OK, now it's your turn! (See test trials on following page)

Source: Cartwright, Marshall, Dandy, & Isaac (2010). Version 2

VERSION D

Test Trials

Clear board, spread out cards in a row (see below for order).
Can you put these cards on the game board for me? Remember, the cards on this side *(gesture to first column)* **have to go together, and the cards on this side** *(gesture to second column)* **have to go together. But also, the cards on the top** *(gesture to first row)* **have to go together, and the cards on the bottom** *(gesture to second row)* **have to go together.**

Record child's final answer in the tables below

Trial 1: Big yellow, big red, small red, small yellow		
Trial 2: Yellow car, yellow fish, green fish, green car		
Trial 3: Small balloon, small book, big book, big balloon		
Trial 4: Big blue, small blue, small red, big red		
Trial 5: Big cup, big mitts, small mitts, small cup		
Trial 6: Red bird, yellow bird, yellow train, red train		

Source: Cartwright, Marshall, Dandy, & Isaac (2010). Version 2

Inductive Version, Two Dimensions Varied On The Practice Trial

VERSION C

Matrix Sort Task
Demo Trial

Now you and I are going to play a different game. Here's our game board *(take out board)*.

In this game we have to put all the cards on the board. The cards on this side (*gesture up and down right-hand column*) **have to go together, the cards on that side** (*gesture up and down left-hand column*) **have to go together, and also the cards on the top** *(gesture along top row)* **have to go together, and the cards on the bottom have to go together** (*gesture along bottom row)*.

I have four cards here, see? *(show all four cards)*
I'm going to put them on this game board.

Put cards on game board:

Blue plane	*Red plane*
Blue mitts	*Red mitts*

See? The ones on this side (*gesture up and down right-hand column*) **go together, and the ones on that side** (*gesture up and down left-hand column*) **go together. And look at it this way, the ones on the top** *(gesture along top row)* **go together, and the ones on the bottom** (*gesture along bottom row)* **go together.**

OK, now it's your turn! (See test trials on following page)

Source: Cartwright, Marshall, Dandy, & Isaac (2010). Version 2

VERSION C

Test Trials

Clear board, spread out cards in a row (see below for order).
Can you put these cards on the game board for me? Remember, the cards on this side *(gesture to first column)* **have to go together, and the cards on this side** *(gesture to second column)* **have to go together. But also, the cards on the top** *(gesture to first row)* **have to go together, and the cards on the bottom** *(gesture to second row)* **have to go together.**

Record child's final answer in the tables below

Trial 1: Big yellow, big red, small red, small yellow		
Trial 2: Yellow car, yellow fish, green fish, green car		
Trial 3: Small balloon, small book, big book, big balloon		
Trial 4: Big blue, small blue, small red, big red		
Trial 5: Big cup, big mitts, small mitts, small cup		
Trial 6: Red bird, yellow bird, yellow train, red train		

Source: Cartwright, Marshall, Dandy, & Isaac (2010). Version 2

Appendix N: Normality Indicators And Plots For Study 2

This appendix includes the skewness and kurtosis values, as well as K-S normality test information for the continuous variables used in Study 2 (see Table N1), along with histograms and Q-Q plots. Specifically, it contains information about the following variables:

1. Age in months;
2. Preschool Matrix Completion Task score (correct trials);
3. Matrix Sort Task score (correct trials);
4. Modified Flexible Item Selection Task (contingency score);
5. Self-Ordered Pointing Task (correct sets);
6. Black/White (correct trials);
7. Proportion of Duplicate Errors (out of total number of errors).

