EXAMINING MECHANISTIC AND DEVELOPMENTAL PREDICTORS OF COLLABORATION

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Collaboration, the coordination of actions to achieve a common goal, is a ubiquitous human behavior from an early age. Thus far, most research on collaboration has focused on its evolutionary origins, earliest occurrences, and outcomes (e.g. benefits). In this dissertation, I examine potential mechanistic and developmental causes of young children's collaboration in the hope of shining further light on how human collaboration develops and functions. I do so by conducting a detailed interdisciplinary examination of predictors of young children's spontaneous dyadic collaboration. Chapter 1 provides an outline of how this research aims to contribute to developmental research on human collaboration. Chapter 2 examines cognitive predictors, Chapter 3 environmental predictors, and Chapter 4 a physiological predictor of collaboration. Finally, Chapter 5 discusses the significance of the results for future research and important issues on the horizon for researchers to consider.

BIOGRAPHICAL SKETCH

Christopher Vredenburgh grew up in Vermont, received his B.A. in 2006 from Fordham University and his M.A. in 2010 from Cornell University. During his time at Cornell, he was fortunate to work as a Graduate Community Advisor in the Hasbrouck Graduate Residences, an instructor for the Cornell Prison Education Program, and an instructor for Cornell Outdoor Education. His early work focused on help-seeking and joint attention. He later became interested in linking cognitive, environmental, and biological research approaches and theory to study young children's collaborative social dynamics.

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Additionally, many undergraduate students contributed to designing, recruiting, testing, coding, and analyzing this research. From the day that we obtained recycled cardboard boxes for the experimental stimuli to the day we began showing the experimental results, a devoted team of undergraduate Research Assistants provided the outstanding energy and work needed to complete this research. So I would like to thoroughly thank all of the Research Assistants who contributed to this research and made it possible.

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CHAPTER 1

INTRODUCTION

In the past two decades, developmental psychologists have demonstrated considerable interest in young children's prosocial behavior. Among a wide range of important findings, this research has documented that young children show early altruistic and moral tendencies (Chernyak & Sobel, 2016; Warneken, Lohse, Melis, & Tomasello, 2011), a predilection to engage in and appreciate joint attention (Gergely & Csibra, 2013), and an appreciation for collaboration without need of explicit rewards (Paradise & Rogoff, 2009; Tomasello, Dweck, Silk, Skyrms, & Spelke, 2009; Warneken, Chen, & Tomasello, 2006; Warneken, Gräfenhain, & Tomasello, 2011). Indeed, the resulting findings on children's early-emerging prosocial faculties and abilities have led some researchers to boldly argue that collaborative, prosocial capacities are primarily what differentiate humans from non-human primates (Tomasello, 2008; Tomasello et al, 2009).

While researchers have shown attention to a variety of prosocial behaviors, children's collaboration in particular has received substantial interest. Collaboration is defined in the developmental literature as a sequence of coordinated actions towards a shared goal (Tomasello et al, 2009). As such, collaboration is arguably an essential component of other prosocial behaviors (Tomasello, 2008; Tomasello et al, 2009). Specifically, to the extent that other important prosocial behaviors (e.g. sharing, helping) involve social action coordination toward specific goals, they entail collaboration. It is perhaps due to this pervasiveness that researchers from a wide range of backgrounds, including cognitive, educational, and evolutionary, have researched collaboration.

The substantial interest in young children's collaboration has yielded important and intriguing findings. For example, experimental psychology research has found that preschoolers from a wide range of cultural backgrounds (e.g. including western European, Amazonian, and Chinese backgrounds) collaborate (Callaghan et al, 2011) and children often select to collaborate over independent action (Warneken, Gräfenhain, & Tomasello, 2012). Interestingly, research shows that children not only have a predilection to collaborate, but it can provide some learning benefits. In at least some social contexts, children learn more efficiently when collaborating, including memory of toy assembly, event planning, and adoption of cultural practices (Paradise & Rogoff, 2009; Ratner, Foley, & Gimpert, 2002; Sommerville & Hammond, 2007). In short, controlled experimental studies indicate that young children actively engage in collaboration and their learning often benefits from such collaborative engagement.

Other developmental collaboration research has focused more on explaining *why* young children demonstrate such a proclivity to collaborate. This wide-ranging body of evolutionary-oriented research strongly suggests that from as young as two years of age humans are substantially more collaborative than non-human primates (Tomasello, Carpenter, Call, Behne, & Moll, 2005; Tomasello et al, 2009). Specifically, young children demonstrate a stronger preference to engage and spend time with others (i.e. over individual activity) than bonobos, chimpanzees, and marmosets, each of which develop in varied social structures (Warneken, Chen, & Tomasello, 2006; Bullinger, Burkart, Melis, & Tomasello, 2013). Moreover, to the extent that the closest non-human primate, chimpanzees, do collaborate, they do so with less vocal, gestural, and visual coordination (Bullinger, Melis, & Tomasello, 2013). In this sense, young children's collaboration is, to a larger degree, more multimodal and rich. Thus, these studies evidence that, overall, young children collaborate more because humans adapted to evolutionary pressures by becoming more collaborative than their non-human primate predecessors. In particular, humans evolved developmental mechanisms that, through unspecified biological (e.g. genetic, epigenetic, and neurological) and behavioral (e.g. cognitive and social) mechanisms, lead them to behave collaboratively in a wide variety of contexts by their preschool years.

Overall, the existing body of developmental research sheds substantial light on apparent evolutionary causes of human collaboration. In particular, the researchers' repeated application of diverse experimental techniques, including evolutionary, cognitive, and cultural studies, are to be commended. (Indeed, in an age in which public mistrust of psychological research is understandably high, this body of research ought to represent a guiding hallmark for future psychological and biological research). Interestingly, an important result of this convincing body of research is that it (somewhat naturally) leads researchers to wonder about the other *kinds* of causes of children's collaboration. Namely, knowing the evolutionary causes leads one to wonder about the mechanistic (i.e. immediate cause preceding the event) and developmental (i.e. ontogenetic processes resulting in an ability and predisposition) causes of collaboration (Tinbergen, 1996). Importantly, knowing the evolutionary causes does not directly address issues such as what makes children collaborate more in one instance than another, or what makes one child more or less collaborative than another child. Presently, experimental psychologists have not systematically investigated the mechanistic or developmental causes of children's collaboration.

Nonetheless, answering these questions is essential for researchers to demonstrate a complete scientific understanding of human collaboration and its causes (Tinbergen, 1996). Additionally, beyond the benefit of increasing our scientific understanding, answering questions of mechanistic and developmental causation is of great practical import for educators, child psychologists and therapists, and policy makers (e.g. Head Start program directors, Department of Health and Human Services) (Blair, 2002; Raver & Zigler, 1997). Indeed, developmental psychologists have documented that children's collaboration is a significant component in their successful development and education across a wide range of cultures and educational contexts (Paradise & Rogoff, 2009; Raver & Zigler, 1997). In this way, investigating collaboration's mechanistic and developmental causes could provide interested parties (e.g. parents, educators, therapists, etc.) with more reliable and effective means of identifying and addressing factors detrimental to children's developing collaboration. Thus, for reasons scientific and beyond, investigating collaboration's mechanistic and developmental is of high interest.

In light of this very gap in our understanding of collaboration, the following research aimed to examine potential mechanistic and developmental causes of young children's collaboration. Specifically, based on the existing developmental literature, my colleagues and I identified a set of likely cognitive, environmental, and physiological factors that are potential mechanistic and developmental causes. As is further detailed in Chapters 2:4, we examined their relationship to preschoolers' dyadic peer collaboration using an original experimental design that permitted children to spontaneously collaborate (or not). In the remaining section of this chapter, I briefly outline the research basis and intuition for focusing on the particular selected factors.

Cognitive Predictors: *Children's Competency and Task Difficulty*. In prior research on preschoolers' help-seeking, we found that young children spontaneously sought and engaged assistance from an adult in accord with children's relative need for assistance (Vredenburgh & Kushnir, 2016). We measured each child's ability to independently complete a toy assembly activity, termed their competency, as well as the relative difficulty of each step of the toy assembly. We found that less competent children sought more assistance overall than more competent children. Moreover, children sought more assistance on difficult steps of the activity than they did on less difficult ones. Indeed, over 50% of children's decisions of whether to seek assistance on a step was explained by (1) children's competency and (2) the relative difficulty of the step.

Similar to collaboration, help-seeking involves coordinating actions towards a shared goal with the helper. The principal difference is that, in help-seeking, the collaboration is first initiated by an agent who signals a need for assistance to the helper(s) (Newman, 2000). Given the close definitional relationship between help-seeking and collaboration, known predictors of help-seeking are potentially good candidates for predictors of collaboration. Similar to help-seeking, the intuition is that agents (e.g. children) may increase their collaboration relative to their need to coordinate in order to complete the shared goal. Thus, in this study, we evaluated whether children's competency and the relative difficulty of the activity act as mechanistic predictors of children's collaboration.

Cognitive Predictors: Children's Theory of Mind. A large body of intriguing developmental psychology research focuses on children's developing social cognition (Gopnik, Meltzoff, & Kuhl, 1999; Kushnir, 2013; Wellman, 2014). An important component of social cognition research concerns children's theory of mind. Here, theory of mind refers to children's understanding that other people have and act in response to mental states (i.e. beliefs, desires, etc.) (Wellman & Liu, 2004). Children's developing theory of mind and its potential role in collaboration is somewhat intuitive. Through their interactions and verbalizations across development, children learn social cognitive information that they employ in their own social interactions. Hence, children who possess a greater understanding of the beliefs and desires related to other children's actions may be expected to better predict and collaborate with other children.

Indeed, some developmental research indicates that social cognition may play a role in supporting children's everyday social behavior. For instance, behaviorally inhibited children who demonstrate high negative behaviors in their peer interactions pass less theory of mind scale items (Suway, Degnan, Sussman, & Fox, 2012). Additionally, researchers have found that children's performance on theory of mind scales correlates with some sharing behavior (Yu & Leslie, 2016). This project therefore assesses whether children's developing theory of mind, as measured by a standardized theory of mind scale, relates to their peer collaboration.

Environmental Predictors: Low Income Backgrounds & Parental Behavior. A wide body of developmental research indicates that children raised in low income households demonstrate greater social behavior problems (Brooks-Gunn & Duncan, 1997; Evans, 2004; Evans, Gonnella, Marcynyszyn, Gentile, & Salpekar, 2005; McLoyd, Ceballo, & Mangelsdorf, 1996). For example, studies indicate that low income children exhibit higher levels of internalizing and externalizing behavior problems (Adams, Hillman, & Gaydos, 1994; Brooks-Gunn & Duncan, 1997) and have lower social competence than their non-low income peers (Zhang, Chen, Zhang, & Sun, 2009). Additionally, there is evidence that increases in family income relate to increases in young children's positive social behavior (Morris & Gennetian, 2003). Thus, there is a wide ranging body of evidence that negatively links children's social development to their social-economic background.

Moreover, a wealth of research associates parental behavior, such as measures of maternal sensitivity, parental attachment security, and parental social attitudes, to preschoolers' social competence and social behavior (Pettit, Dodge, & Brown, 1988; Repetti, Taylor, & Seeman, 2002; Scrimgeour, Blandon, Stifter, & Buss, 2013). As an example, an impressive longitudinal study demonstrated that the social skill and lack of aggression in children's peer play with a familiar friend at 3 and 4.5 years of age related positively to observational ratings of maternal sensitivity (i.e. responsive and sensitive care of the child) (NICHD ECCRN, 2001; 2006). Hence, this body of research supports the notion that sensitive and responsive parenting, which correlates with income (Blair, 2002), supports children's healthy social development. Based on this research, this study investigates whether low income family environments and parenting behavior relate to preschoolers' peer collaboration as potential developmental predictors.

Physiological Predictor: Cortisol Reactivity. A large body of developmental psychology and biology research provides compelling reason to suspect that arousal (i.e. the non-specific activation of neural circuits and bodily organs relevant to the production of behavioral responses) may be relevant to preschoolers' social development. Arousal is supported by interacting sympathetic nervous systems (SNS), parasympathetic nervous systems (PNS), and hormonal systems, including the well-characterized hypothalamic-pituitary-adrenal (HPA) axis hormone cortisol (McEwen, 2007; Porges, 2007). The literature on arousal demonstrates that moderate increases in arousal support the allocation of the biological and cognitive resources needed to address cognitive and/or social challenges requiring sustained, attentive engagement (Aston-Jones & Cohen, 2005; Hostinar, Gunnar & Sullivan, 2013; Marcovitch et al, 2010; McEwen, 2007; Porges, 2007; Vermetten & Bremner, 2002). Contrarily, hypoaroused states are characterized by sluggishness and environmental disengagement, while hyperaroused states are associated with distractibility and exploration of the environment (Aston-Jones & Cohen, 2005; Porges, 2007).

Prior developmental psychology research has related children's arousal to their cognitive performance and social behavior. For example, increases in preschoolers' arousal have been shown to correlate with their performance on executive function tasks (Marcovitch & Lewkovitz, 2004) and social interaction with an unfamiliar peer (Stansbury & Harris, 2000). Thus, based on these well-known biological mechanisms and developmental findings, this study investigates whether preschoolers' cortisol reactivity, a marker of arousal adjustment, relates to children's spontaneous peer collaboration as a potential mechanistic predictor.

Overview. In sum, this research project aims to initiate a close, multidisciplinary study of selected factors that prior research suggests may be mechanistic or developmental causes of young children's peer collaboration. In selecting cognitive, environmental, and physiological factors for analysis, this research aims to first identify important predictors to lay the groundwork for further research of what are likely complex, multidisciplinary causal pathways that influence young children's collaboration. Lastly, as is discussed in the following chapters, this study aims to contribute to the collaboration literature by employing behavioral measurements of collaboration that better capture children's rich, dynamic play behavior and the field's working conceptual definition. Thus, by both employing a multidisciplinary analysis of predictors and detailed behavioral measurements, this research seeks to contribute to a solid basis for future developmental collaboration research.

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CHAPTER 2

EXAMINING COGNITIVE PREDICTORS OF YOUNG CHILDREN'S COLLABORATION

Introduction

Young children's peer collaboration is a ubiquitous phenomenon observable in formal and informal settings, from preschools to playgrounds to multi-sibling homes. Indeed, young children from diverse cultural backgrounds engage in collaborative play (Callaghan et al, 2011; Tomasello, Carpenter, Call, Behne, & Moll, 2005) and it's a significant skill needed in a wide range of educational settings from preschool onwards (Blair, 2002; Raver & Zigler, 1997).

Developmental research has revealed some important fundamental features of children's collaboration. Children from as young as two years old often choose to collaborate instead of act independently even when collaboration is not necessary to achieving a goal (Warneken, Gräfenhain, & Tomasello, 2012). Relatedly, when compared with other non-human primates, children tend to collaborate across a wider set of social contexts, apparently for the sake of the collaboration itself (Warneken, Chen, & Tomasello, 2006). Thus, developmental research indicates that children have a predilection to collaborate in a wide range of settings.

Other research on collaboration has investigated collaboration's impact on children's learning. Interestingly, researchers have found evidence that collaboration enhances planning and learning in some social contexts compared with more independent activity (Foley & Ratner, 1998; Gauvain & Rogoff, 1989; Ratner, Foley, & Gimpert, 2002; Sommerville & Hammond, 2007). For example, in one study preschoolers assembled a toy one-on-one with an experimenter in either the High Collaboration or Low Collaboration Group. Children in the High Collaboration Group were permitted to coordinate actions more frequently with the experimenter. In both an immediate independent toy reconstruction and a 4 month follow up, children in the High Collaboration Group recalled the toy's assembly more accurately (Sommerville & Hammond, 2007). Furthermore, researchers have found that cultures emphasize a diverse range of informal collaborative exchanges with young children that support children's learning via intermodal patterns of communication (i.e. visual, oral, and/or tactile coordination) (Rogoff & Gauvain, 1989; Rogoff, Paradise, Arauz, Correa-Chávez, & Angelillo, 2003). Thus, substantial evidence indicates that, at least in some formal and informal social settings, children's collaboration relates to enhanced learning.

While the reviewed research sheds light on important features of children's collaboration, an important gap in the literature concerns identifying mechanistic (i.e. immediate) and developmental (i.e. ontogenetic processes) causes of children's collaboration (Tinbergen, 1996). In the following study, my colleagues and I aim to examine cognitive factors that may facilitate children's spontaneous (i.e. without specific instruction nor necessary material affordances) peer collaboration. Knowing such predictors would enhance our understanding of the circumstances under which a given set of young children may be more or less likely to collaborate, as well as why particular sets of children may be more or less likely to collaborate than others.

In selecting the cognitive predictors to evaluate, we focused on factors that (a) research suggests may be important contributors and (b) that we have experience measuring in preschoolers. Based on these premises, we focused on a few factors from the developmental social cognition and help-seeking literatures that may logically relate to children's collaboration. Below we briefly discuss the background of our predictors before explaining the experimental and analytical approach of the current study.

Children's Collaboration and Information Gathering. In past research, we evaluated cognitive predictors of children's help-seeking with an adult experimenter in a toy assembly activity (Vredenburgh & Kushnir, 2016). In particular, we evaluated whether young children's decisions of whether to seek assistance or not related to the gap between the child's ability to complete the activity independently and the necessary ability to do so. Based on this information gathering perspective, we predicted that children would (a) be more likely to seek help on steps that were more difficult for them and (b) avoid seeking help on steps for which children did not need assistance.

To examine this information gathering perspective, we measured each child's relative competency at toy assembly on an Assessment Toy and the relative difficulty of each step of the Test Toys with the average performance of a Control Group of children (Vredenburgh & Kushnir, 2016). Our results indicated that children's competency related negatively to help-seeking (i.e. more competent children sought less help than less competent ones) and step difficulty related positively to help-seeking (i.e. children sought more help on difficult steps than they did on less difficult ones). These results are consistent with the theory that children's help-seeking relates serves an important information gathering purpose. That is, young children flexibly seek social assistance to bridge the information gap between their ability to complete an activity and that required to do so.

Importantly, help-seeking is closely related to collaboration in definitional terms. Collaboration is defined as coordinating actions to achieve a shared goal (Tomasello et al, 2005; Tomasello, Dweck, Silk, Skyrms, & Spelke, 2009) while help-seeking is defined as signaling to a helper to coordinate actions to achieve a goal (Newman, 2000). Help-seeking differs from collaboration in that it begins with a signal for help that, if successful, institutes a shared goal. Notably, help-seeking entails coordinating action to achieve a goal (i.e. the goal for which the help-seeker sought assistance to achieve), but the extent of action coordination may vary widely.

This definitional similarity suggests that help-seeking may share predictors with collaboration. Based on our prior help-seeking research, we designed a similar toy assembly task for dyads of preschoolers (see Methods for details). As with our prior research, we measured each child's competency on an Assessment Toy and the step difficulty of each Test Toy step via the average performance of a Control Group of children. We then assessed whether children's competency and step difficulty predicted dyadic peer collaboration on each step.

Our hypotheses for these factors are based on the information gathering perspective that young children will tend to act so as to support their information gain. Similar to the help-seeking context, we (1) hypothesize that step difficulty will relate positively to children's collaboration, in that children will collaborate (i.e. engage social assistance) more to overcome difficult challenges. However, different from the help-seeking context with a restrained experimenter, we (2) hypothesized that children's competency will relate positively to collaboration. Specifically, consistent with the information gathering perspective, children are expected to engage with materials in support of their own learning to the extent that action is more informative than observation. Hence, children who demonstrate greater competency are expected to collaborate more since doing so is more supportive of learning than merely observing their partner's action (Sommerville & Hammond, 2007).

Children's Collaboration and Theory of Mind. Research on children's theory of mind has shed substantial light on how children's cognitive representations of other people's beliefs, perspectives, and desires develops. This research demonstrates that between the ages of 3 and 5 children typically develop an understanding that other people have different beliefs and emotions than they do, and these beliefs and emotions are linked to people's experiences and information access (Gopnik & Astington, 1988; Hogrefe, Wimmer, & Perner, 1986; Wellman & Liu, 2004; Wellman, 2014). For example, this research shows that 3-year-old children tend to believe that other people share their own knowledge and belief states, while children older than 4 generally base other people's belief states on the information available to the person (e.g. visual access and/or verbal information, etc.) (Hogrefe, Wimmer, & Perner, 1986; Wellman & Liu, 2004). Moreover, children's developing theory of mind correlates with a range of other cognitive attributes, such as language and inhibitory control (Carlson, Koenig, & Harms, 2013; Wellman, Cross, & Watson, 2001). In short, prior research has identified important developmental trajectories and cognitive correlates of children's theory of mind, making a substantial contribution to our understanding of children's cognitive development.

While much is understood about children's explicit cognitive representations, less research has focused on how children's developing theory of mind relates to their real-world, dynamic social behavior. More recently, some studies have narrowed this knowledge gap. For instance, one study found behaviorally inhibited children who demonstrate high negative behaviors in their peer interactions (i.e. as determined by teacher ratings of classroom behavior) pass less theory of mind scale items (Suway, Degnan, Sussman, & Fox, 2012). Additionally, researchers have found that children's performance on theory of mind scales correlates with some sharing behavior (Yu, Zhu, & Leslie, 2016). This study aims to further contribute to this research by examining whether children's developing theory of mind relates to their dyadic peer collaboration. Specifically, we (3) hypothesize that as children's ability to understand and consider other people's beliefs and desires increases, their ability to predict and coordinate actions with others increases. Thus, theory of mind is hypothesized to relate positively to children's collaboration.

Participants. Substantial prior research on help-seeking, theory of mind, and collaboration has focused on preschoolers. As noted above, prior theory of mind research has identified considerable variance in preschoolers' theory of mind between the ages of 3 to 5 years, which supports our ability to detect a relationship with collaboration. Additionally, the collaboration research reviewed indicates that preschoolers collaborate in a variety of contexts. Thus, based on our hypotheses and relevant research, we chose to examine the peer collaboration of preschoolers (i.e.

children ages 3 to 5 years) specifically.

In analyzing preschoolers, we strengthened the representativeness of our sample by including children from a range of socioeconomic backgrounds. Specifically, our research group recruited children from low and working class backgrounds from the surrounding area of a rural, upstate New York university (see Methods for details). This resulted in a sample in which over 60% of the participants had not previously participated in a research study and approximately half of the dyads consisted of low income children. This recruitment effort may support increased variance in some of our predictors and dependent variable, as lower income children tend to demonstrate delays and variance in social development (Cicchetti, Rogosch, Maughan, Toth, & Bruce, 2003; Cutting & Dunn, 1999; Shatz, Diesendruck, Martinez-Beck, & Akar, 2003).

Experimental Design and Approach. To assess the above hypotheses, we implemented an experimental design and analysis that enabled us to examine children's spontaneous peer collaboration in close detail. Similar to Sommerville & Hammond (2007), Vredenburgh & Kushnir (2016), and an activity at a regional Ithaca, New York preschool, we utilized a step-by-step toy assembly activity (see Methods for details). By following the instructional photos for each step, children sought to assemble the blocks so as to make the blocks look like the depicted instructional photo. Children were allowed to contribute and collaborate as much or as little as they chose, thereby enabling the dynamic collaborative exchanges indicative of preschoolers' classroom play.

Afterwards, trained Research Assistants coded children's behavior second-by-second and lag sequential analysis (Gottman & Roy, 1990; Kenny, Kashy, & Cook, 2006) was employed to compute the extent to which children collaborated on each step. As noted above, the literature defines collaboration as a sequence of goal-directed actions between involved agents (Tomasello et al, 2009). As is further described in the Methods and Results, our use of lag sequential analysis to compute the sequential contingency in children's goal-directed actions reflected the conceptual definition. In sum, applying this experimental and analytical approach supported a more dynamic, ecologically valid, and definitionally consistent dependent variable with which we examined our hypotheses.

Method

Participants

Participants were fifty dyads of one-hundred preschoolers (*M* = 50.88 months, *SD* = 2.76 months; twenty-five female dyads). All dyads consisted of unfamiliar children of the same gender and within six months of age of one another (*M* = 3.24 months, *SD* = 2.28 months).

As noted above, we conducted substantial recruitment efforts to ensure the sample better reflected the socioeconomic makeup of the university's surrounding region. Twenty-two of the study's fifty dyads consisted of children from families classified as low income by the standards of the United States Census Bureau. Children were recruited from nearby Head Start facilities, a database of research participants, and public postings at venues frequented by low income parents (e.g. a Walmart store). The children were predominantly Caucasian and middle and working class. Under 40% of the participants had participated in a prior research study. All participants were native English speakers.

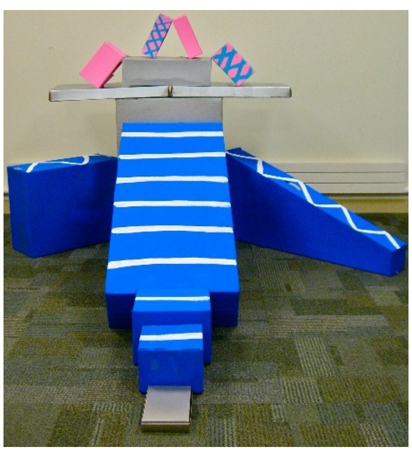
Four dyads that arrived to participate were excluded from the final sample due to the children's refusal to engage cooperatively and safely enough to complete the protocol. All four of the excluded dyads were from low income backgrounds.

All families were given $75-100 and teddy-bears and coloring books for their participation. If needed, transportation was provided via local taxis.

Additionally, a separate Control Group of children (*M* = 51.8 months, *SD* = 5.68 months) completed the two Test Toys independently in order to provide a measure of the step difficulty (see Results for further details). These children were recruited via the same methods described directly above.

Stimuli

Similar to a super-sized Lego set, the stimuli consisted of painted cardboard boxes assembled step-by-step to form larger toys (see Figure 2.1). Some of the boxes were weighted so as to make them more physically difficult to maneuver.



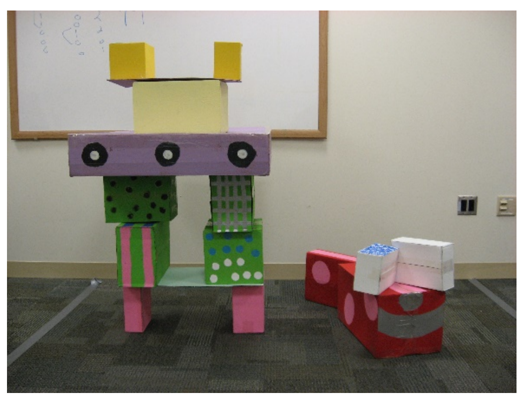


Figure 2.1: The two completed Test Toys. The Space Ship is on the left and the Mommy Alien is on the right.

At each step, children had to add boxes (i.e. varying from 1 to 3 boxes) and, on some steps, reposition existing boxes (see Figure 2.2).

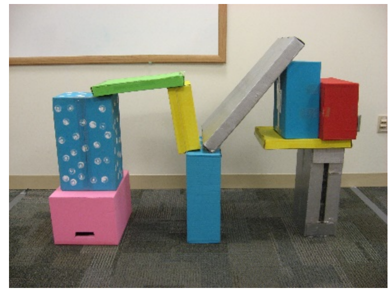


Figure 2.2: Two sequential steps from the Assessment Toy, termed the Space School. Children had to add a slim silver box to go from the step on the left to the step on the right.

Four space-themed toys were assembled by the children. The first, termed “Baby Alien”, served as the instructive Warm-up Toy and was constructed with an experimenter’s constructive feedback. The second, termed the “Space School”, served as the Assessment Toy to separately measure each child’s individual competency and was constructed independently by each child. The last two toys, termed “Mommy Alien” and the “Space Ship”, served as the Test Toys on which children’s peer collaboration was measured. The ordering of the Test Toys was systematically varied by dyad such that an even number of dyads completed the Mommy Alien first and vice versa.

For each child and dyad, the boxes were arranged in the exact same manner at the start. This ensured that all children were tasked with solving the same cognitive and physical problem. To assemble the toys, children followed a sequence of instructive photos that depicted each step, similar to a Lego set. The photos were available on Dell laptops and children learned to press a button to proceed through the sequence. An experimenter assured that children did not skip steps on any of the toys.

Apparatus

Play sessions occurred in two adjacent and connected child-safe rooms in the Early Childhood Cognition Laboratory at Cornell University. The interactions were recorded with four Sony DCR-SR68 digital cameras that captured the entire space. Dell Inspiron laptops were used to depict the instructive photos.

Procedure

Warm-up Phase. The Warm-up Phase served to introduce the two unfamiliar children to one another, the rooms, and the experimenters. The children played with blocks, stuffed animals, and marbles with the experimenters and parents. Depending on their comfortability, children and parents spent from twenty to forty-five minutes in the Warm-up Phase. Before commencing, all children were asked if they'd like to play with the large space blocks and the study proceeded if both children indicated that they were. Parents were also asked if they were comfortable proceeding with the study.

Warm-up Toy. The Warm-up Toy immediately followed the Warm-up Phase. During the Warm-up Toy, children were separated into adjacent rooms with an experimenter and taught how to manipulate the toy pieces in order to make them look like the instructive pictures on the laptops. The experimenter told the child that they had some toys and some pictures, and they could make the toys look like the pictures. The experimenter told the child to watch her as she completed the first step. After completing the first step, the experimenter asked the child, “Does that look like the picture?” If the child said no, the experimenter explained that the color, position, and number of boxes all made it look like the picture. The child and experimenter then took turns making the Baby Alien. Corrective feedback was given for mistakes.

Assessment Toy. Next the children each independently completed an Assessment Toy, termed the Space School, which provided a graded assessment of the child’s competency in independently constructing the toys as shown in the instructive pictures. The experimenter presented the child with the photo of the completed Space School. The experimenter asked the child to do the Space School independently, saying, “You can do this one by yourself by making it look like the picture. Start with the first picture. Each time you need a new picture, just press the button. Now go ahead and make it look like the picture.” As the child completed the Space School, the experimenter expressionlessly watched the child. If the child commented about their progress, asked for assistance, became inactive, or talked about not building the Space School, the experimenter responded, “Try to make it look like the picture!” and “Remember, you do this toy by yourself.” The experimenter did not provide any corrective feedback at any point. The child had up to twelve minutes to complete the Space School. When the child finished, either by completing the steps or reaching the twelve-minute limit, all children were told, “That was a great try!”

Test Toys. To determine whether children’s collaboration relates to their competencies and the difficulty of the activity, the children completed two Test Toys, the Space Ship and Mommy Alien, together as a dyad. Twenty-five of the dyads were randomly assigned to complete the Mommy Alien first and twenty-five the Space Ship first. The children were given a maximum of fifteen minutes per toy. The toys were completed one after the other.

At the start of each Test Toy, the experimenter said, “OK, here’s the first picture of the toy. Now you two do this toy together! OK, so you two build this toys together. So go ahead and make the toy.” As the children assembled the toy, the experimenter sat expressionless on a stool near the laptop. The experimenter did not intervene or provide corrective feedback, but did ensure that the children proceeded step-by-step instead of skipping steps.

If the children sat down, began assembling other objects, or asked for assistance, the experimenter responded “Make it look like the picture” and “You two do this toy together”. If a child became aggressive, the experimenter told the child not to be aggressive. The toys were finished when both children indicated the toy was complete or the fifteen-minute limit elapsed.

Theory of Mind. After the Test Toys, children were given water, juice, and a small snack. They were permitted to free play with the experimenters for up to 10 minutes. Then, each child’s theory of mind was separately assessed employing the standardized six-question theory of mind scale developed by Wellman & Liu (2004). The scale assesses false belief, diverse desire, diverse belief, knowledge access, and real versus apparent emotion understanding. Recently, researchers have successfully used scale to identify relations between young children’s developing theory of mind and other factors, such as temperament and executive function (Duh et al, 2016; Mink, Henning, & Aschersleben, 2014).

Social Evaluation Questions. Children were also asked questions about their partner in order to assess how young children may evaluate social experiences with peers. Children were prompted to recall their recent toy assembly session and asked to provide the name of a best friend for comparison. Then, children were asked the following three questions:

- Does [partner's name] know how to build toys?
- Does [partner's name] know a lot or a little about building toys?
- What if we had *another, new* toy to do tomorrow; would you want to build it with [best friend's name] or with [partner's name]?

The ordering of the children's names was counterbalanced (i.e. half of children were asked the question with the best friend's name first) across children.

Coding

Coding Children's Competency (*Assessment Toy- Space School*). To quantify children's independent abilities to assemble the toys, we assessed children's competency in constructing the Assessment Toy. Each child's competency was quantified in a Competency Score. The Competency Score consisted of summing five parameters that assessed for each step of the toys whether the child: (1) added the correct number of boxes, (2) made the correct number of connections with those boxes, (3) made the correct type of connection(s) (i.e. orientation of the boxes), (4) added boxes of the correct color(s), and (5) connected the boxes to the correct part of the existing toy structure. For each step, children earned from 0-5 points; each of the five parameters was worth a minimum of 0 and a maximum of 1 point. Partial credit (e.g. ½ points) was given for partial completion. Children's performance score on each step of the Assessment Toy therefore had a minimum of 0 and a maximum of 5.