Normality Indicators

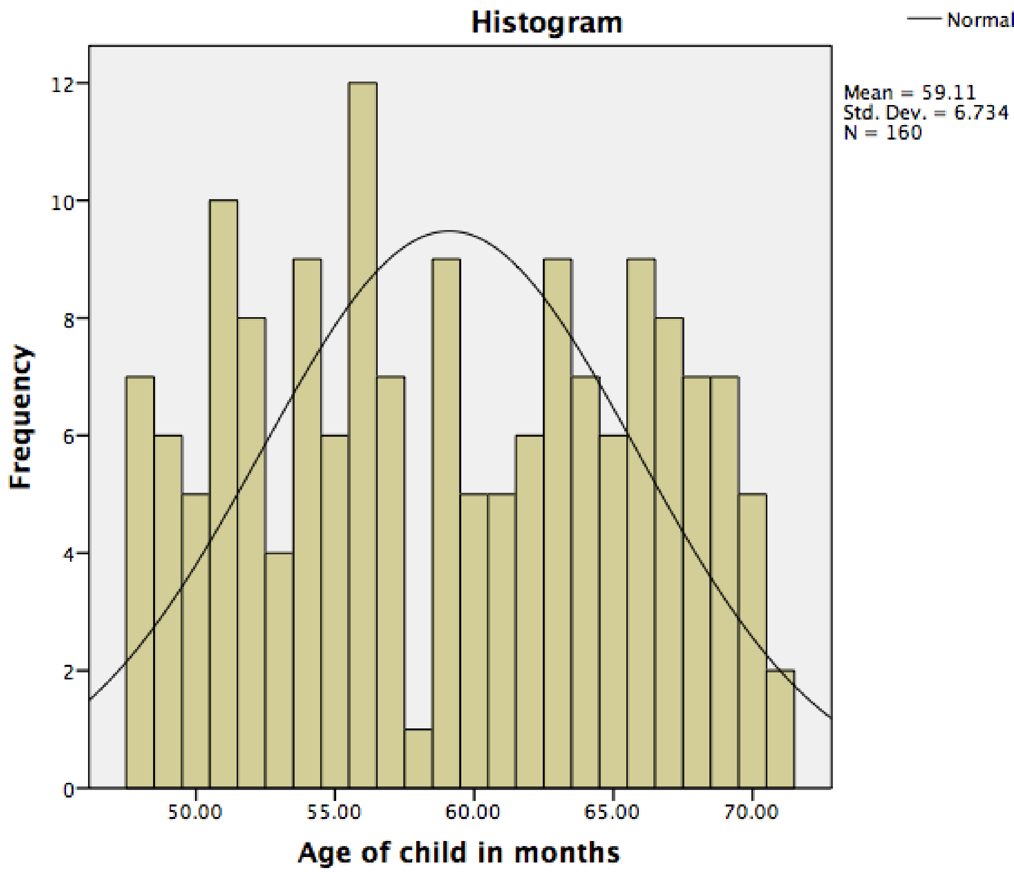
Table N1

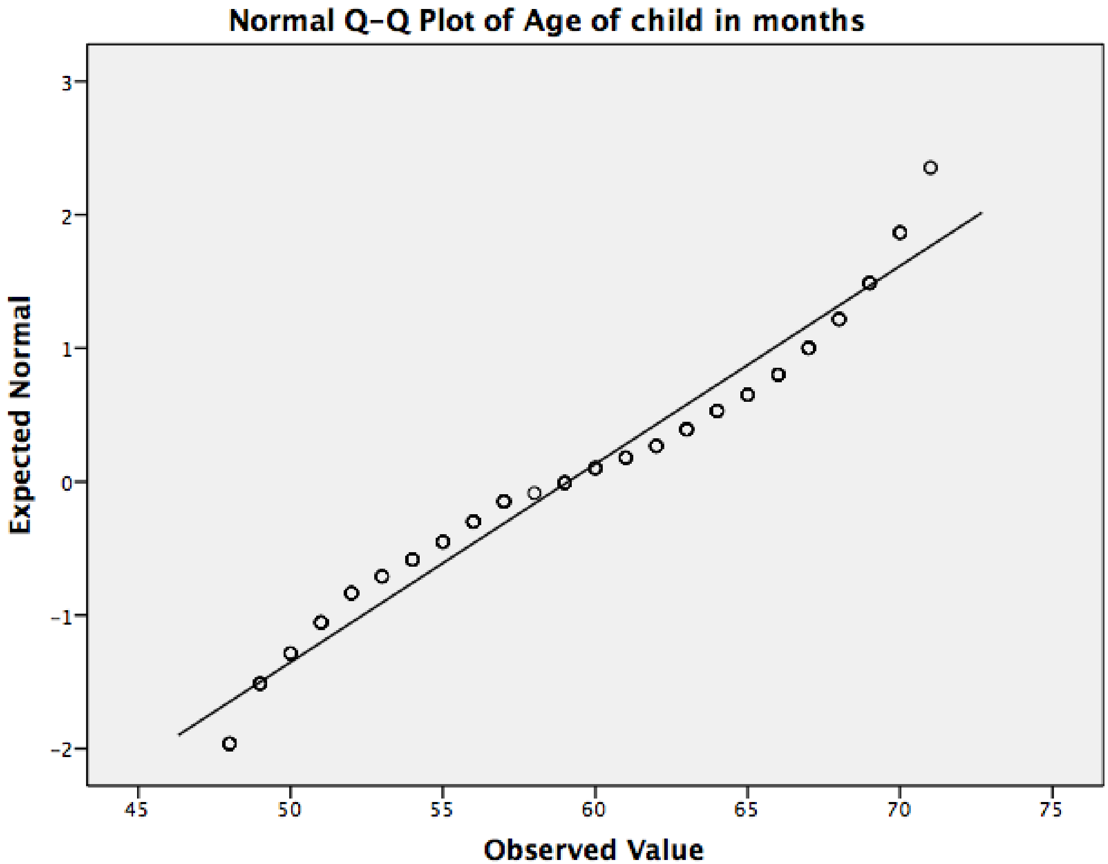
Normality Indicators for Study 2 Continuous Variables

Score	Skewness Score (SD)	Skewness Z-Score	Kurtosis Score (SD)	Kurtosis Z-Score	K-S Statistic (df)	K-S p-value
Age (in months)	0.01 (0.19)	0.05	-1.25 (0.38)	-3.29	0.10 (160)	.001
PMC	0.10 (0.19)	0.53	-1.34 (0.38)	-3.53	0.13 (160)	.000
MST	-0.77 (0.19)	4.05	-0.14 (0.38)	0.37	0.20 (160)	.000
MFIST	-1.28 (0.19)	-6.74	1.52 (0.38)	4.00	0.22 (160)	.000
SOP	0.66 (0.19)	0.03	0.06 (0.38)	0.16	0.13 (160)	.000
B/W	-1.76 (0.19)	-9.26	2.43 (0.38)	6.39	0.25 (157)	.000
Duplicate Errors (Proportion)	-1.54 (0.21)	7.33	1.25 (0.41)	3.05	0.35 (138)	.000

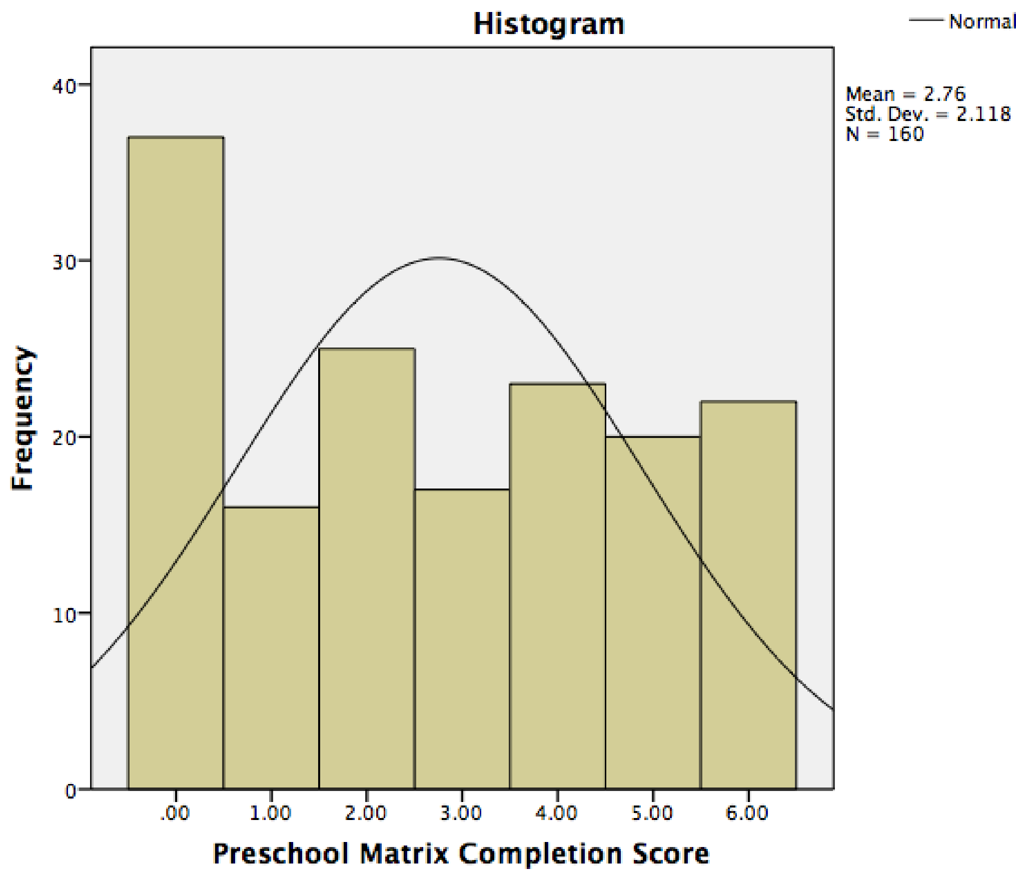
Note. PMC = Preschool Matrix Completion Task; MST = Matrix Sort Task; MFIST = Modified Flexible Item Selection Task; B/W = Black/White; SOP = Self-Ordered Pointing Task; K-S = Kolmogorov-Smirnov.