The sum of the child's performance on each of the eleven steps formed the child's Competency Score (i.e. range 0-55). The Competency Scores were assessed and computed by one hypothesis-blind coder after testing for the experiment had finished. The coder utilized all of the video views to clarify children's scores, followed the detailed guidelines discussed above, and met weekly with the first author to resolve any ambiguities. Another blind reliability coder coded 10 of the children. A one-way intra-class correlation coefficient assessing coding agreement indicated a high rate of reliability ($F = 35.6$, $p = .001$; obtained with R's irr package using the icc function).

Coding Step Difficulty (*Test Toys- the Space Ship and Mommy Alien*). The relative difficulty of each step of the Space Ship and the Mommy Alien was computed with a separate sample of 28 preschoolers ($M = 4.43$) who independently attempted to construct the Test Toys. Their average accuracy (i.e. assessed via applying the same 5 parameters above for Competency Scores) in constructing each step, subtracted from 5, provided the Step Difficulty Scores for each Test Toy step. Thus, the range of possible Step Difficulty Scores was from 0 to 5. The Step Difficulty Scores were computed after testing finished by the same coder who completed the Competency Scores.

The above Step Difficulty measure focused more on the cognitive difficulty children had in properly selecting and manipulating the boxes. In addition to this cognitive measure of difficulty, we analyzed basic physical features of the boxes that relate to motoric aspects of task difficulty. In particular, we measured and analyzed the (1) number of boxes necessary to manipulate per step and (2) the sum volume and (3) the sum mass of those boxes.

Coding Children's Theory of Mind. Each child's performance on the theory of mind scale was coded in accordance with Wellman & Liu (2004). The scale ranges from integer scores of 0 to 6 based on the number of scale items to which children correctly respond. A single hypothesis blind coder coded the scale items according to the established ordinal scale. The coder met weekly with the first author. Ambiguities were resolved with the input of the first author and another graduate student experienced with the theory of mind scale. A reliability coder completed 10 of the children. A weighted kappa analysis using the kappa2 function from R's irr package indicated a high rate of reliability ($\kappa = 0.94$, $p = 0$; equal weights employed).

Coding Children's Social Evaluations. Children's social evaluations were coded to reflect the binary structure of the questions. The first two questions were coded affirmatively (=1) if children affirmed their partner knew how to build toys and knew a lot, and the questions were coded (=0) otherwise. Similarly, if children selected their partner for a new toy, the question was coded affirmatively (=1) and (=0) otherwise. Lastly, a summary social evaluation was formed as the sum of each of the three questions.

Coding Each Child's Goal-Directed Action. Two trained Research Assistants coded children's actions during the Test Toys. The coders followed detailed guidelines, summarized below, and met together with the first author to collectively agree upon how to consistently code any ambiguities encountered. The coders used all 4 synced camera views to provide the best platform for coding. Reliability between the two coders was assessed based on recoding three dyads (i.e. 6 children). Reliability was high ($\kappa = 0.99$, $p = 0$; unweighted analysis). In particular, using the open source coding software Elan, each child's actions were coded as goal-directed toy assembly based on the following parameter definition. The coding was completed at 50% video speed using all of the synchronized camera views.

- Assembling Box(es): The child was manipulating, handling, and/or moving a box in a manner that contributed to the construction of the toy.

For example, if a child picked up a box and moved it toward the toy, then that action would be coded as Assembling Box(es). (See Figure 2.3 for an image of action in which each child was coded as Assembling Boxes).

Figure 2.3: Two children assembling the Space Ship. Both children are moving boxes to assemble the toy and are therefore both coded as Assembling Box(es). This instance is computed as collaborating.

However, if a child picked up a box and threw it, then that action would not be coded due to its irrelevance to toy assembly. All questionable/ambiguous actions were resolved through discussion involving both coders and the author. Approximately 2% of the coding data involved such resolutions.

The coding was downloaded to Microsoft Excel and transformed to a binary time series as follows. If the Assembling Box(es) parameter was coded as occurring at a point in time, the parameter was valued as active (= 1). If it was not coded as occurring, then the parameter was valued as inactive (= 0). The entire temporal length of each Test Toy was reflected in the vectors and each cell of the vectors represented 0.20s of Test Toy activity.

Computing Children's Collaboration. As described above, each child's goal-directed toy assembly was coded and transformed to a binary time series vector (i.e. goal-directed toy assembly = 1, no goal-directed toy assembly = 0). The proportion and the sum of each dyad's collaboration was computed for each step of the two Test Toys using the two vectors that reflected each child's Assembling Box(es) activity.

Recall the literature's commonly employed definition of collaboration is a sequence of coordinated actions towards a shared goal (Tomasello et al, 2009). This defines collaboration as sequential goal-directed action between the involved parties. Guided by this definition, we measured children's dyadic collaboration in two ways.

- This first definition provided the *proportion* of goal-directed activity that could reasonably be described as collaborative. Specifically, collaboration was measured as the sum of instances in which a child's box assembly was followed by their partner's box assembly within a temporal lag (i.e. 1s and 3s) divided by the total sum of instances that the children spent assembling the boxes (i.e. whether or not the action was followed by their partner's action).
- The second definition provided the *sum* of collaborative activity. That is, the sum of instances in which one child's box assembly was followed by their partner's box assembly within a temporal lag (i.e. 1s and 3s) was computed.

Results

General: Multi-level Modeling Analysis Approach. To analyze the relationship of our predictors to each dyad's collaboration across the steps, we used a multi-level modeling (i.e. also termed mixed-effects or hierarchical linear modeling) approach (Bickel, 2007; Luke, 2004). Specifically, we employed a two-level regression model in which the step-level variables (i.e. step number, step order, and step difficulty) were nested within the dyads. This approach enabled us to account for within dyad variation across the steps. For dyad level variables, we computed dyadic indices of the variables measured on individual children (i.e. theory of mind and competency) (Kenny, Kashy, & Cook, 2006). Given our dyadic dependent variable (i.e. children's dyadic action coordination), our use of dyadic indices for our predictors enabled us to reflect the dependence in our independent variables.

Independent Variable: Children's Competency Scores (Assessment Toy). Children's performance on the Assessment Toy was measured by the Competency Score. The Competency Score provided a means of assessing each child's ability to complete the assembly tasks independently. Each child's Competency Score was computed by summing the child's accuracy on each step of the Assessment Toy. Collectively, the Competency Scores (*M* = 34.78, *SD* = 13.04) indicated that our sample of preschoolers possessed considerable variability in competency. The sample's Competency Scores ranged from a minimum of 0 to a maximum of 53 out of a possible range of 0 to 55.

Competency Dyadic Indices. We formed straightforward dyadic indices (Kenny, Kashy, & Cook, 2006) of each dyad's two Competency Scores to assess our hypothesis. Given the lack of relevant research, we did not have empirical evidence that one particular feature of the dyad's competency would be of more import than another. We therefore computed indices reflecting the dyad's mean, similarity, maximum, and minimum competency level. Specifically, we computed the Average Competency Score (M = 34.88, SD = 9.65; see Figure 2.4), the Competency Score Difference (M = 12.91, SD = 11.02), the Minimum Competency Score (M = 28.01, SD = 13.93), and Maximum Competency Score (M = 41.56, SD = 7.38) for each dyad. (See Appendix A for additional distribution tables).

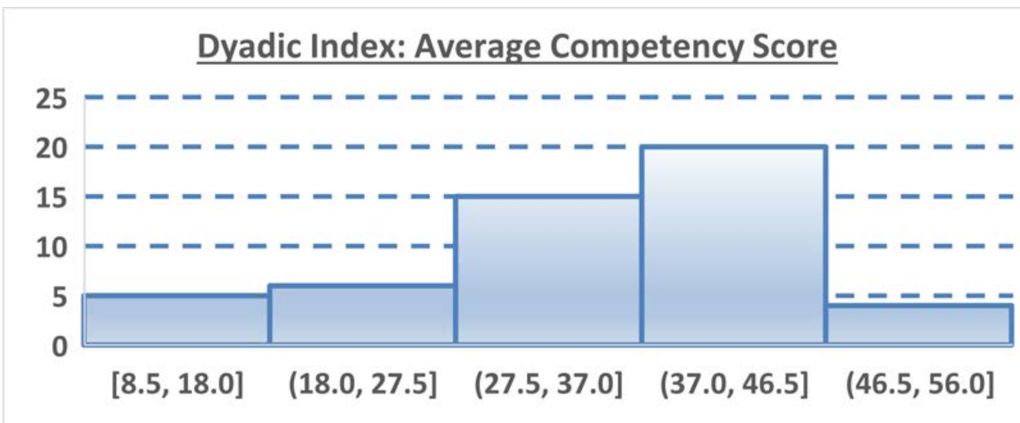


Figure 2.4: This histogram shows the distribution of the dyadic index of Average Competency Score.

Independent Variable: Step Difficulty (Control Sample on the Test Toys). As described in the Coding section, Step Difficulty (M = 3.79, SD = 0.63; see Figure 2.5) was measured as the average performance of a Control Group of preschoolers, subtracted from 5, on each step of the two Test Toys. Step difficulty served as a measure of the cognitive difficulty of each step and did not vary by dyad and hence did not have a dyadic index. The twenty-two steps ranged in step difficulty from 2.45

to 4.47.

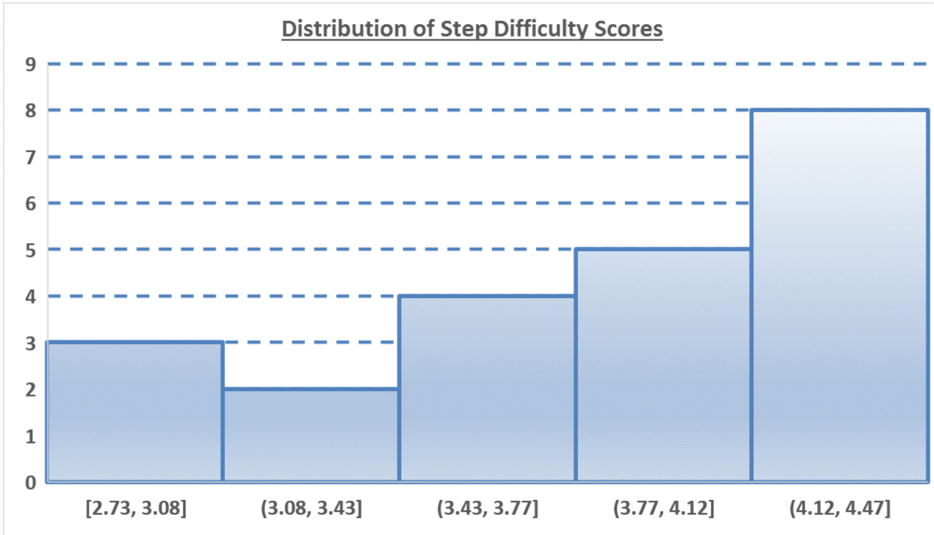


Figure 2.5: This histogram shows the distribution of the Step Difficulty scores.

Independent Variables: Box Features. As noted in the Methods, we measured three additional features of the motoric difficulties of the steps. These measures consist of the number of boxes (*M* = 1.5, *SD* = 0.66), volume of boxes (*M* = 454.68, *SD* = 596.53), and mass of boxes (*M* = 1.98, *SD* = 2.99) on each step. (See Appendix A: Tables 2.10-2.12 for further distribution information).

Independent Variable: Children's Theory of Mind. Children's theory of mind was tested on the latter 78% of the sample (Age: *M* = 4.66, *SD* = 0.46; Gender: 32 females (16 dyads), 46 males (23 dyads)) following its addition to the study protocol. Our sample of children performed a bit lower on average (*M* = 3.10, *SD* = 1.29) than other studies with similarly aged children (Mink, Henning, & Aschersleben, 2014; Wellman & Liu, 2004). Our distribution contained scores ranging the entire scale, from 0 up to 6.

Theory of Mind Dyadic Indices. To analyze the dyadic outcome (i.e. dyadic collaboration on each step), we computed profile scores for each dyad that represented important aspects of the dyad's theory of mind that may relate to collaboration. Specifically, we employed the dyadic average (*M* = 3.09, *SD* = 1.04; see Figure 2.6), the dyadic difference (*M* = 1.21, *SD* = 0.95), the minimum (*M* = 2.49, *SD* = 1.12), and the maximum (*M* = 3.69, *SD* = 1.17).

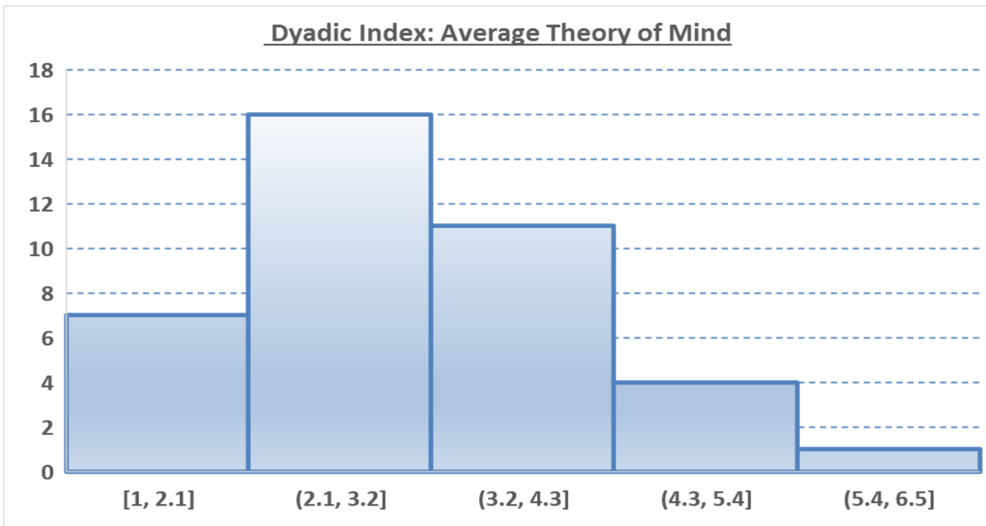


Figure 2.6: This histogram shows the distribution of the dyadic index of average Theory of Mind score.

(See Appendix A: Tables 2.13-2.15 for additional distribution tables). These indices represent the average theory of mind across each dyad's two children, the difference in theory of mind between the two children, the greatest theory of mind score of the two children, and the lowest theory of mind score of the two children. As detailed below, we investigated whether these aspects of the dyad's theory of mind related to the children's dyadic collaboration.

Dependent Variable: Children's Dyadic Collaboration (Test Toys). As noted in the Introduction and Methods, we used lag sequential analysis (Gottman & Roy, 1990; Kenny, Kashy, & Cook, 2006) to compute 2 measures of each dyad's collaboration on each step. Specifically, we computed both the sum total and proportion of instances in which one child's goal-directed toy assembly was closely followed by the other child's. These two measures were measured twice, once using a lag time of 1 second and again using a lag time of 3 seconds.

We first analyzed the similarity between the two measures and time scales of collaboration. As noted above, we measured both the proportion of children's goal-directed activity that was collaborative and the sum of collaborative activity. Across the dyads' activity on both test toys, the correlation between the two measures was high ($r = 0.79$ for the 1s lag; $r = 0.74$ for the 3s lag). Since the two measures strongly correlated and the proportion of collaborative actions more closely fits the hypotheses of children increasing the extent to which they collaborate, we proceeded with the proportion of collaboration on each step as our dependent variable.

The proportion of collaborative action was measured twice (i.e. with a lag time of 1 second and a lag of 3 seconds). These two measures of children's collaboration also correlated highly ($r = 0.88$). Thus, whether we used a 1 second or 3 second lag did not materially impact our measure of how much the dyads collaborated. We therefore used the proportion of collaborative action with a lag time of 1 second as our dependent variable for the following analyses. Figure 2.16 shows the distribution of the dyads' average collaboration across all of the steps.

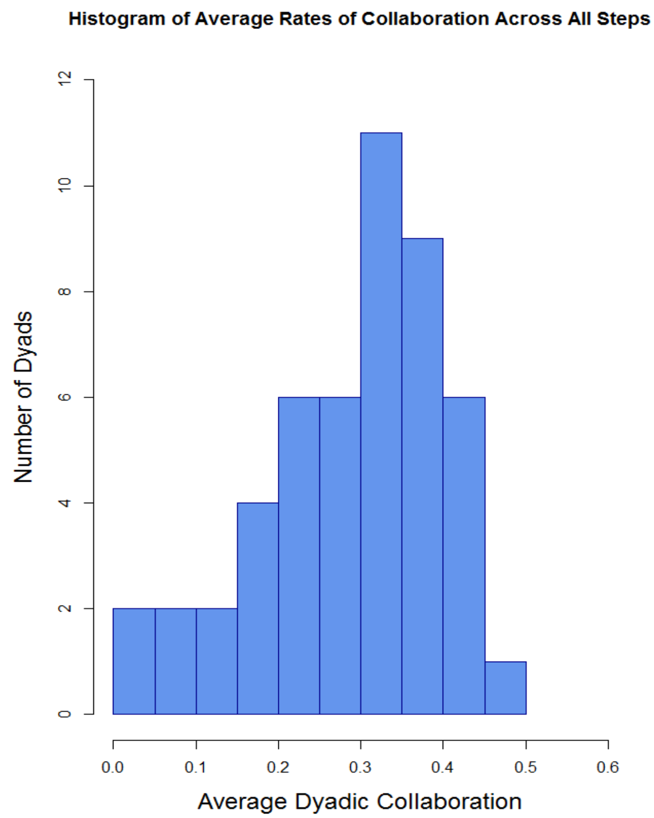


Figure 2.16: This histogram shows the distribution of average rates of collaboration across all of the toy steps.

Multilevel Analysis: Assessing Within And Between Dyad Variance. As noted above, we employed a multilevel modeling approach to examine whether and how our predictors related to the dyads' collaboration across the steps. We first examined the data's within and between group variance in order to determine whether the variance associated with our group level variable, the dyads, justified a multilevel modeling approach. Through fitting a null multilevel model in R (version 3.2.2) using the lme command, we identified considerable intraclass correlation ($ICC = 0.098$, $n = 50$). An ANOVA between the null multilevel model and a generalized linear model (i.e. one level) without the random dyad term revealed that the variance associated with the dyads was statistically significant ($\chi^2 = 188.8303$, $p < .0001$). This result indicates that children's average collaboration varied considerably by dyad, thereby statistically justifying a multilevel modeling approach that adjusts for dyadic variance.

Multilevel Analysis: Assessing Predictors of Between and Within Dyad Variance. Basic Variables. Employing R 3.2.2's lme command with a random dyad intercept term, we began by assessing predictors of the between and within dyad variances. As outlined in the following sections, we used a hybrid approach of forward and backwards selection. Specifically, we began with forward selection by assessing separate, single predictors in the model. After determining the significant predictors (i.e. $p < 0.05$) described below, we added them together in a single model and removed the highest p value variable until no variable with a p value over 0.20 remained. Note that all the following continuous predictors were normalized as z scores in the following analyses. Additionally, as is detailed where necessary, some predictors were transformed to produce a more normally distributed predictor.

The forward selection analyses began by analyzing whether the order of toys, order of steps, average age, age difference, and gender statistically related to children's collaboration. Separate, single predictor models indicated that the order of toys factor (Toy Order: $\beta = 0.006$, $t = 0.32$, $p = 0.734$), sequence of steps (Step Order: $\beta < -0.001$, $t = -0.08$, $p = 0.934$), difference in ages (Age Difference: $\beta = -0.014$, $t = -0.89$, $p = 0.376$), and gender (Gender: $\beta < .009$, $t = 0.31$, $p = 0.754$) did not relate to children's overall collaboration. However, the dyad's average age (Average Age: $\beta = 0.041$, $t = 2.85$, $p = 0.007$) positively related to collaboration; as the average age of the dyad increased children tended to collaborate more.

Competency Predictors. Separate, single predictor models indicated that the dyadic indices of Average Competency Score (Average Competency Score: β = 0.047, t = 3.57, p < 0.001), Minimum Competency Score (Competency Score Minimum: β = 0.04, t = 3.46, p = 0.001), and Maximum Competency Score (Average Competency Maximum: β = 0.039, t = 2.87, p = 0.006) all positively related to children's overall collaboration across the steps of both toys. Additionally, the difference in children's competencies related negatively to children's collaboration (Square Root Transform of Competency Score Difference: β = -0.029, t = -2.01, p = 0.050). Thus, these analyses indicated that more competent dyads collaborated more and larger differences in children's competencies was associated with less collaboration.

Step Difficulty Predictors. Separate, single predictor models revealed that children tended to collaborate more as the cognitive difficulty of the steps increased (Square Root Transform of Step Difficulty: β = 0.025, t = 2.72, p = 0.007). The box mass and volume measures were (element-wise) multiplied to produce a single score, Physical Step Difficulty, which also related positively to children's collaboration (Step Physical Difficulty: β = 0.025, t = 2.72, p = 0.007). Lastly, the factor number of boxes manipulated per step did not relate to children's collaboration (Two Step Boxes: β = -0.006, t = -0.30, p = 0.767; Three Step Boxes: β = 0.035, t = 1.02, p = 0.310). In sum, increases in cognitive and physical difficulty related to more dyadic collaboration.

Theory of Mind Predictors. Similar single predictor model analyses indicated that children's average theory of mind (Average Theory of Mind Score: β = 0.017, t =

1.07, p = 0.292), maximum theory of mind (Maximum Theory of Mind Score: β = 0.028, t = 1.70, p = 0.111), minimum theory of mind (Minimum Theory of Mind Score: β = 0.003, t = 0.20, p = 0.840), and difference in theory of mind (Difference in Theory of Mind Score: β = 0.021, t = 1.63, p = 0.160) did not relate to children's collaboration. Hence, we did not identify a significant relationship between children's theory of mind and dyadic collaboration.

Uniting a Cognitive Predictor Model. Having identified a collection of significant predictors of children's collaboration, we added all of the significant predictors (i.e. $p <= .05$) of each type together into a single model. In a series of backward selection steps, we removed the variable with the highest p value until no variable with a p value over 0.20 remained. This resulted in a model that consisted of (1) children's average competency (Average Competency Score: β = 0.037, t = 2.43, p = 0.019), (2) average age (Average Age Score: β = 0.022, t = 1.40, p = 0.167), (3) the cognitive aspects of step difficulty (Step Difficulty: β = 0.022, t = 2.46, p = 0.014), and (4) the physical aspects of step difficulty (Step Physical Difficulty: β = 0.021, t = 2.30, p = 0.022). For clarity, the form of this model is depicted in the formula below:

$$
\begin{aligned}
&DyadicCollab_{ij} = \beta_{0j} + \beta_{1j}(StepDiff_{ij}) + \beta_{2j}(StepPhysDiff_{ij}) + r_{ij} \\
&\beta_{0j} = \gamma_{00} + \gamma_{01}(AveAge_j) + \gamma_{02}(AveComp_j) + \mu_{0j} \\
&\beta_{1j} = \gamma_{10} \\
&\beta_{2j} = \gamma_{20}
\end{aligned}
$$

The first row states that the dyad's collaboration is a function of each dyad's intercept plus two linear components reflecting the effects cognitive and physical step difficulty as well as a random error term. The second row states that each dyad's intercept is a function of a common intercept term plus a linear effect of average age, a linear effect of average competency, and random between-dyad error. The third and fourth rows state that the slopes between the step difficulty terms and collaboration are fixed.

With this model of predictors significantly related to the between and within dyad variance in children's collaboration, we evaluated the variance addressed by the model. An analysis of the variance components of the final model and that of the null model indicated that the final model (i.e. formulated above) accounted for 1.3% of the within dyad variance and 31.8% of the between dyad variance (see Figure 2.17 and Figure 2.18 in the Appendix).

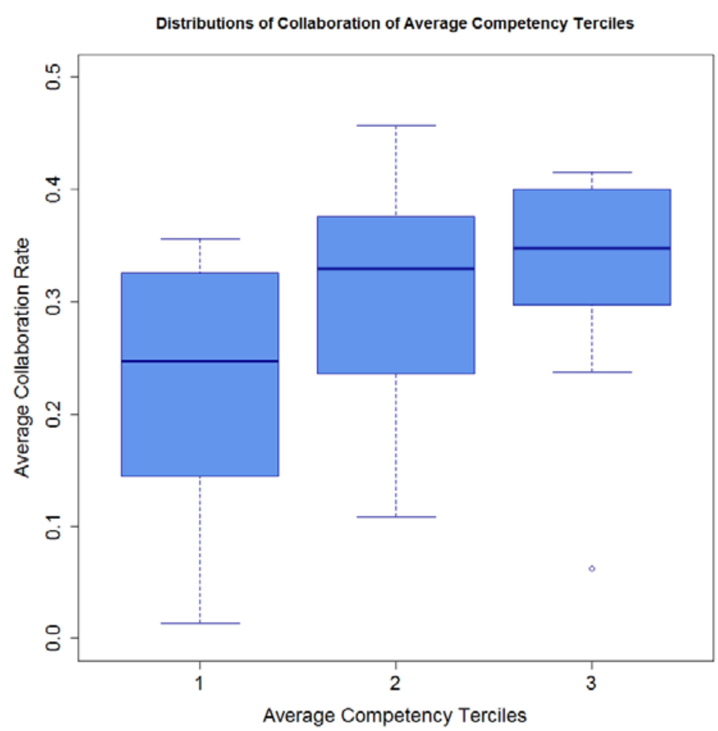


Figure 2.17: This figure shows the average collaboration across the steps for the three terciles of the dyads' Average Competency Score.

This result indicates that our model was considerably more successful in addressing between dyad variance (i.e. the different rates at which different dyads collaborated) than the within dyad variance (i.e. variance among the steps on which dyads collaborated).

Social Evaluation Outcomes. Lastly, we examined whether children's social evaluations of their partners following the peer collaboration related to their prior peer collaboration. Specifically, we examined whether dyadic indices of children's responses to each of the three questions and to the sum of the questions related to dyads' average collaboration across the steps. The dyadic indices of children's social evaluations were formed by summing across the two children for each of the three questions [First Question (i.e. Partner Know to Build Toys): M = 1.53, SD = 0.65; Second Question (i.e. Partner Know A Lot or A Little): M = 0.79, SD = 0.58; Third Question (i.e. Choose Partner for New Toy): M = 0.68, SD = 0.66] and for the summary statistic (M = 3.0, SD = 1.12). Thus, if both children answered that their partner knew how to build toys, the dyadic index equaled 2.

The exploratory hypothesis of this analysis concerns the fact that children's peer social evaluations may be informed by, or relate to, the extent to which children collaborate. A Pearson correlation assessment between the social evaluation indices and the dyads' average collaboration across the steps did not reveal any statistically significant relationships supporting this hypothesis (First Question: r = -.12, p = .47; Second Question: r = .05, p = .78; Third Question: r = .03, p = .88; Summary: r = -.03, p = .89).

Additional, nonsignificant analyses of predictors are provided in Appendix D.

These exploratory analyses were conducted in the course of producing these papers.

Discussion

Our analyses of cognitive predictors of young children's dyadic peer collaboration revealed important contributing factors. We found that young children increase their collaboration in response to cognitive and physical challenges, and children of higher competency are more likely to collaborate. Older children also collaborated more than younger ones. These findings lend support to our information gathering proposal. While we did not find evidence here that young children's developing theory of mind supports their collaboration, considerable variance remains unexplained and it is possible that other measurements of social cognition may yield different results. These findings and future directions for research are discussed below.

One of the study's important findings is that dyads of higher competency collaborated more than less competent dyads. Indeed, this factor contributed to explaining considerable between dyad variance. The finding indicates that *one* important mechanistic predictor of children's collaboration concerns the participants' combined abilities to engage and manipulate the materials and/or information at hand. Importantly, this finding coheres intuitively with the literature's definition of collaboration. A participant who cannot independently manipulate the relevant information is less likely to be able to collaboratively manipulate that information. Hence, as the independent competencies of the children increase, their ability and likelihood of collaboration increases. This finding therefore neatly links with the literature's conception of collaboration.

Our analyses also indicated that children spontaneously respond to cognitive and physical challenges by increasing their collaboration to overcome those challenges. It must be noted that this is not a trivial result. While increased coordination and challenges may seem to obviously correlate, this relationship is not "natural" nor biologically widespread. Indeed, Tomasello et al (2009) notes that no one has ever observed non-human primates coordinating to move large objects to collectively gain (e.g. from increased food access), despite frequently confronting such challenges. Contrarily, this result with young children indicates that external challenges of different forms (e.g. cognitive, physical, and potentially others) contribute as a mechanistic predictor of human collaboration. This finding therefore suggests that at least some subsets of human collaboration relate directly to the needs and affordances of the materials or information being manipulated.

Together, these two findings lend support for the possible relevance of an information gathering perspective of children's collaboration. This perspective proposes that children will collaborate when doing so enhances their information gain in contrast to independent or no action, thereby supporting children's learning. These results contribute by exhibiting that (1) children increase collaboration to address difficult challenges and (2) involve themselves and collaborate (i.e. instead of observing) more as their ability to contribute increases. Combined, these results indicate that children spontaneously seek out social assistance when needed and increasingly involve themselves based on their ability to contribute. These features are consistent with an approach that supports children's learning, as discussed in the Introduction. Moreover, prior research provides evidence that information gain is relevant to children's help-seeking (Vredenburgh & Kushnir, 2016) and individual play activities (Bonawitz et al., 2011; Schultz). This study extends support for this perspective to children's peer collaborative play. Future research ought to explore actively manipulating children's information gaps during collaborative dynamics to further our comprehension of how information and social dynamics intersect.

This study did not find support for a direct relationship between children's developing theory of mind and their collaboration. This result may reflect that there is no such relationship. In other words, children's cognitive representations of social interactions may not closely or directly relate to their dynamic social behavior. However, it may also be the case that the theory of mind scale, while very useful for assessing some aspects of social cognitive development, is not the most applicable for collaborative dynamics. For instance, it may be that questions more directly related to recognizing patterns of collaborative behavior and inferring from those patterns are more informative and relevant to children's dynamic collaboration. To this end, it is suggested that future research further explore the relationships between different measures of children's developing social cognition and their social dynamics.

Lastly, this study did not identify any prominent relationship between children's peer collaboration and children's post-hoc peer social evaluations. This portion of the study was somewhat exploratory and the possible causes for the negative result are many. Notably, children tended to view their partners as not knowing a lot about toy assembly and also tended to select a best friend over their partner. Thus, young children overall demonstrated selectivity in endorsing the new and random partner, whether or not the dyad consistently collaborated. One possibility is therefore that preschoolers' social evaluations are not quickly or easily influenced by social experiences (i.e. evidence). However, it is also possible that the wording and timing of the questions (i.e. very soon after the social experiences) influenced children's responses. Future research ought to further explore the development of children's social evaluations and how they relate to social experiences and evidence.

In sum, this study contributes to the developmental collaboration literature by identifying important cognitive mechanistic predictors of young children's collaboration. The cognitive predictors identified by this study extend prior research on children's information gathering in less collaborative contexts. Future research further exploring information gathering and collaborative dynamics is encouraged, as is future research exploring potential social cognitive predictors of collaboration.

Lastly, these findings support the notion that mechanistic and developmental predictors of children's collaboration can be studied and identified. In identifying some predictors, this study certainly raised additional questions. Namely, why and how is it that human collaboration is quite sensitive to cognitive and motoric challenges, but non-human primate coordination is not? Additionally, what factors are responsible for the fact that older dyads collaborate more than younger ones? Answering these questions likely requires investigating additional predictors of collaboration across different levels of analysis (e.g. environmental, physiological, etc.). The next two chapters represent complementary contributions to this important endeavor.

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CHAPTER 3

EXAMINING INCOME AND PARENTAL BEHAVIOR AS ENVIRONMENTAL PREDICTORS OF YOUNG CHILDREN'S PEER COLLABORATION

Introduction

In the past two decades, young children's prosocial development has attracted great interest from across the developmental psychology literature (Blair, 2002; NICHD ECCRN 2001; 2003; Pianta & Stuhlman, 2004; Tomasello, Carpenter, Call, Behne, & Moll, 2005). A subsection of this interest is fueled by growing evidence that prosocial behavior is essential for children's broader educational development (Anderson et al, 2003; Blair, 2002; Pianta & Stuhlman, 2004). Specifically, from preschool classrooms onwards, children are expected to share and collaborate with others, comply with teacher commands, listen when appropriate, and refrain from disruptive displays of emotion (Blair, 2002; Raver & Zigler, 1997).

Interestingly, a wide-ranging body of research links the family environments in which young children develop to their broader social and prosocial development. In particular, studies have frequently found that young children from low income environments demonstrate delayed social development and a higher prevalence of anti-social behavioral problems than their non-low income peers (Evans, 2004; Evans, Li, & Whipple, 2013; Levanthal & Brooks-Gunn, 2000; McLoyd, Ceballo, & Mangelsdorf, 1996). For instance, observational studies indicate that low income children exhibit higher levels of internalizing and externalizing behavioral problems

(Adams, Hillman, & Gaydos, 1994; Brooks-Gunn & Duncan, 1997) and have lower social competence (i.e. a composite scale of social, emotional, and cognitive skills related to social development) than their non-low income peers (Zhang, Chen, Zhang, & Sun, 2009). Moreover, there is evidence that increases in family income correspond to increases in young children's observed positive social behavior in classrooms (Morris & Gennetian, 2003).