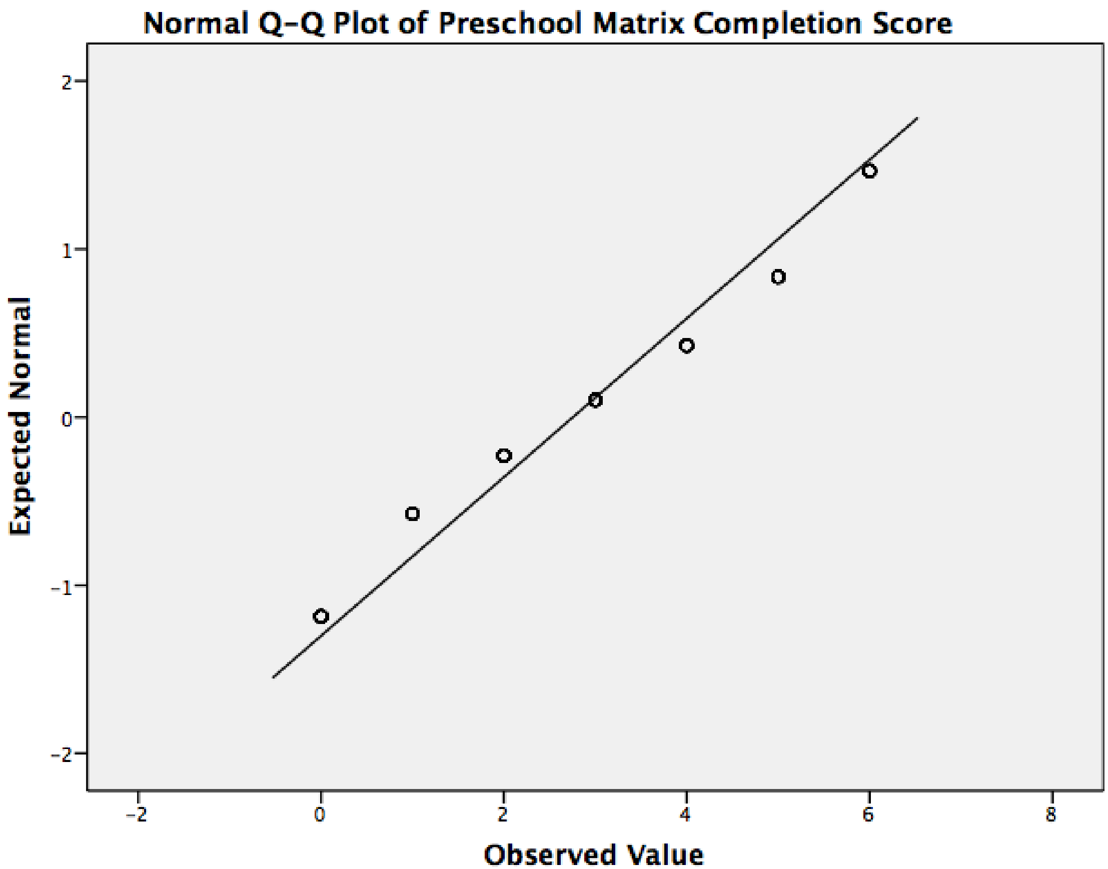
Age in months



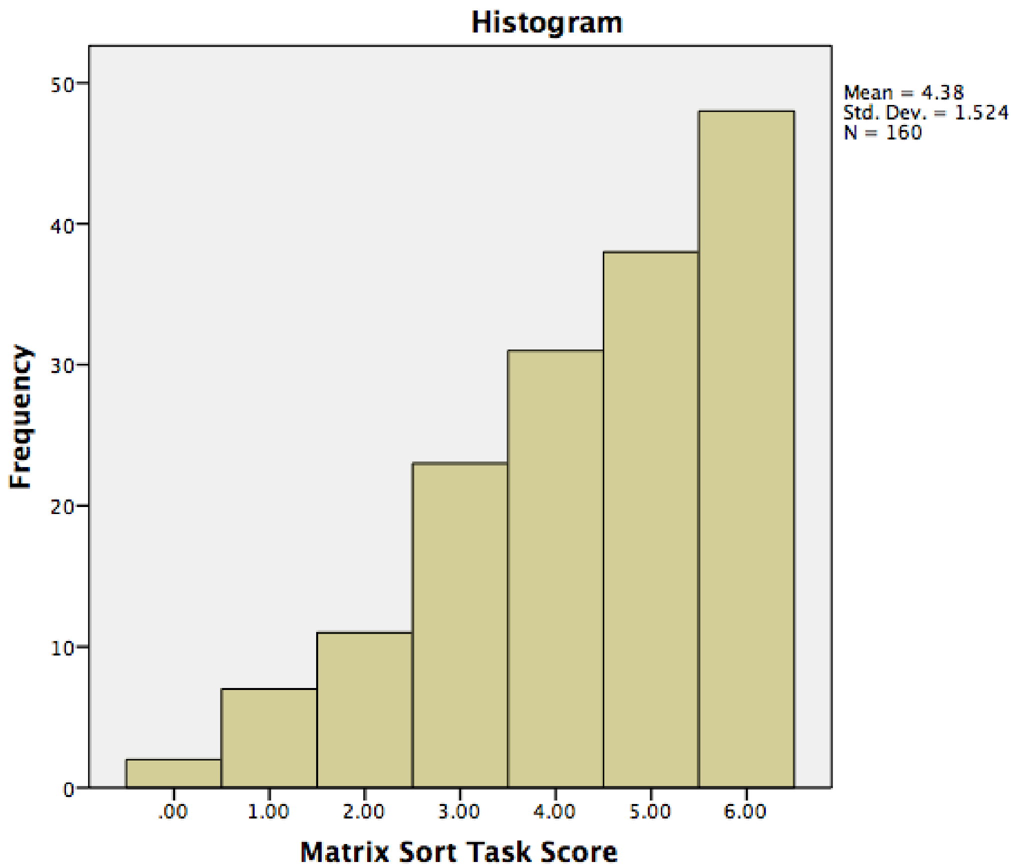

Normal Q-Q Plot of Age of child in months
Expected Normal
3
2
1
0
-1
-2
45
50
55
60
65
70
75
Observed Value

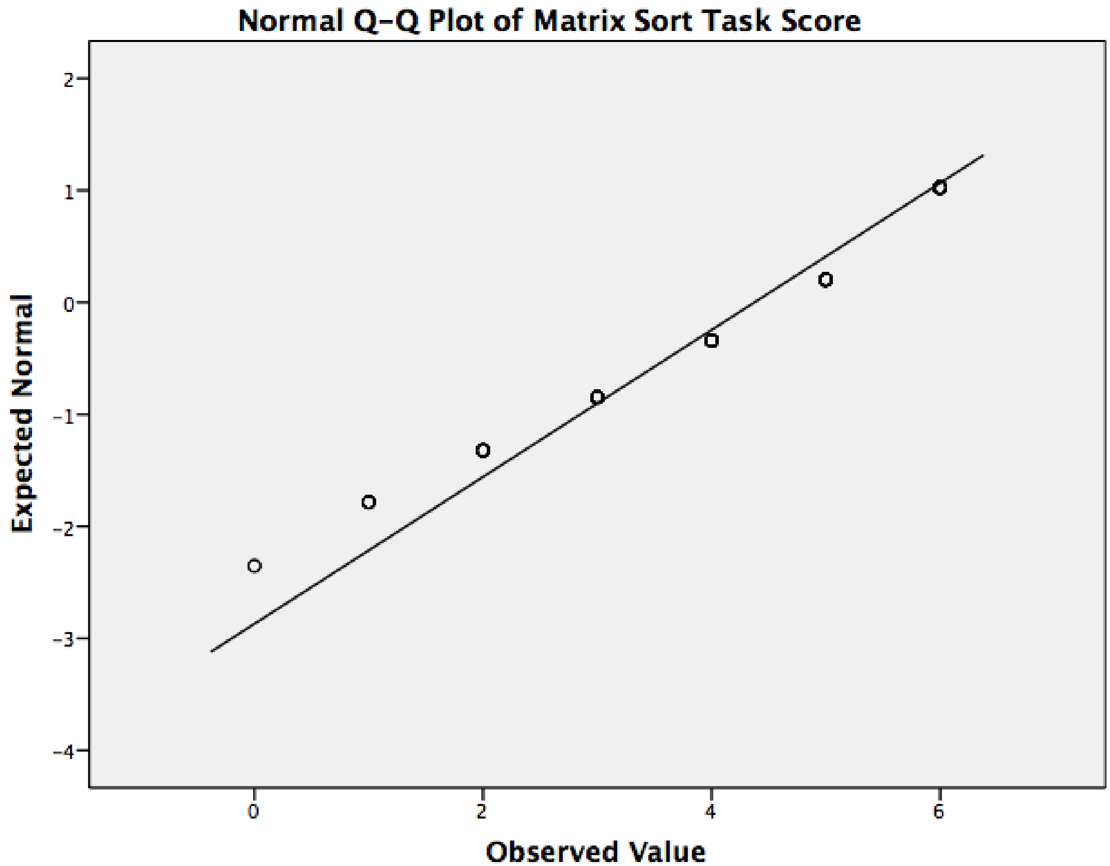
Preschool Matrix Completion Task



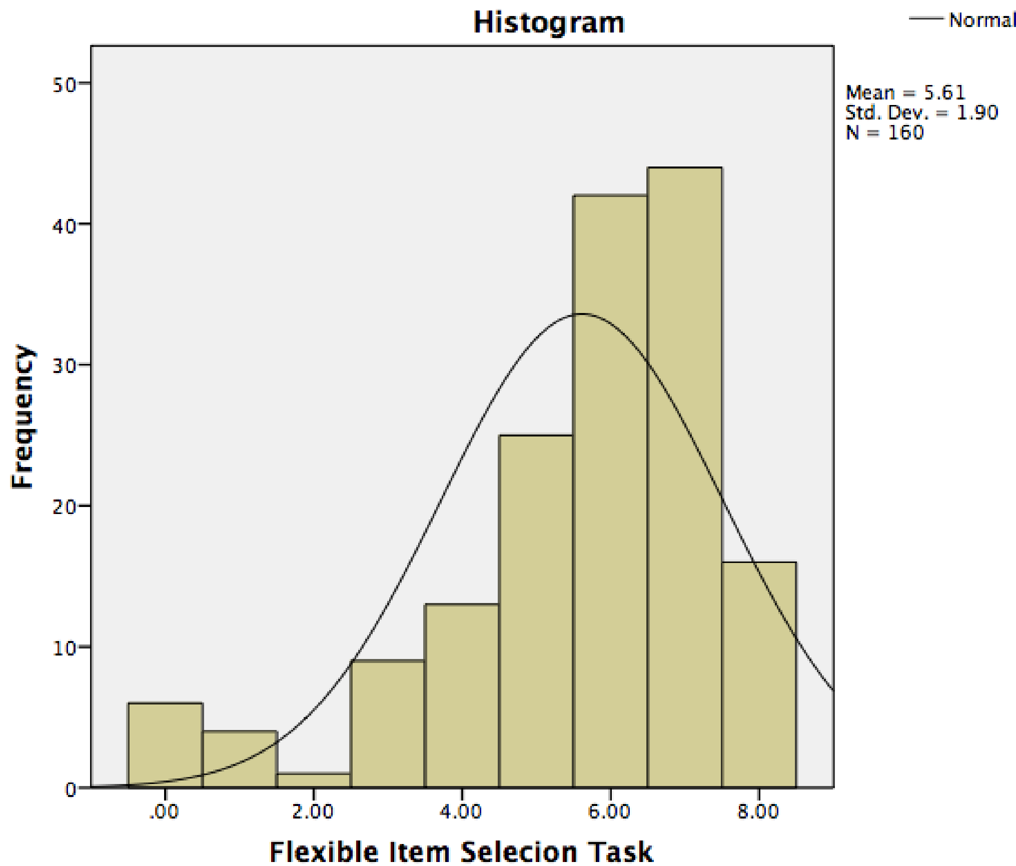

Normal Q-Q Plot of Preschool Matrix Completion Score
Expected Normal
Observed Value
2
1
0
-1
-2
-2
0
2
4
6
8