The causal pathways by which family income relates to young children's social development are notably diverse and complex. While not well understood, research suggests they involve associations with familial, community, physical, and educational risk factors that, cumulatively, "get under the skin" to influence children's development (Evans, Li, & Whipple, 2013; McEwen, 2012). Indeed, the environment of childhood poverty is characterized by disproportionate exposure to risk factors of several types across different levels of analysis, including less responsive caregiving at home and at preschool (Bradley & Corywn, 2002; Evans, 2004; McLoyd, Ceballo, & Mangelsdorf, 1996). A complete discussion of these pathways is beyond the limits of this paper. Instead, this paper selects to focus on the possible relevance of preschoolers' family social environments for the development of a particularly important prosocial behavior, namely children's peer collaboration.

Indeed, a wealth of research has associated family social characteristics, such as measures of maternal sensitivity, parental attachment security, and parental social attitudes, to preschoolers' social development (Repetti, Taylor, & Seeman, 2002). For example, an impressive longitudinal study demonstrated that the social skill and lack of aggression in children's observed peer play with a familiar friend at 3 and 4.5 years of age related positively to observational ratings of maternal sensitivity (i.e. responsive and sensitive care of the child) (NICHD ECCRN, 2001; 2003). Similarly, with a sample of Head Start preschoolers, Bost, Vaughn, Washington, Cielinski, & Bradbard (1998) found maternal attachment security related positively to preschoolers' social competence (i.e. a composite of classroom observations of positive and negative affect, and classmates' sociometric ratings). Moreover, features of mothers, such as the extent to which mothers endorse hostile and aggressive responses to social problems, has also related negatively to preschoolers' social competence (i.e. as measured by teacher ratings of positive and negative social behaviors, and classmate endorsements) (Pettit, Dodge, & Brown, 1988). More recent research has examined associations of parental interactions with preschoolers' prosocial behavior. Specifically, parental reports of preschoolers' prosocial behavior related to cooperative parenting practices, with preschoolers' prosocial behavior increasing as parents employ more cooperative parenting practices (Scrimgeour, Blandon, Stifter, & Buss, 2013). Taken together, this body of research supports the conclusion that sensitive and responsive parenting and a cooperative family social climate support children's healthy social development.

This study seeks to add to and extend this body of research by investigating how low income status and parental behavior may relate to the development of young children's peer collaboration. Specifically, it investigates whether responsive parental caregiving is a mechanism by which income relates to young children's collaboration. Based on the research reviewed above, it is (1) hypothesized that parental caregiving will relate positively to children's collaboration. In particular, the hypothesis is that consistent and contingent parental responsiveness behaviorally informs children's own social coordination, which exemplifies itself in more collaborative behavior. Based on prior research described above, it is also (2) hypothesized that parental caregiving will mediate the relationship between low income status and children's collaboration. This study therefore hypothesizes that one important manner in which poverty may impact children's collaboration is through parental caregiving practices.

It should be noted that collaboration is an essential prosocial behavior to investigate. Collaboration, defined as the coordination of actions with (an)other person(s) to complete a common goal, is ubiquitous in classrooms and homes (Tomasello, Dweck, Silk, Skyrms, & Spelke, 2009). Researchers convincingly argue that collaboration is an important component of other prosocial behaviors and children's overall social development (Tomasello et al, 2005; 2009). Indeed, preschoolers are known to collaborate in a wide range of settings without any explicit rewards (Warneken, Chen, & Tomasello, 2006; Warneken, Gräfenhain, & Tomasello, 2012). Importantly, collaboration has more than social benefits, as it is associated with improved learning in some contexts (Ratner, Foley, & Gimpert, 2002; Sommerville & Hammond, 2007). However, less is known about the developmental pathways that support young children's collaboration (Tomasello et al, 2005; 2009). This study aims to directly address this gap in collaboration research. As outlined by the above hypotheses, this research seeks to shed light on the developmental mechanisms relevant to collaboration by linking research on children's environments with the growing literature on children's collaboration.

Defining Terms. We chose to follow well established norms in the developmental psychology literature to measure our predictors and dependent variable. As is further described in the Methods, we employed the United States Census Bureau's definition of low income. Using the definition, we systematically recruited unfamiliar low and non-low income preschooler dyads into the laboratory.

As a measure of responsive parental caregiving, we selected the widely applied and broader Emotional Availability Scale (Biringen, Derscheid, Vliegen, Closson, & Easterbrooks, 2014; Easterbrooks & Biringen, 2005; Pipp-Siegel & Biringen, 1998). Derived from attachment theory, the scale measures the "overall emotional and interactional quality of the parent-child" relationship. Its four subcomponents measure sensitivity to the child, the ability to structure the child's play, non-hostility, and non-intrusiveness toward the child (Biringen et al, 2014; Easterbrooks & Biringen, 2005; Pipp-Siegel & Biringen, 1998). As is further described below and in the Methods, the scales components were used to measure parent-child interactions based on in-depth parental interviews.

Lastly, we followed the developmental psychology literature in defining collaboration as a sequence of coordinated actions between children directed towards a shared goal (Tomasello et al, 2009). Our use of lag sequential analysis, described below, operationalized the sequential dependence inherent in the definition.

Experimental Methodology. In examining these two hypotheses, my colleagues and I sought to improve upon the methodological paradigms of prior environmental psychology research by conducting a controlled, experimental laboratory study. Specifically, we structured each dyad's opportunities to collaborate with a toy assembly activity (see Methods for details). As children collaborated, in separate rooms parents completed a semi-structured interview and forms regarding their income and parent-child relations. (Research indicates interviews have a higher success rate than questionnaires of measuring aspects of social relationships (Ellis, Boyce, Belsky, Barkemans-Kranenburg, & Van-Ijzendoorn, 2011). Thus, semi-structured interviews were used to provide a more detailed measure of parental behavior.) Following the experimental sessions, trained Research Assistants recorded the activity of each dyad employing a detailed coding scheme. Then, lag sequential analysis was used to compute the extent to which each dyad collaborated on each step of the toy assembly. As described in the Results section below, multilevel modeling was used to analyze whether and how income and parental sensitivity related to children's peer collaboration.

Methods

Participants

Participants were fifty dyads of one-hundred preschoolers (*M* = 50.88 months, *SD* = 2.76 months; twenty-five female dyads). All dyads consisted of unfamiliar children of the same gender and within six months of age of one another (*M* = 3.24 months, *SD* = 2.28 months).

As noted above, we conducted substantial recruitment efforts to ensure the sample better reflected the socioeconomic makeup of the university's surrounding region. In particular, we screened participants to ensure we recruited a sizable number of low income dyads (i.e. both children of low income status). Twenty-two of the study's fifty dyads consisted of children from families classified as low income by the standards of the United States Census Bureau. Children were recruited from nearby

Head Start facilities, a database of research participants, and public postings at venues frequented by low income parents (e.g. a Walmart store). The children were all from the surrounding region of a rural university town and were predominantly Caucasian. Under 40% of the participants had participated in a prior research study. All participants were native English speakers.

Four dyads that arrived to participate were excluded from the final sample due to the children's refusal to engage cooperatively and safely enough to complete the protocol. All four of the excluded dyads were from low income backgrounds.

All families were given $75-100 and teddy-bears and coloring books for their participation. If needed, transportation was provided for participants via local taxis.

Stimuli

The stimuli were exactly as described in Chapter 2: Methods.

Apparatus

The children's session apparatus was as described in Chapter 2: Methods.

Parental interviews occur in separate rooms adjacent to the child testing rooms. The interviews were recorded on a laboratory Sony IC Audio Recorder. The interviews were then directly downloaded to secure laboratory computers and stored in MP3 format.

Procedure

Warm-up Phase. As described in Chapter 2: Methods, the Warm-up Phase served to introduce the two unfamiliar children to one another, the rooms, and the experimenters. The children played with blocks, stuffed animals, and marbles with the experimenters and parents. Depending on their comfortability, children and parents spent from twenty to forty-five minutes in the Warm-up Phase. Before commencing, all children were asked if they'd like to play with the large space blocks and the study proceeded if both children indicated that they were. Parents were also asked if they were comfortable proceeding with the study.

Children's Dyadic Collaboration. The stimuli, procedure, and protocols for children's collaboration are exactly as described in Chapter 2: Methods. The additional parental portions of data collection are described below.

Parental Interviews and Forms. After electing to proceed with the study, parents were separately asked to provide their annual household income, number of adults and children in the home, levels of parental education, and all types of social support (e.g. food stamps, energy, disability, Home Energy Assistance Program, Family Assistance Program, etc.) on a participant study form.

Following completion of the form, each parent completed a semi-structured, recorded interview with two trained Research Assistants. In the interviews, parents were asked to describe the most recent day with their child from waking to sleeping. Parents were also asked to describe a recent situation of conflict involving their child. On average, the interviews lasted approximately 25 minutes.

Coding

Coding and Computing Children's Collaboration. The coding guidelines and computation of children's collaboration are exactly as described in Chapter 2: Methods. The additional coding and employment of coding scales for parental information are described below.

Income. A binary variable reflected the status of the dyad as low income (=1) or not low income (=0) depending on whether the children were from low income households. Consistent with other research, this study employed the United States Census Bureau standards of income. This standard includes household income, number of adults, and number of children as determinants.

A more descriptive variable for household income was also employed. This common ordinal assignment ranged from 0 to 5 based solely on the household's income. Table 3.1 shows the specific variable assignment below.

Reported Income Range	\$0-\$15000	\$15001-\$30000	\$30001-\$50000	\$50001-\$80000	\$80001-\$120000	=> \$120000
Assignment	0	1	2	3	4	5

Table 3.1: This table shows the household income variable assignment based on family's report household income.

Parental Caregiving. Based on the social dynamics and recent experiences described by parents in the semi-structured interviews, two trained coders used the validated, reliable, and commonly used Early Childhood Emotional Availability Scale (Pipp- & Biringen, 1998; Easterbrooks & Biringen, 2005) to measure the emotional and interactional quality of the parent-child relationship. The scale is appropriate for children aged 0 to 6 years and is designed for assessing caregiver-child relationships. Specifically, the scale assesses the capacity of the dyad to share an emotionally healthy and responsive relationship (Easterbrooks & Biringen, 2005; Biringen et al, 2014). The four components employed are Adult Sensitivity and Child Responsiveness (i.e. balanced, genuine, and emotionally responsive affect and behavior), Adult Structuring and Child Involvement (i.e. consistently provides appropriate guidance and suggestions, and proactively sets activity boundaries), Adult Non-hostility (i.e. lacking negativity, threats, mocking, etc.), and Adult Non-intrusiveness (i.e. permits child to lead when appropriate and enacts non-interruptive ports of entry). Based on the scales' definitions and examples, parents were given a score ranging from 0 (low) to 10 (high) for each of these four components.

The coders followed a consistent process to code the interviews. Each coder listened to the parental interviews at least twice. The coders first listened to the interviews and documented relevant information for each of the above-described variables. The coders then listened to the interview a second time and assessed whether the documented information for each variable best captured the information obtained from the interview. Any changes were made following the second listening session. Coders then assigned scores to each of the four scale components. Lastly, if the coders were unsure of any scoring, they met with the other coder and the first author collectively to discuss the most appropriate score. This impacted approximately 15% of the scores.

The two coders performed reliability coding on four dyads (i.e. eight children). Inter-coder reliability was high as assessed by an intra-class correlation coefficient with R's icc function from the irr package ($F = 2.31$, $p = .043$).

Results

General: Multi-level Modeling Analysis Approach. As in Chapter 2, to assess the relationship between our environmental predictors and the dyads' collaboration across the steps we used a multi-level modeling approach (Bickel, 2007; Luke, 2004). We employed a two-level regression model in which the step-level variables were nested within the dyads. This approach enabled us to account for within dyad variation across the steps. For the dyad level predictors, we employed dyadic indices of the variables measured on individual children (Kenny, Kashy, & Cook, 2006). This use of dyadic indices for our predictors enabled us to reflect the dependence in our independent variables.

Dependent Variable: Children's Dyadic Collaboration (Test Toys). For the results and distribution of children's collaboration, see the section with the same title in Chapter 2: Results. We employed the same dependent variable as in Chapter 2, namely the rate of children's collaboration on each step across the two Test Toys.

Independent Variables: Low and Non-Low Income Dyads. As described in the Methods, we recruited low and non-low income children to participate. (Children were classified as low or non-low income based on the United States Census Bureau guidelines, which includes both family income and number of household members as determinants). Unfamiliar low income children were paired with one another to form low income dyads (n = 22; Average Age: 4.64 years; Female = 9) and similarly for non-low income children (n = 28; Average Age: 4.70 years; Female = 16). A binary factor (i.e. 1=low income, 0=not low income) represented the low income status of the dyads.

We also included a common and more continuous household income variable. This variable assignment is ordinal and the resulting distribution is depicted in Figure

3.2.

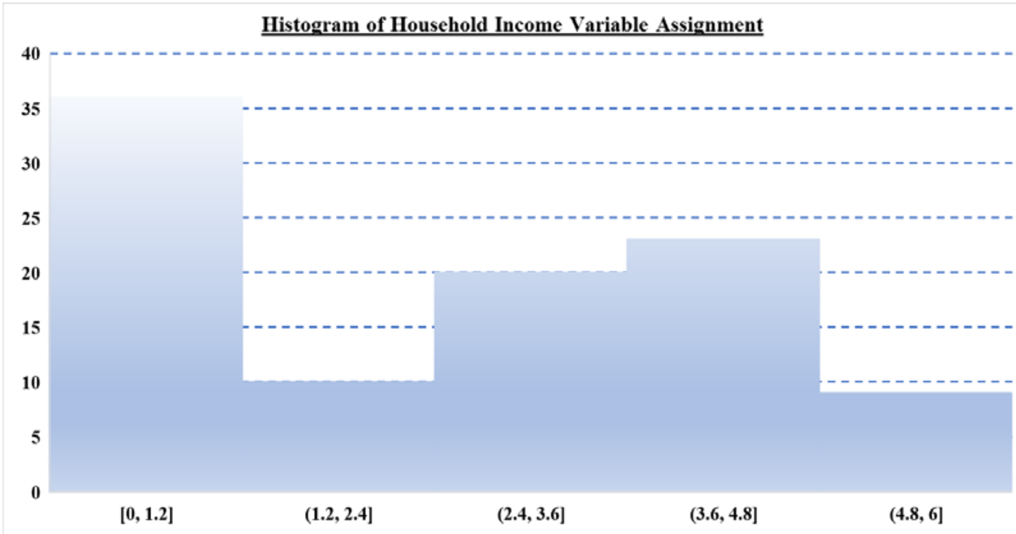

Figure 3.2: This histogram shows the distribution of household income variable assignment. The assignments were made using the common assignment method depicted in Table 3.1.

Independent Variables: Parental Caregiving. We measured parental caregiving with the four primary components from the Early Childhood Emotional Availability Scale (Easterbrooks & Biringen, 2005), as discussed in the Methods above. The four components are Adult Sensitivity and Child Responsiveness (*M* = 6.28, *SD* = 1.98), Adult Structuring (*M* = 6.32, *SD* = 2.08), Adult Non-hostility (*M* = 7.96, *SD* = 1.72), and Adult Non-intrusiveness (*M* = 6.58, *SD* = 1.92). These four variables were also averaged to produce an Emotional Availability variable (*M* = 6.79, *SD* = 1.72).

Parental Caregiving Dyadic Indices. Similar to Chapter 2 and as noted above, we assessed dyadic indices of the independent variables that reflect the dyadic dependence of our dependent variable. Specifically, we assessed the dyadic average. As an example, Figure 3.3 depicts the dyadic average of Emotional Availability (*M* = 6.82, *SD* = 1.38). (See Appendix B: Figures 3.4-3.7 for additional distribution information of the other dyadic index predictors).

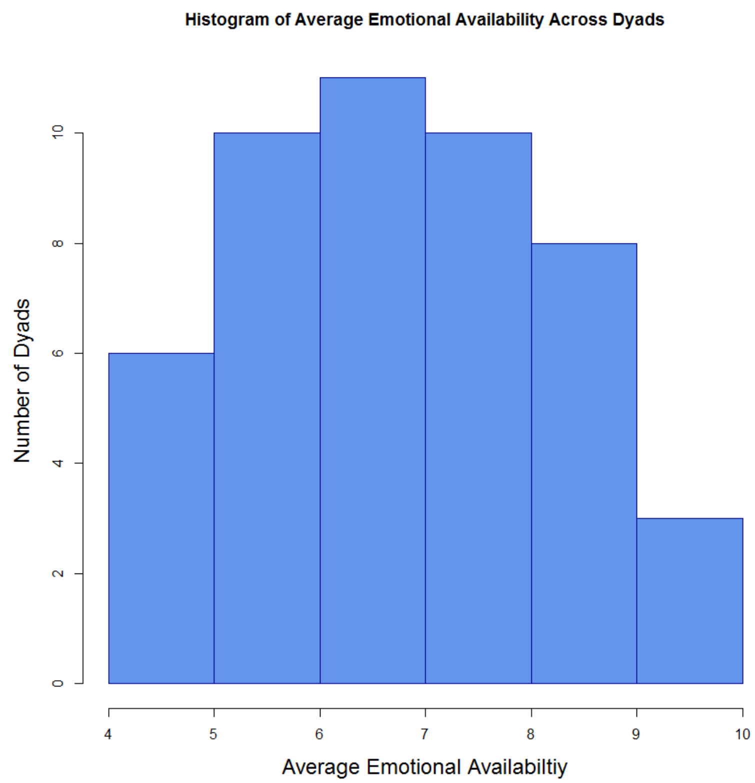

Figure 3.3: This histogram depicts the distribution of the dyadic index of Emotional Availability.