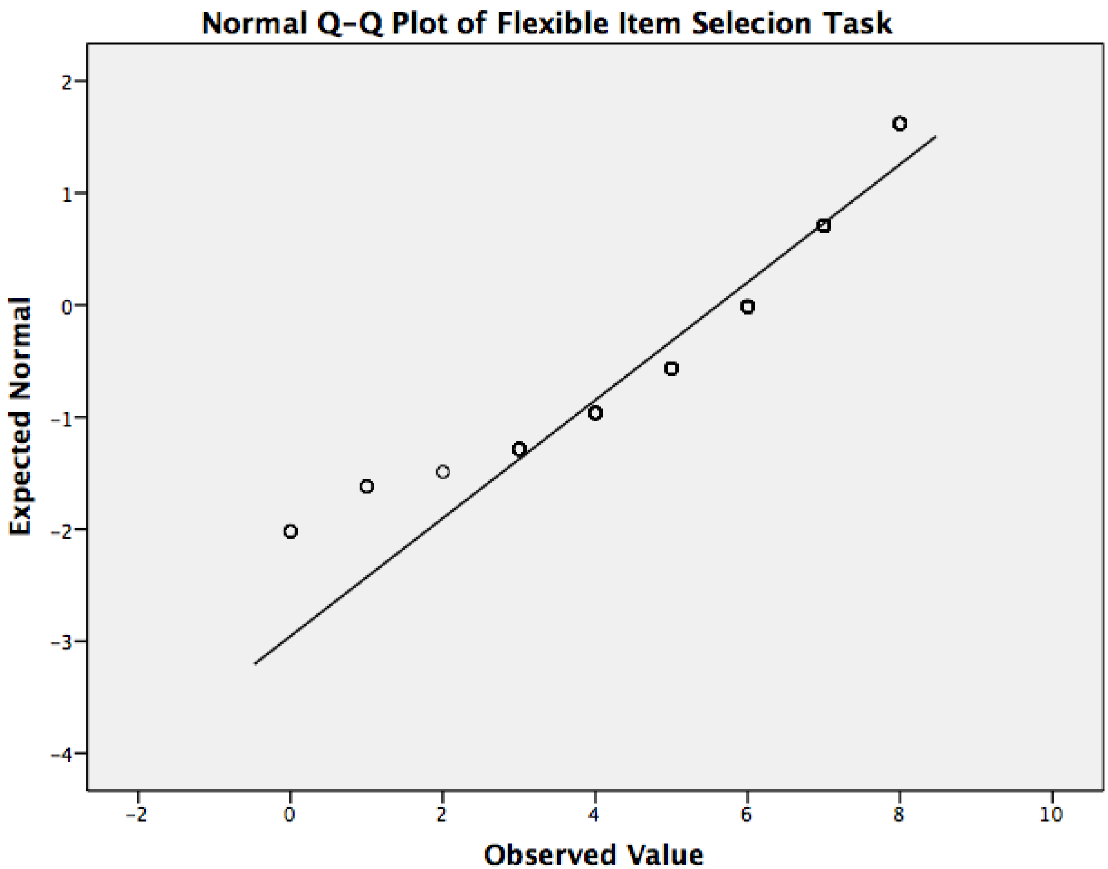
Matrix Sort Task



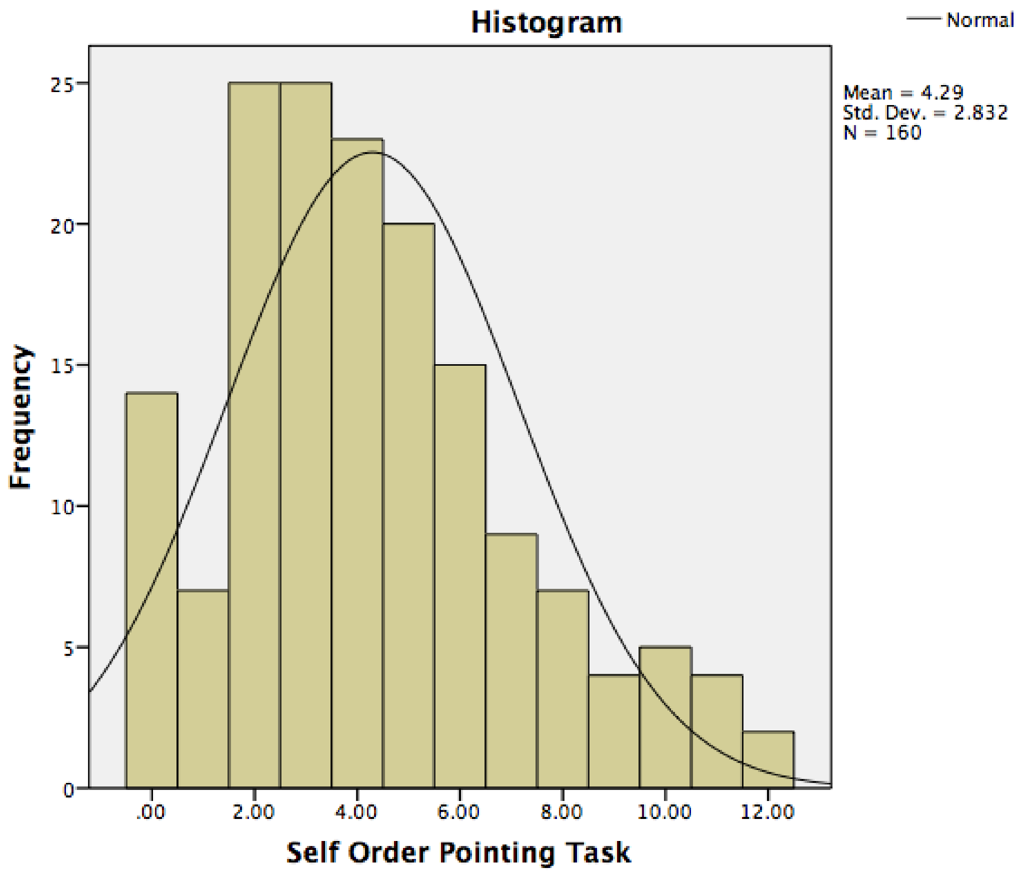

Normal Q-Q Plot of Matrix Sort Task Score
Expected Normal
2
1
0
-1
-2
-3
-4
0
2
4
6
Observed Value

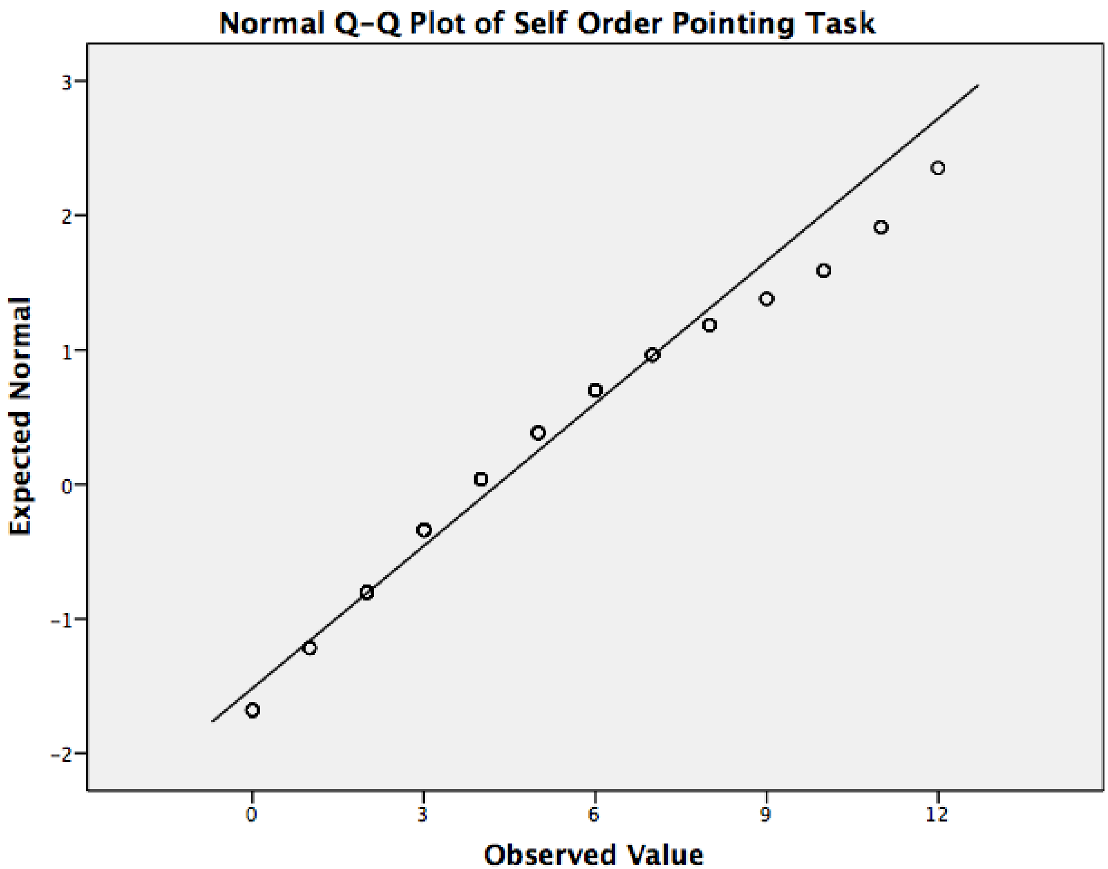
Modified Flexible Item Selection Task



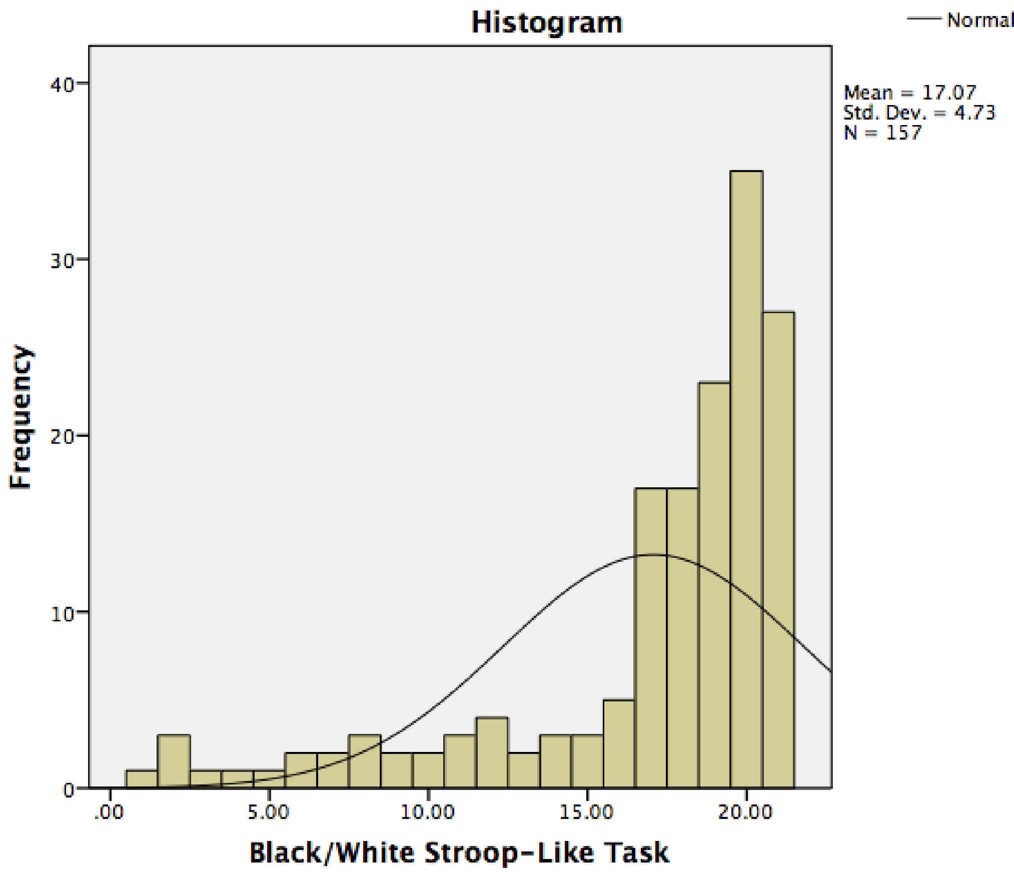

Normal Q-Q Plot of Flexible Item Selecion Task
Expected Normal
2
1
0
-1
-2
-3
-4
-2
0
2
4
6
8
10
Observed Value