Multilevel Analysis: Assessing Environmental Predictors. As described above, the following analyses involved a two level model structure wherein the steps were nested within the dyads. The analyses employed R 3.2.2's lme command with a random dyad intercept term. Note that the continuous predictors were normalized as z scores in the following analyses. Additionally, as is noted where appropriate, some predictors were transformed to form a more normally distributed predictor.

Assessing Income. We assessed whether low income status related to children's collaboration by testing the binary factor of income status as a dyad level variable. A two predictor model that included the dyads' ages indicated that low income status related to decreased collaboration overall at a moderately statistically significant level (Low Income Status: $\beta = -0.053$, $t = 1.57$, $p < 0.083$). This result suggests that children's peer collaboration relates to their family income background, in particular to very low levels of income. See Figure 3.8 for a bar plot relating to this result.

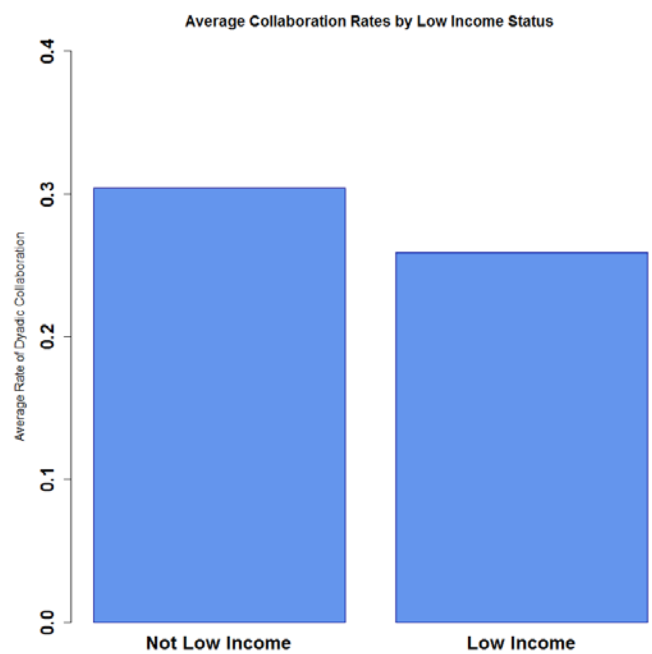

Figure 3.8: This figure shows the average collaboration rate across the steps for children from low income versus non-low income family backgrounds.

We also assessed the more continuous household income variable. Given the categorical result regarding more extreme low incomes, we attempted to determine whether income related in a more continuous and linear (i.e. at least within this income variable range) fashion. To do so, we created a dyadic index, Average Household Income Assignment, by averaging the children's household income assignments within each dyad. A single predictor test of this dyadic index did not find a relationship between household income variability (Average Household Income Assignment: $\beta = -0.010$, $t = -0.66$, $p = 0.514$) and children's collaboration. Thus, while we identified a relationship between more extreme family income backgrounds and children's collaboration, but we did not find a more continuous and broader relationship.

Assessing Parental Caregiving. We next assessed whether parental caregiving related to children's collaboration across the steps. We tested both the overall Average Emotional Availability index as well as the sub-components of the score. Assessments of separate, single predictor models suggested that the dyadic indices of Average Emotional Availability (Average Emotional Availability: $\beta = -0.005$, $t = -0.30$, $p = 0.762$), Average Parental Sensitivity and Child Responsiveness (Average Emotional Availability: $\beta = -0.004$, $t = -0.26$, $p = 0.794$), Average Parental Structuring (Average Parental Structuring: $\beta = -0.007$, $t = -0.46$, $p = 0.651$), Average Parental Non-hostility (Average Parental Non-hostility: $\beta = -0.003$, $t = -0.16$, $p = 0.874$), and Average Parental Non-intrusiveness (Average Emotional Availability: $\beta = -0.002$, $t = -0.14$, $p = 0.89$) did not relate to children's collaboration. These results therefore provided no evidence that the parent-child relationship, as measured using the Emotional Availability scale, relates directly to children's peer collaboration.

Given these negative results, we did not have the necessary statistical support to further pursue whether parent-child interactions function as a mediator between low income and children's collaboration.

Discussion

This study explored potential developmental predictors of young children's peer collaboration. On the basis of prior research, we examined whether income and the parental caregiving related to children's dyadic peer collaboration. The analysis obtained mixed results. We found moderate statistical support linking low income backgrounds to lower rates of collaboration, but did not find evidence that the parent-child relationship related to children's collaboration. These findings and their implications for future research are discussed below.

The finding that low income children tended to collaborate at lower rates is consistent with our hypothesis. Indeed, substantial prior research has long found a variety of developmental outcomes impacted by poverty (Blair, 2002; Evans, 2004). This research extends prior research by (a) linking low income backgrounds to a particularly important prosocial behavior and (b) doing so using a clearly structured and controlled experimental paradigm. Importantly, this finding suggests that the development of human collaboration is related to, and perhaps impacted by, the family environment in which children develop.

Interestingly, while low income status related negatively to collaboration, no broader (i.e. beyond low income status itself and across the spectrum of income), statistically significant relationship was found between income and collaboration. This finding may reflect a few prominent plausible possibilities, including our sample characteristics. First, it is possible that only very low levels of income are of developmental import to children's collaboration. Low income status, as defined by the United States Census Bureau, characterizes an impoverished state wherein families may find it difficult to provide basic resources for children, including consistent and predictable parental interaction. Thus, it may be that low income backgrounds, but not less extreme financial circumstances, are detrimental to children's prosocial development. This possibility is consistent with the non-linear finding.

Second, another possibility consistent with our dichotomous results concerns the multiple determinants of low income status. Specifically, low income status includes income as well as household occupancy information, thereby more closely reflecting the financial resources per occupant. This leads to the possibility that low financial resource levels *per person* may be a more accurate or powerful predictor of detriments to children's collaboration. Note that this possibility is not inconsistent with the first possibility. That is, it may be that very low levels of income per person, but not less extreme levels, are of particular import.

Third, it may be that any more broader income effects on children's collaboration are relatively weak and our study was unable to detect them. In particular, recent studies demonstrating broader income-related effects on development have included sample sizes (i.e. and degrees of freedom) near or larger than 1,000 (e.g. Morris & Gennetian, 2003; NICHD, 2001; 2003; Zhang, Chen, Zhang, & Sun, 2009). This study was markedly smaller, in large part due to the experimental component and detailed nature of the collaboration coding. Moreover, our study did not at all contain a uniform portion of children from higher income brackets; our sample was decidedly skewed towards the income of the surrounding region. Hence, it is certainly possible that a weaker and broader income effect on collaboration exists, but this study did not have the statistical power, nor an appropriate sample, to detect it.

Notably, this study did not find any relationship between the parent-child relationship and children's collaboration. As with most negative results, this may be due to a number of possibilities and does not prove that no such relationship exists. However, to be clear, it is certainly possible that this result indicates that parent-child interactions do not have a strong, material impact on children's own peer social coordination. For instance, this could be the case if children's collaboration required little (or no) parental input. This seems unlikely, given the known relevance of social input for other social coordination behaviors, such as language (Goldstein & Schwade, 2008; Yurovsky, Smith, & Yu, 2013). Relatedly, it is possible that by the preschool years the correlation between parent-child interaction and peer interaction weakens as children interact more and more with their preschool peers. Overall, then, this result could indicate that preschoolers' collaboration may not depend strongly on their parent-child interactions.

For the purposes of analyzing this result and with regards to aiding future research, two other prominent possibilities are also discussed. First, the methodology we employed, parental interviews, was more detailed than surveys but less informative than the most desired method- observing parent-child interaction. Researchers are understandably and commendably seeking to employ more accurate and detailed behavioral measurements, and parental interviews represent a step in this direction from surveys. But our hypothesis rests on the logic that consistent, structured, and contingent parent-child interactions would relate to children's own social coordination. Interviews offer some information on those interactions, but do not present the interactions themselves and are potentially biased or skewed. Moreover, no clear contingency information (e.g. lagged dependencies in parent-child actions, etc.) is obtained from parental interviews. It is therefore strongly advised that future researchers directly explore the possible relationship between parent-child interactions and peer collaboration through structured observational methodologies.

Second, beyond the particular methodology it is possible that the Emotional Availability scales employed are not the most effective lens for our purposes. Our study selected a widely used and age-appropriate parent-child relationship measure (Pipp-Siegel & Biringen, 1998; Biringen et al, 2014). However, there are some differences between what this scale measures and this study's hypothesis of what interactions may directly support the development of collaboration. As described in the Introduction, our study hypothesizes that consistent, contingent, and responsive parent-child interactions support the child's ability to learn contingent, cooperative social interaction, such as the child's peer collaboration. While the Emotional Availability Scale does measure, in broad strokes, the appropriateness of parental responses, a lack of negative responses (e.g. angry or demeaning behavior), and appropriate structuring of child activities, it does not necessarily (nor precisely) measure the contingent, cooperative behavior at the heart of the hypothesis. This leaves open the possibility that a more direct and refined parental caregiving and responsiveness measure would demonstrate such a relationship.

In sum, this study's findings suggest an important relationship between impoverished family backgrounds and young children's spontaneous peer collaboration. However, the study did not identify a broader relationship across the income spectrum with collaboration, nor a relationship between the parent-child relationship and collaboration. This leaves developmental researchers with important work: to more clearly and definitively explain how impoverished backgrounds influence children's dynamic collaborative behavior. As described above, it is advised that this research further explore, through observational methods and dynamic social coordination measures, parent-child interactions as a mediator. Moreover, it is also advised that this research open-mindedly explore factors across levels of analysis (e.g. cognitive, physiological, genetic, etc.) using dynamic and detailed behavioral measures.

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CHAPTER 4

CORTISOL REACTIVITY AS A PHYSIOLOGICAL PREDICTOR OF YOUNG CHILDREN'S COLLABORATION

Introduction

Young children's prosocial behavior has been a topic of great interest in the developmental literature in the past two decades (Blair, 2002; Chernyak & Kushnir, 2013; NICHD ECCRN 2001; 2003; Paradise & Rogoff, 2009; Pianta & Stuhlman, 2004; Ratner, Foley, & Gimpert, 2002; Tomasello, Carpenter, Call, Behne, & Moll, 2005; Warneken, 2015). This attention stems from educational (Blair, 2002; Pianta & Stuhlman 2004), philosophical (Chernyak & Kushnir, 2013; Tomasello et al, 2005), cultural (Paradise & Rogoff, 2009), and environmental (NICHD ECCRN 2001; 2003) oriented researchers and literatures. Across the diversity of backgrounds, researchers highlight the significance of collaborative behavior for reasons ranging from practical (Blair, 2002) to philosophical (Tomasello, Dweck, Silk, Skyrms, & Spelke, 2009).

This wide-ranging research has substantially improved our understanding of the features and benefits of children's collaboration. Research has shown that from as young as two years of age children engage in a range of prosocial, collaborative behaviors. Children select to engage in collaborative exchanges over independent action without any explicit reward for doing so (Warneken, Chen, & Tomasello, 2006; Warneken, Gräfenhain, Tomasello, 2012). However, the benefits of collaboration are not limited to social interaction, as collaboration benefits children's learning in some social contexts (Ratner, Foley, & Gimpert, 2002; Sommerville & Hammond, 2007).

Moreover, from the preschool years on collaborative exchanges are ubiquitous in educational settings (Blair, 2002; Raver & Zigler, 1997) and often a fundamental part of developing into cultural participants (Paradise & Rogoff, 2009).

This research enhances our understanding of the typical developmental milestones, cognitive benefits, and social significance of children's collaboration. However, less is understood about the proximate and developmental causes of children's collaboration. That is, while past research has enriched our understanding of the evolutionary causes and important correlates of collaboration (Tomasello et al, 2005; 2009), it has focused less attention on identifying mechanistic and developmental predictors of children's collaboration (Tinbergen 1996). Importantly, among other benefits, knowing such predictors would improve our ability to predict when children are likely to collaborate, and whether a given dyad of children are likely to collaborate more or less than another dyad.

In this paper, my colleagues and I seek to improve our understanding of the mechanistic causes of children's collaboration by investigating a potential physiological predictor. In particular, we investigate whether cortisol, a well-studied hormone that supports physiological arousal (i.e. the non-specific activation of neural circuits and bodily organs relevant to the production of appropriate behavioral responses) (Hostinar, Sullivan, & Gunnar, 2013; Sapolsky, Romero, & Munk, 2000), positively relates to children's collaboration. As discussed below, prior research in humans and non-human primates supports the hypothesis that moderate increases in arousal may facilitate collaborative interactions.

Extensive prior research indicates that increases in cortisol support increased arousal, which, at moderate levels, tends to enhance cognitive performance (Hostinar, Sullivan, & Gunnar, 2013; Sapolsky, Romero, & Munk, 2000). Indeed, recent developmental research on cortisol in preschoolers has demonstrated such effects (Gunnary, Talge, & Herrera, 2009). For example, increases in preschoolers' cortisol levels positively associated with their performance on an executive function task (Blair, Granger, & Razza, 2005). Additionally, developmental research indicates that increases in cortisol support social engagement as well. In an intriguing experimental design, Stansbury & Harris (2000) asked preschoolers to enter a room and free play with two unfamiliar peers. The researchers then examined children's behavioral response and cortisol reactivity. Contrary to the researchers' expectations, they found that children's cortisol reactivity depended on whether the child approached and played with the unfamiliar peers or avoided them. Specifically, children who approached and played with the peers, as opposed to avoided them, demonstrated larger increases in cortisol. In sum, developmental research supports the hypothesis that increases in cortisol may support young children's collaboration, which involves both cognitive and social engagement.

To assess our hypothesis, we developed an original experimental design to simultaneously assess children's dyadic collaboration and cortisol reactivity. Specifically, we developed a step-by-step toy assembly task that consistently structured each dyad's opportunities to collaborate (see Method for details). Using appropriately timed salivary cortisol sampling, we assessed both children's cortisol responses to the lab, independently completing the toy assembly activity, and collaborating with their partner on the assembly activity. Following the experimental sessions, trained Research Assistants recorded the activity of each dyad second-by-second employing a detailed coding scheme. Then, lag sequential analysis was used to compute the extent to which each dyad collaborated on each step of the toy assembly. As described in the Results section below, multilevel modeling was used to analyze whether and how cortisol reactivity related to children's independent and collaborative toy assembly.

Methods

Participants

Participants were fifty dyads of one-hundred preschoolers (*M* = 50.88 months, *SD* = 2.76 months; twenty-five female dyads). All dyads consisted of unfamiliar children of the same gender and within six months of age of one another (*M* = 3.24 months, *SD* = 2.28 months).

As noted above, we conducted substantial recruitment efforts to ensure the sample better reflected the socioeconomic makeup of the university's surrounding region. In particular, we screened participants to ensure we recruited a sizable number of low income dyads (i.e. both children of low income status). Twenty-two of the study's fifty dyads consisted of children from families classified as low income by the standards of the United States Census Bureau. Children were recruited from nearby Head Start facilities, a database of research participants, and public postings at venues frequented by low income parents (e.g. a Walmart store). The children were all from the surrounding region of a rural university town and were predominantly Caucasian. Under 40% of the participants had participated in a prior research study. All participants were native English speakers.

Four dyads that arrived to participate were excluded from the final sample due to the children's refusal to engage cooperatively and safely enough to complete the protocol. All four of the excluded dyads were from low income backgrounds.

All families were given $75-100 and teddy-bears and coloring books for their participation. If needed, transportation was provided for participants via local taxis.

Stimuli

The stimuli were the same as those described in Chapter 2: Methods.

Apparatus

The apparatus were exactly the same as described in Chapter 2: Methods. Additionally, the same Dell Inspiron laptops were used to depict the instructive photos for the play session were used to show children a playful video they watched during saliva sampling.

Salimetrics Child Oral Swabs (SCS), which are widely used in physiological research with children (Granger et al, 2007), were used to obtain children's saliva samples. (The SCS differ from adult swabs in that their length is extended, thereby prohibiting children from swallowing them.)

Procedure

Warm-up Phase. The Warm-up Phase served to introduce the two unfamiliar children to one another, the rooms, and the experimenters. The children played with blocks, stuffed animals, and marbles with the experimenters and parents. Depending on their comfortability, children and parents spent from twenty to forty-five minutes in the Warm-up Phase. Before commencing, all children were asked if they'd like to play with the large space blocks and the study proceeded if both children indicated that they were. Parents were also asked if they were comfortable proceeding with the study.