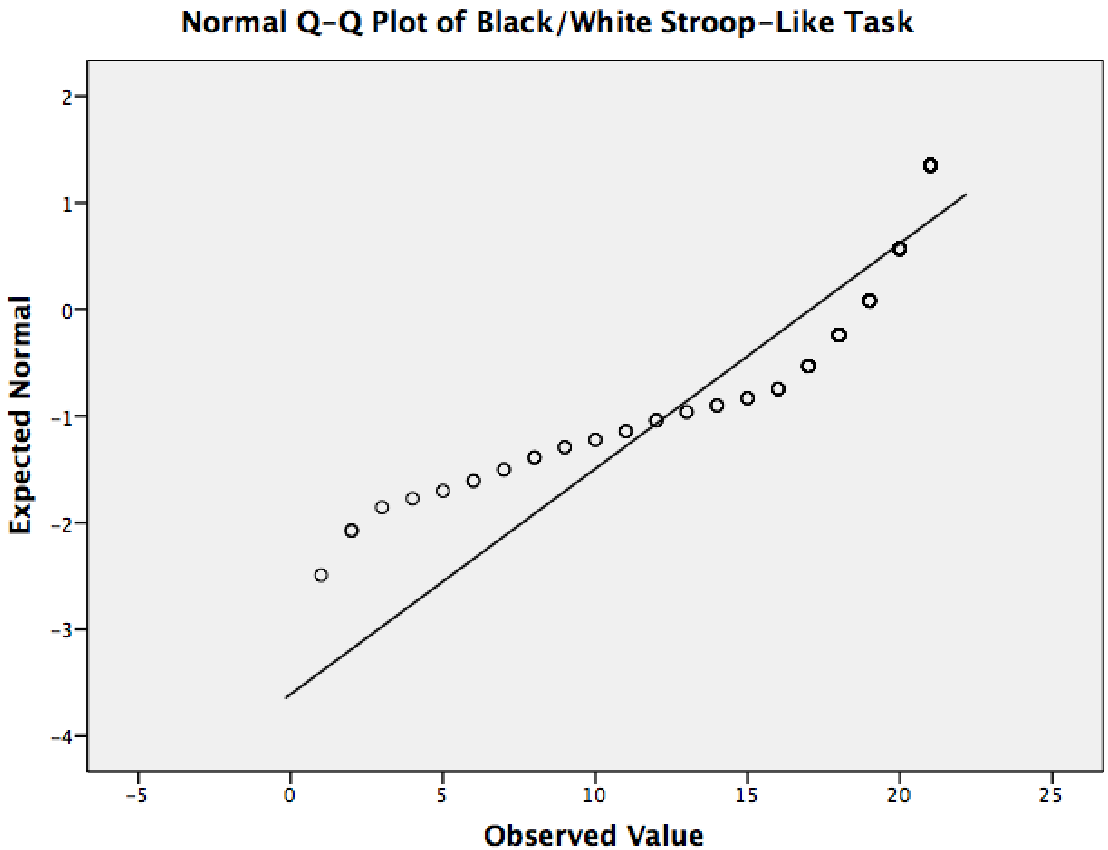
Self-Ordered Pointing Task



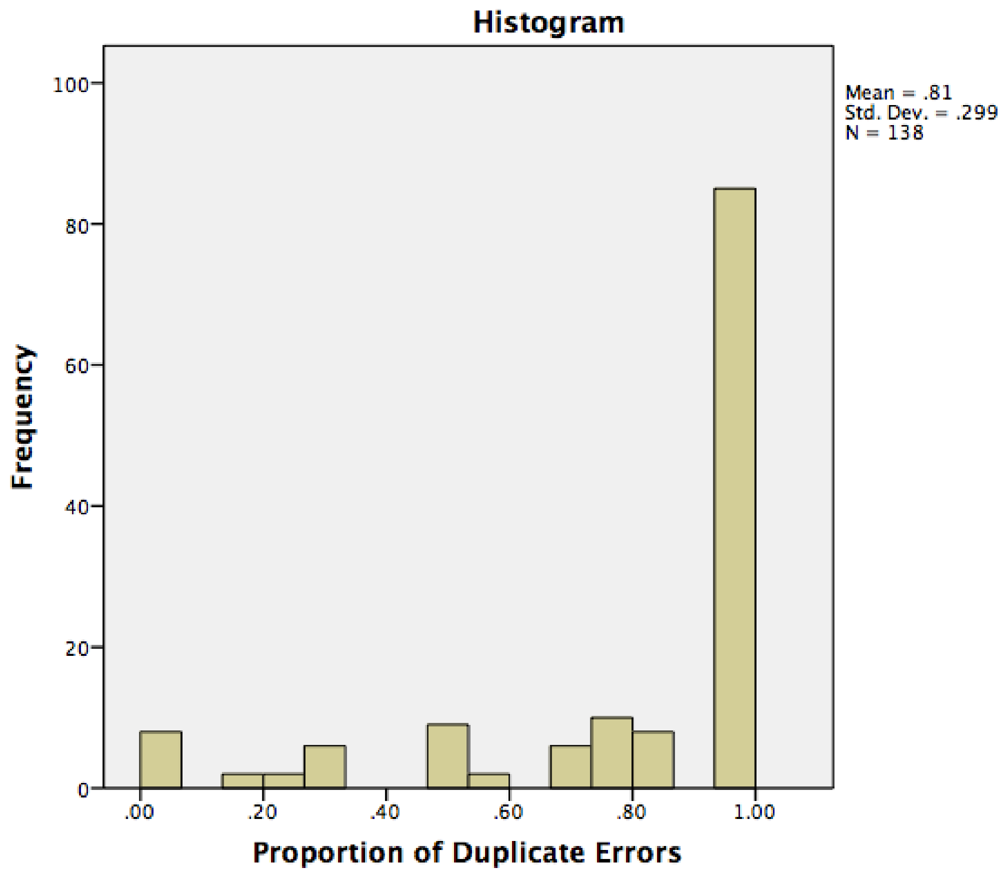

Normal Q-Q Plot of Self Order Pointing Task
Expected Normal
Observed Value
3
2
1
0
-1
-2
0
3
6
9
12

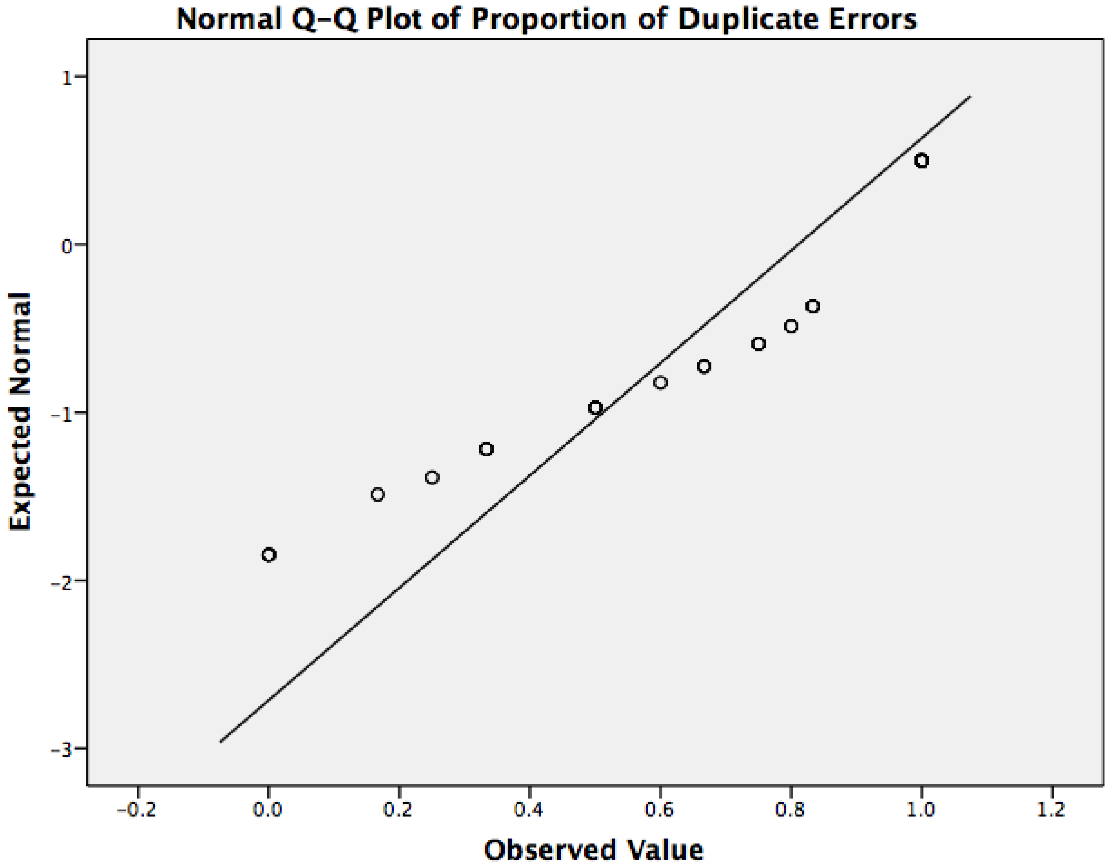
Black/White Stroop-Like Task




Normal Q-Q Plot of Black/White Stroop-Like Task
Expected Normal
Observed Value
2
1
0
-1
-2
-3
-4
-5
0
5
10
15
20
25

Proportion of Duplicate Errors




Normal Q-Q Plot of Proportion of Duplicate Errors
Expected Normal
1
0
-1
-2
-3
-0.2
0.0
0.2
0.4
0.6
0.8
1.0
1.2
Observed Value

Appendix O: Study 2 Non-Parametric Correlation Tables

This appendix includes non-parametric correlations (Kendall's Tau-b; see Field, 2013, p. 278) for Study 2. Table O1 presents bivariate correlations for the entire sample, as well as correlations for the entire sample with age (in months) partialled out. Table O2 presents bivariate correlations by task version (inductive and deductive).

Table O1

Study 2 Non-Parametric Correlations For Full Sample

	PPVT	PTONI	PMC	MST	MFIST	SOP	B/W
Age	-.020	-.053	.176**	.212**	.152**	.123*	-.012
PPVT	-	.172**	.138*	.007	.235**	.021	.018
PTONI	.171*	-	.165**	.126*	.191**	.158**	.005
PMC	.144	.177*	-	.174**	.125*	.104	.078
MST	.012	.141	.142	-	.258**	-.068	.078
MFIST	.241**	.202*	.101	.234**	-	.047	.233**
SOP	.023	.166*	.084	-.097	.029	-	.041
B/W	.018	.005	.081	.082	.238**	.043	-

Note. Bivariate correlations presented above the diagonal. Partial correlations with age (in months) controlled presented below the diagonal. PPVT = Peabody Picture Vocabulary Test; PTONI = Primary Test of Nonverbal Intelligence; PMC = Preschool Matrix Completion Task; MST = Matrix Sort Task; MFIST = Modified Flexible Item Selection Task; SOP = Self-Ordered Pointing Task; B/W = Black/White Stroop Task.
* $p < .05$ ** $p < .01$

Table O2

Study 2 Non-Parametric Correlations By Task Version

	Age	PPVT	PTONI	PMC	MST	MFIST	SOP	B/W
Age	-	-.023	-.033	.214*	.266**	.158	.094	-.006
PPVT	-.015	-	.098	.079	-.089	.185*	.054	.035
PTONI	-.063	.239**	-	.117	.160	.171*	.225**	-.055
PMC	.139	.188*	.205*	-	.186*	.169	.157	.122
MST	.212*	.129	.099	.157	-	.224*	-.099	.157
MFIST	.139	.306**	.222**	.094	.312**	-	.005	.320**
SOP	.157*	-.009	.126	.065	-.019	.083	-	-.075
B/W	-.001	.001	.072	.039	-.038	.159	.152	-

Note. Correlations for children who received inductive versions of the matrix tasks are presented above the diagonal. Correlations for children who received deductive versions of the matrix tasks are presented below the diagonal. PPVT = Peabody Picture Vocabulary Test; PTONI = Primary Test of Nonverbal Intelligence; PMC = Preschool Matrix Completion Task; MST = Matrix Sort Task; MFIST = Modified Flexible Item Selection Task; SOP = Self-Ordered Pointing Task; B/W = Black/White Stroop Task.
* $p < .05$ ** $p < .01$