Children's Independent Activity: The Assessment Toy. The stimuli, procedure, and protocols for children's collaborative activity are exactly as described in Chapter 2: Methods.

Children's Dyadic Collaboration: The Test Toys. The stimuli, procedure, and protocols for children's collaborative activity are exactly as described in Chapter 2: Methods. The additional saliva sampling portions of data collection are described below.

Saliva Sampling Procedure. To assess a potential relation between cortisol and children's collaboration, each child provided three salivary samples taken with Salimetrics Child Oral Swabs (SCS). During each sampling, children were seated and watched a space-themed cartoon movie created by Research Assistants to capture children's attention during the sampling. Children were instructed to position the swab under their tongue and get it wet. The movie and samplings lasted approximately 90 seconds. Children were prohibited from drinking water within 15 minutes of a sample. The samples were put in Salimetrics storage vials and kept in a subzero freezer until being assayed for cortisol by Salimetrics. The samples were stored on dry ice and sent to Salimetrics (Carlsbad, CA) for the assays.

Saliva Sample Timing. The saliva samples were scheduled to reflect children's cortisol responses to (1) meeting their peer and the laboratory, (2) independently assembling the toys (i.e. the end of the Assessment Toy), and (3) collaborating with their peer partner on the Test Toys. Research indicates children's peak salivary responses to events is delayed by approximately 25 minutes from time of the event (Cirulli & Alleva, 2009; Gunnar et al, 2009; Nam et al, 2007). Hence, the first sample was taken 25 minutes following children's introduction and the second sample 25 minutes following the end of the Assessment Toy. The third sample was timed to reflect children's response to both the first and second Test Toys. Hence, it was taken 12.5 minutes after the completion of the second Test Toy in order to reflect a portion of children's cortisol response to first Test Toy as well.

Lastly, depending on their scheduling needs, dyads were tested at either 9:30am or 4:30pm to provide more consistency and control over the diurnal timing of the saliva samples.

Coding

Computing and Coding Children's Collaboration. The coding guidelines and computation of children's collaboration are exactly as described in Chapter 2: Methods.

Results

General: Multi-level Modeling Analysis Approach. As in Chapters 2 and 3, to examine the relationship between our environmental predictors and the dyads' collaboration across the steps we used a multi-level modeling approach (Bickel, 2007; Luke, 2004). We employed a two-level regression model in which the step-level variables were nested within the dyads. This approach enabled us to account for within dyad variation across the steps. For the dyad level predictors, we employed dyadic indices of the variables measured on individual children (Kenny, Kashy, &

Cook, 2006). This use of dyadic indices for our predictors enabled us to reflect the dependence in our independent variables.

Dependent Variables: Children's Dyadic Collaboration (Test Toys) and Competency (Assessment Toy). For the results and distributions of children's collaboration and Competency Scores, see the section with the relevant titles in Chapter 2: Results. We employed the same dependent variable as in Chapter 2, namely the rate of children's collaboration on each step across the two Test Toys.

Independent Variables: Cortisol Reactivity. As described in the Methods, we obtained salivary cortisol measurements indicative of children's response to (1) entering the laboratory (M = 0.1013 µl, SD = 0.1625 µl), (2) individually assembling the Assessment Toy (M = 0.0877 µl, SD = 0.1221 µl), and (3) collaborating with their peer on the Test Toys (M = 0.1008 µl, SD = 0.1382 µl). To assess children's cortisol response to individual assembly, we assessed the difference between the 2nd and 1st samples, here termed Individual Activity Cortisol Reactivity. Similarly, to assess children's cortisol response to collaborative assembly, we assessed the difference between the 3rd and 2nd samples, here termed Collaborative Cortisol Reactivity. We used the Individual Activity Cortisol Reactivity (M = -0.0041 µl, SD = 0.0686 µl) to assess whether children's cortisol response related to their individual assembly of the Assessment Toy. We worked with the Collaborative Cortisol Reactivity (M = 0.0051 µl, SD = 0.0470 µl) to assess whether children's cortisol response related to their collaboration on the Test Toys. Figure 4.1 shows the distribution of the Individual Cortisol Reactivity and the Collaborative Cortisol Reactivity distribution can be found in Appendix C: Figure 4.2.

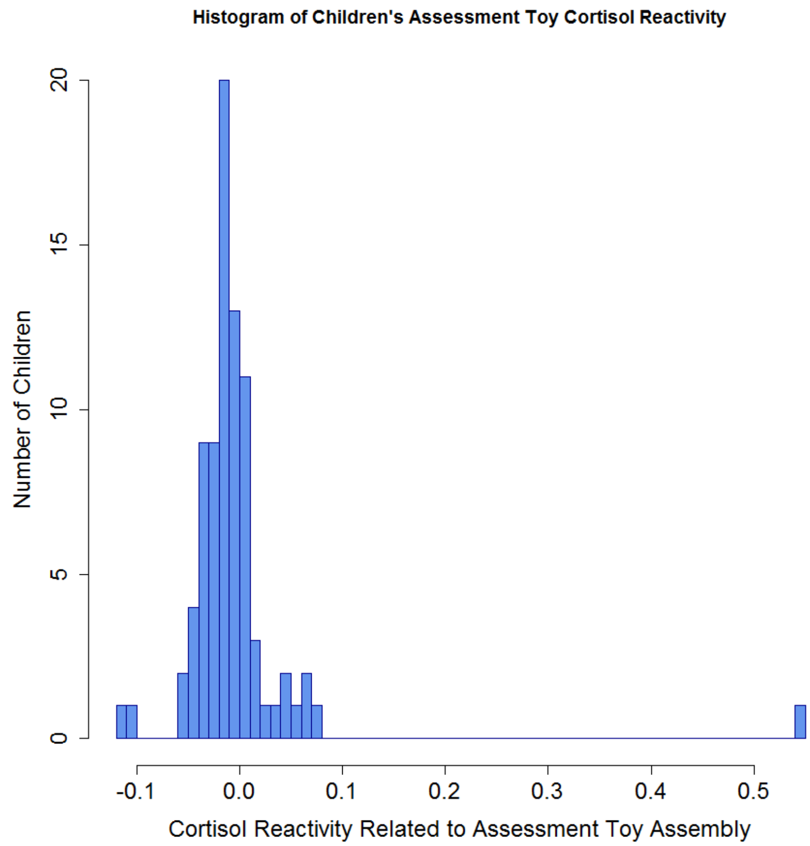

Figure 4.1: This histogram shows the distribution of children's cortisol reactivity, here termed the Individual Activity Cortisol Reactivity, which is mainly distributed around 0.0. Outliers were adjusted and accounted for in the below analyses.

Dyadic Cortisol Reactivity Indices. Consistent with the approach of Chapters 2 and 3, dyadic indices of cortisol were employed to reflect the dependency of the dependent variable in the independent variables. Specifically, the Average Cortisol Reactivity (M = 0.0039 µl, SD = 0.0367 µl) and Cortisol Reactivity Difference (M = -0.0411 µl, SD = 0.0451 µl) dyadic indices were computed from the children's Collaborative Cortisol Reactivity scores. Figure 4.3 shows the distribution related to the dyadic index of Average Cortisol Reactivity. (Similarly, Figure 4.4, in Appendix C, shows the dyadic index of Cortisol Reactivity Difference).

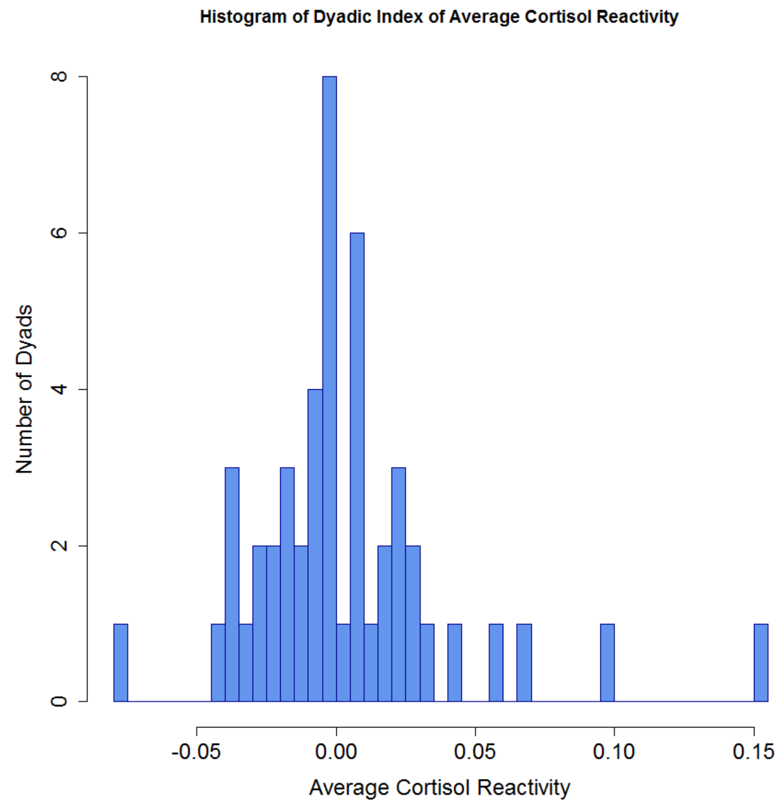

Figure 4.3: This histogram shows the distribution of the dyads' average cortisol reactivity, here termed Average Cortisol Reactivity.

Standard Linear Regression: Assessing Individual Activity and Cortisol Reactivity. Before assessing the relationship between children's collaboration and cortisol reactivity, we assessed the relationship between children's individual Assessment Toy performance and cortisol reactivity. This analysis serves to provide an indication of how specific cortisol reactivity may be to toy assembly versus collaborating with a peer on toy assembly. In particular, by assessing the relationships with both individual and collaborative activity, we can provide additional evidence as to the character of the role cortisol may play.

The relationship between children's Assessment Toy activity and cortisol reactivity examined children's Competency Scores and Individual Activity Cortisol Reactivity. The former assessed children's overall performance in correctly manipulating the boxes to assemble the Assessment Toy (see Chapter 2: Methods and Results). The latter assessed the difference between the first and second salivary cortisol samples. A simple linear model employing R's lm command indicated that children's cortisol reactivity negatively related to children's Competency Scores (Children's Competency Score: $\beta = -0.016$, $t = -2.17$, $p = 0.033$). Thus, the degree to which children's cortisol continued to rise at the second sample related negatively to children's performance on the Assessment Toy.

Multilevel Analysis: Assessing Collaboration and Cortisol Reactivity. As with Chapters 2 and 3, the following analyses involved a two level model structure wherein the steps were nested within the dyads. The analyses employed R 3.2.2's lme command with a random dyad intercept term. Note that the cortisol reactivity predictors were normalized as z scores in the following analyses. Additionally, as is noted where appropriate, some predictors were transformed to form a more normally distributed predictor.

The relationship between cortisol reactivity and collaboration was assessed with the dyadic indices of Average Cortisol Reactivity and Cortisol Reactivity Difference. Since these variables were measured once for each dyad, they were entered as predictors at the dyad level of the model. The assessment indicated that Cortisol Reactivity Difference (Cortisol Reactivity Difference: $\beta = -0.002$, $t = -0.14$, p

= 0.893) did not relate to children's collaboration, but Average Cortisol Reactivity negatively related to collaboration (Average Cortisol Reactivity: $\beta = -0.038$, $t = -2.37$, $p < 0.022$). (See Figure 4.5 below for related depiction of this analysis's results and Figure 4.6 in the Appendix).

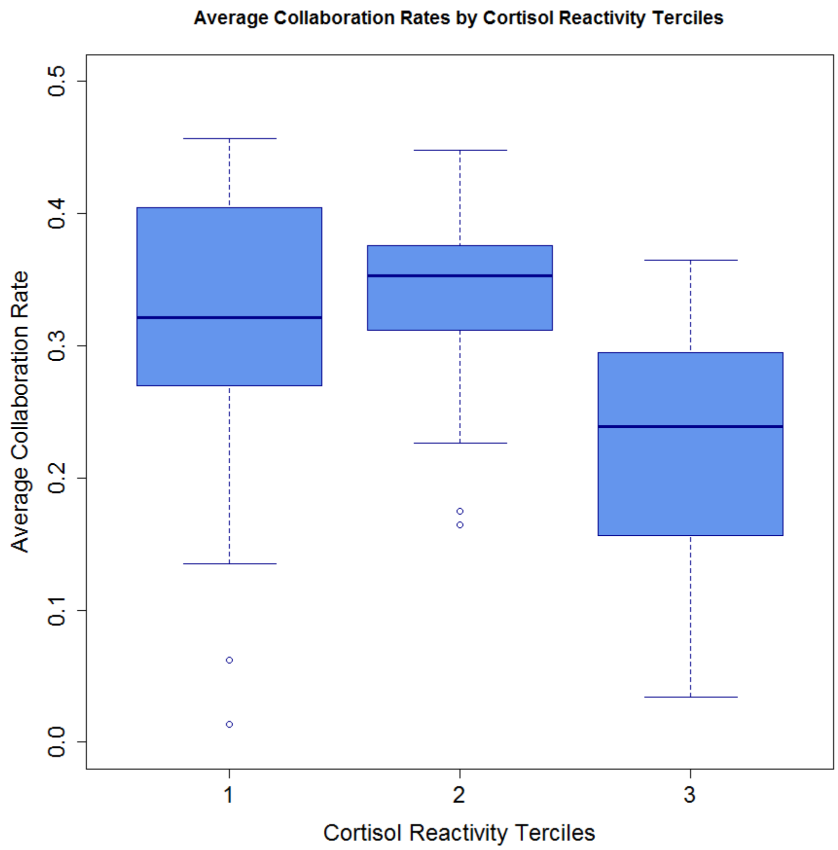

Figure 4.5: This figure shows the average rate of collaboration by cortisol reactivity terciles. The rate of collaboration decreased with increasing cortisol reactivity.

Additionally, the squares of Cortisol Reactivity Difference (Cortisol Reactivity Difference Squared: $\beta = -0.080$, $t = -1.68$, $p = 0.101$) and Average Cortisol Reactivity (Average Cortisol Reactivity Squared: $\beta = 0.005$, $t = 0.23$, $p = 0.821$) were assessed to examine possible quadratic effects. These analyses provided moderate statistical support for a quadratic relationship with respect to dyadic differences in cortisol reactivity.

Overall, these analyses indicate that the extent to which both children's cortisol reactivity did *not* increase during the collaborative episode positively related to children's peer collaboration. Additionally, the relative difference in children's cortisol reactivity may relate in a non-linear fashion to collaboration, but this only received moderate statistical support. The significance of these results is discussed further below in the Discussion section.

Discussion

This study assessed whether and how cortisol reactivity, a marker of change in arousal, may relate to children's dynamic peer collaboration. The results suggest that there is a relationship between young children's collaborative dynamics and their shared arousal adaptation. Specifically, rates of collaboration related negatively to increases in cortisol reactivity, meaning that collaboration was associated with a lesser increase in arousal. Moreover, a moderately significant result suggested that differences in arousal activity may have a negative non-linear relationship to children's collaboration. Lastly, analogous to the result in the collaborative context, increases in cortisol reactivity related negatively to children's individual toy assembly activity. These results and their significance for future research are discussed further below.

A careful analysis and interpretation of this study's results has the opportunity to make an important contribution to the developmental literatures on arousal and prosocial behavior. First, the result that cortisol reactivity related negatively to children's performance on the Assessment Toy ought to be considered with an understanding of the experimental context. More than prior studies discussed above (e.g. Blair, Granger, & Razza, 2005; Stansbury & Harris, 2000), in our study children entered the laboratory and spent on average 28 minutes and 26 seconds before beginning the Assessment Toy. During that time, children met and were asked to interact with (1) novel adult experimenters, (2) novel adult parents, and (3) novel peers in a novel space in which they learned a novel assembly task. These interactions and experiences likely increased children's arousal in a manner that is often not well appreciated in interpretations of experimental arousal analyses (Gunnar, Talge, & Herrera, 2013). This recognition of the experimental procedure and its impact on young children supports the following argument. The negative relationship between children's cortisol reactivity and Assessment Toy performance likely reflects that children with more moderate cortisol responses were already experiencing relatively elevated cortisol levels appropriate for engagement with the activity, while children with stronger responses indicates a stress-related response. From this perspective, it is not surprising that children's Competency Scores correlated negatively with children's cortisol reactivity during the Assessment Toy. In short, children's arousal most likely increased considerably in relation to the experimental context, and a lack of further stress-level cortisol increases associated positively with Assessment Toy performance.

This last point deserves further discussion as well. Associations between arousal and behavior are often assumed to reflect arousal causes driving behavior. This influence likely holds to some extent and researchers have made some convincing, if incomplete, arguments to this end (Aston-Jones & Cohen, 2005;

Sapolsky, Romero, & Munk, 2000). However, behavioral impacts on arousal, or some form of feedback, must also be considered. In this case, it should be noted that children's toy assembly performance may have contributed to decreased cortisol reactivity. In particular, children performing well by engaging in toy assembly may have moderated any stress associated with the expectation of completing the toy assembly task in the unfamiliar environment. Thus, the result should be interpreted as indicating that decreased cortisol reactivity and toy assembly performance may reflect arousal-to-behavior as well as behavior-to-arousal influences. Future research employing more dynamic arousal measures may be able to better decompose the causal pathways.

Second, the result that children's collaboration also related negatively to children's average cortisol reactivity contains similarities with the first result. Analogous to the first result, it is likely that this result reflects the association between a moderate level of arousal and children's active collaborative engagement. Specifically, as with the first result, children were in an unfamiliar environment for a considerable period of time during which their cortisol levels likely rose and sustained before the testing samples were taken. Thus, the negative association with further increases in cortisol most probably reflects that moderate levels of arousal, as opposed to stressful levels, associated with children's collaboration. Indeed, the results indicated that strong cortisol increases indicative of a stress response to the collaborative task largely influenced this negative relationship (see Figure 4.5 above).

Unlike the Assessment Toy context, the second analysis focused on a social output, dyadic collaboration, and employed a shared arousal measure (i.e. Average

Cortisol Reactivity). The result indicates that socially shared arousal adaptation directly relates to an essential human prosocial behavior, collaboration. Again, this result is consistent with arousal-to-behavior and behavior-to-arousal causal influences. Analogous to the first result, it is likely that children's shared mitigation in arousal increases facilitated their collaborative engagement to complete the toy assembly. But perhaps even more interesting than the first result, this result also suggests that *each child's* collaborative behavior influenced their arousal adjustment. That is, a child's own behavior and that of their partner's may feedback to influence the child's arousal activity. Thus, this result suggests that collaboration, a monumental and possibly even distinctive human behavior (Tomasello et al, 2009), directly relates to shared, moderate arousal states. More dynamic future research ought to vigorously pursue clarifying the causal influences in collaborative social contexts.

Third and lastly, the study obtained some moderately significant support for the notion that differences in cortisol reactivity negatively relate to collaboration. This would suggest that divergences in arousal in some way relate to decreased collaborative behavior. In particular, the result was non-linear and characterized by stronger decreases in collaboration for more extreme differences in cortisol reactivity. Broadly, this coheres with the notion that children's shared arousal adjustments support and relate to their shared collaborative behavior. Large differences in arousal may reflect the disengagement of one or both children from the task. However, this result was only moderately significant and future research should work to confirm or disconfirm this result.

In sum, this study provided important evidence for a physiological mechanistic predictor of young children’s collaboration. The results support the notion that shared moderate levels of arousal adjustment facilitate and relate to children’s dynamic peer collaboration. These results provide a solid foundation on which future research can build to better characterize the causal and social pathways involved in young children’s collaboration.

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CHAPTER 5

COMMENTS ON FUTURE COLLABORATION RESEARCH

The first chapter outlined the significance and basic rationale for examining mechanistic and developmental predictors of children's collaboration. Chapters 2, 3, and 4 presented the results of initial experimental analyses of candidate cognitive, environmental, and physiological predictors. This final chapter summarizes the implications of the analyses for future research and offers some commentary on two important issues for future research of children's collaboration to consider.

Summary of Findings and Future Directions

Cognitive Predictors. The Chapter 2 analyses provided two main results of potential cognitive predictors of children's collaboration. First, the analyses did not provide support that children's collaboration relates to children's developing theory of mind, at least as assessed by a traditional theory of mind scale (Wellman & Liu, 2004). Given the clear intuition that prediction of others' future actions may facilitate coordinating with others' actions, it is advised that future research further explore the relationship between children's social cognition and dynamic collaboration. For example, it may be that measures more closely related to collaboration (e.g. asking about what characters are likely to do in collaborative contexts) are most useful. Another interesting possibility is that children's relative ability to discern and articulate patterns from observing collaborative interactions may support their own ability to collaborate. These future directions are important to explore.

Second, the analyses found both that children increased their collaboration in response to cognitive and physical difficulty, and more competent dyads collaborated more than less competent ones. These findings are consistent with an information gathering perspective in which children's collaboration functions to support children's learning. Specifically, by increasing their collaboration in response to challenges, children can learn to address and collectively overcome challenges that they are less likely to overcome alone. Additionally, competent children are more likely to learn through action than observation of their partner's action. While these results do not prove that collaboration is primarily a function of children's information gathering, they do suggest that children's collaboration has interesting features that may organically support children's active learning. However, future research ought to experimentally confirm whether and how peer collaboration supports children's learning.

Many intriguing questions remain open regarding children's collaborative dynamics and learning. Future research should seek to identify whether particular features of children's collaborative dynamics are predictive of children's learning. As an example, it could be that more balanced collaborative interactions relate most strongly to learning. Relatedly, future research could manipulate children's information gaps to explore how changes may impact children's collaborative dynamics. For instance, it is possible that changing which child is more competent leads to changes in the dyad's collaborative dynamics (e.g. child leads more often during collaborative bouts). These are some of the open, interesting, and fundamental issues for future cognitive collaboration research to explore.

Environmental Predictors. This study found moderate statistical support indicating that low income dyads collaborate less than non-low income ones. However, the study did not find a relationship between collaboration and parental caregiving nor with a more continuous income variable. Interestingly, this finding suggests, but does not prove, that particularly low levels of financial resources impact the development of children's collaborative abilities and/or tendencies, but not less extreme financial circumstances. Future research should target a more balanced income sample in order to more definitively explore this issue.

Moreover, it is not clear how financial backgrounds influence collaboration, but prior research indicates that the causal pathways are likely diverse (e.g. nutritional, parental behavior, crowding, education, etc.). This study employed the Emotional Availability Scale with parental interviews to assess parental caregiving, but did not find any relationship to children's collaboration. It is suggested that future research assess parent-child interactions observationally and employ measures that more closely relate to the contingent, cooperative behavior inherent to peer collaboration. Additionally, future research ought to vigorously explore, in a multidisciplinary fashion, how a diverse and comprehensive set of environmental factors may relate to the collaborative dynamics young children produce.

Cortisol Reactivity. We found support for a link between children's peer collaboration and their arousal adjustment. Specifically, analogous to their independent toy activity, children's average cortisol reactivity exhibited a negative relationship to their collaboration. Thus, the dyads that collaborated more on average exhibited lower increases in cortisol. It is argued that this relationship indicates an association between moderately high cortisol levels and children's collaboration.

Moreover, a moderately statistically significant result suggested that the difference in children's cortisol reactivity negatively related to their collaboration. Interestingly, this would indicate that dyads whose cortisol reactivity did not move in similar magnitudes and/or directions tended not to collaborate as much. Given its relatively weak statistical standing, this latter result must be further investigated by future research to confirm.

These results have significant and interesting implications for both collaboration and arousal research. They indicate that shared arousal adaptation that supports more moderate arousal states may be an important support for children's collaboration. Additionally, it is interesting to consider that having predictably collaborative partners may feedback to facilitate sustaining arousal states. Future research ought to pursue characterizing the arousal-to-collaborative behavior and collaborative behavior-to-arousal influences by employing detailed and dynamic measures of both changing arousal states and each participants' behavior. While cortisol reactivity is a reliable and widely used measure, it may be best coupled with more dynamic measures that can be more closely associated with particular instances of collaboration.

In sum, these findings contribute to the collaboration literature by indicating that engaging states of arousal known to be important in non-social contexts may play an important role in human collaboration. Furthermore, the arousal research community may find that prosocial behavioral dynamics are an interesting and profitable avenue for future research.

Discussion of Prominent Future Issues and Directions

Time Scales of Social Dynamics. One potentially fruitful area for future research to explore concerns the concept of collaboration as a social dynamic. As is noted throughout this report, collaboration is defined as a sequence of coordinated actions by two or more involved agents. This definition implies that collaboration is a certain type of social dynamic. For instance, in this paper the coding and use of lag sequential analysis operationalized collaboration as a contingent social dynamic of children's goal-directed actions during toy assembly. Importantly, it is both possible and plausible that shorter term and longer term dynamics contribute and relate to instances of children's collaboration.

In terms of shorter term dynamics, it is possible that shorter term physical (e.g. limb movement, eye movement, etc.) and physiological (e.g. heart rate, skin conductance, neural processes, etc.) dynamics support collaborative dynamics. For instance, interpersonal eye movement, event-related potential, and heart rate dynamics have been identified during adult social interactions (Schinkel, Marwan, & Kurths, 2007; Tolston, Shockley, Riley, & Richardson, 2014; Wallot, Roepstorff, & Mønster, 2016). The exact role of these "lower order", shorter time-scale dynamics is not yet well understood. However, it is suspected that such non-random interpersonal physical and physiological processes may provide an organizational structure for "higher order", slower social dynamics. As an example, heart rate synchronization (as well as other orderly patterns) commonly occurs as adults converse with one another and participate in collective activities (Fusaroli, Bjorndahl, Roepstorff, & Tylen, 2015; Mønster, Håkonsson, Eskildsen, & Wallot, 2016). This shared physiological regulation may play a role in supporting the social communication. Hence, as an important type of "higher order" social dynamic, collaboration may be similarly supported by "lower order" physical and physiological processes. On the other hand, collaborative behavior may influence and structure "lower level", shorter time-scale processes. Future research ought to vigorously build upon this research by identifying the presence, structure, and significance of shorter time-scale physical and physiological processes during children's collaboration.

While less explored, a similar intuition suggests that instances of collaboration across development may integrate to form longer term social processes and patterns. In particular, prior instances of collaboration between the same individuals may make future collaboration more likely and influence the dynamics of the collaboration (i.e. proportion of action by an individual, likelihood of initiating collaboration, etc.). Over time, such patterns could support the foundation of longer term social processes and structures, such as friendships and social network statuses (Flynn & Whiten, 2012; Schaefer, Light, Fabes, Hanish, & Martin, 2010). Again, as with the shorter term dynamics, it is possible that friendships and social network processes could influence the shorter term collaborative dynamics as well. To be clear, these comments are speculative in nature and meant to present potentially profitable routes for future developmental research to explore.

Predictability vs. Specificity. As discussed and encountered in this study, researchers are finding that developmental processes often involve large numbers of variables that inconveniently track across traditional research domains (e.g. cognitive, nutritional, environmental, sociological, etc.) to influence outcomes (e.g. collaborative behavior, theory of mind, etc.). The number of combinations and ways in which variables may influence outcomes are often immense and simply impractical to pursue via traditional statistical model building and testing. Fortunately, a range of non-traditional statistical data mining techniques (e.g. dimension reduction, various non-parametric analyses, multivariate analyses) that better deal with predicting outcomes based on the input of large numbers of predictors are becoming more and more available (Evans, Li, & Whipple, 2013; Hastie, Tibshirani, & Friedman, 2009). These techniques generally rely upon transforming combinations of the predictors and/or completely doing away with computing specific, static variable parameters. They also often seek to identify relationships between collections of predictors and collections of outcomes instead of a single outcome. While the upside of such techniques is often improved predictability and discovery of important relationships, the downsides are a dramatic loss of specificity as to exactly which variables matter and how they relate to the outcomes. Importantly, developmental researchers desire both predictability and specificity that supports straightforward natural language explanations.

This author believes that the tradeoff between predictability and specificity is a critical issue for future collaboration research, and developmental psychology more generally, to explore and exploit. On the one hand, some researchers may be excited by the opportunity to incorporate novel and powerful analytical techniques to a new domain, such as children's collaboration. The prospect of better predicting a dynamic and complex phenomena like human collaboration is indeed valuable and important. Such techniques are likely to provide important insights on how large numbers of variables collectively influence outcomes. On the other hand, researchers may be skeptical of analytical techniques that do not provide clear results, at least on a variable-by-variable basis, consistent with the traditional language used by developmental researchers. Both of these perspectives contain important considerations and are not necessarily mutually exclusive.

The suggested approach is, in essence, to pursue both more traditional statistical model building as well as more novel data mining techniques. First, researchers ought to educate one another and future participants on useful, less traditional analytical techniques for working with large numbers of variables across time. This will spread knowledge of how and when to apply more novel data mining techniques as well as a better understanding of the limitations of various approaches. Second, in collaboration with statisticians, researchers ought to develop appropriate language for describing and interpreting the effects and implications of non-traditional statistical techniques. This is a critical step and issue for the field to resolve. Without a widely shared interpretive language for researchers, it is not clear that employing novel data mining techniques would be able to effectively provide the benefits to the field that such techniques offer. Third, researchers should not abandon the more traditional model building techniques. Rather, they ought to be employed in parallel with less traditional ones in order to provide specific information on the relevance of variables where possible. In this way, the developmental field will have the best possible chances of achieving the upsides of both the new and old analytical frameworks.

Concluding Thoughts

This study provided an initial assessment of plausible mechanistic and developmental predictors. It did so by applying a multidisciplinary experimental approach and useful analytical tools for examining children's dynamic peer collaboration. As described above and in Chapters 2:4, the results shed some light on important cognitive, environmental, and physiological predictors of children's collaboration. Nonetheless, it is expected that this study represents an initial step in a vigorous, multidisciplinary exploration of mechanistic and developmental predictors of children's collaboration. As is argued throughout this paper, enhancing our knowledge of such predictors would provide a more complete understanding of an important prosocial human behavior that has implications for a variety of applied fields (e.g. education, therapeutics, social work, etc.). It is hoped that the future directions and important issues discussed herein are explored and exploited for the benefit of the academic literature, children, families, educators, and other concerned parties.

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APPENDICES

APPENDIX A: CHAPTER 2 ADDITIONAL TABLES AND FIGURES

Table 2.7

Distribution of Dyadic Competency Score Difference	[0-10]	(10-20]	(20-30]	(30-40]	(40-50]
Number of Dyads	23	16	5	4	2

Table 2.7: This table shows the distribution of the dyadic index of differences in Competency Scores. The difference scores were computed by taking the absolute value of the difference between the two Competency Scores for each dyad.

Table 2.8

Distribution of Dyadic Competency Score Minimum	[0-10]	(10-20]	(20-30]	(30-40]	(40-50]
Number of Dyads	7	7	14	22	9

Table 2.8: This table shows the distribution of the dyadic index of Minimum Competency Scores. The minimum scores were computed by taking the minimum of the two Competency Scores for each dyad.

Table 2.9

Distribution of Dyadic Competency Score Maximum	(10-20]	(20-30]	(30-40]	(40-50]	(50-55]
Number of Dyads	1	1	16	26	6

Table 2.9: This table shows the distribution of the dyadic index of Maximum Competency Scores. The maximum scores were computed by taking the maximum of the two Competency Scores for each dyad.

Table 2.10

Distribution of Number of Boxes per Step	(0.60,1.20]	(1.20, 1.80]	(1.80, 2.40]	(2.40, 3.0]
Number of Dyads	13	0	7	2

Table 2.10: This table shows the distribution of the number of boxes necessary to manipulate per step across all twenty-two steps.

Table 2.11

Distribution of Volume of Boxes per Step	(0.0, 150]	(150,300]	(300, 450]	(450, 600]	(600, 2500)
Number of Dyads	11	3	1	2	5

Table 2.11: This table shows the distribution of the sum volume of the boxes necessary to manipulate per step across all twenty-two steps.

Table 2.12

Distribution of Mass of Boxes per Step	(0.0, 0.50]	(0.50, 1.0]	(1.0, 1.5]	(1.5, 2.0]	(2.0, 10.0)
Number of Dyads	6	9	3	0	4

Table 2.12: This table shows the distribution of the sum mass of the boxes necessary to manipulate per step across all twenty-two steps.

Table 2.13

Distribution of Dyadic Difference in Theory of Mind	[0,2]	(2,4]
Number of Dyads	35	4

Table 2.13: This table shows the distribution of the dyadic index of Difference in Theory of Mind scores. The difference scores were computed by taking the absolute value of the difference between the two theory of mind scores for each dyad.

Table 2.14

Distribution of Dyadic Theory of Mind Minimum	[0,2]	(2,4]	(4,6]
Number of Dyads	19	19	1

Table 2.14: This table shows the distribution of the dyadic index of Minimum Theory of Mind scores. The minimum scores were computed by taking the minimum of the two theory of mind scores for each dyad.

Table 2.15

Distribution of Dyadic Theory of Mind Maximim	[0,2]	(2,4]	(4,6]
Number of Dyads	7	25	7

Table 2.15: This table shows the distribution of the dyadic index of maximum theory

of mind scores. The maximum scores were computed by taking the maximum of the two theory of mind scores for each dyad.

Figure 2.18

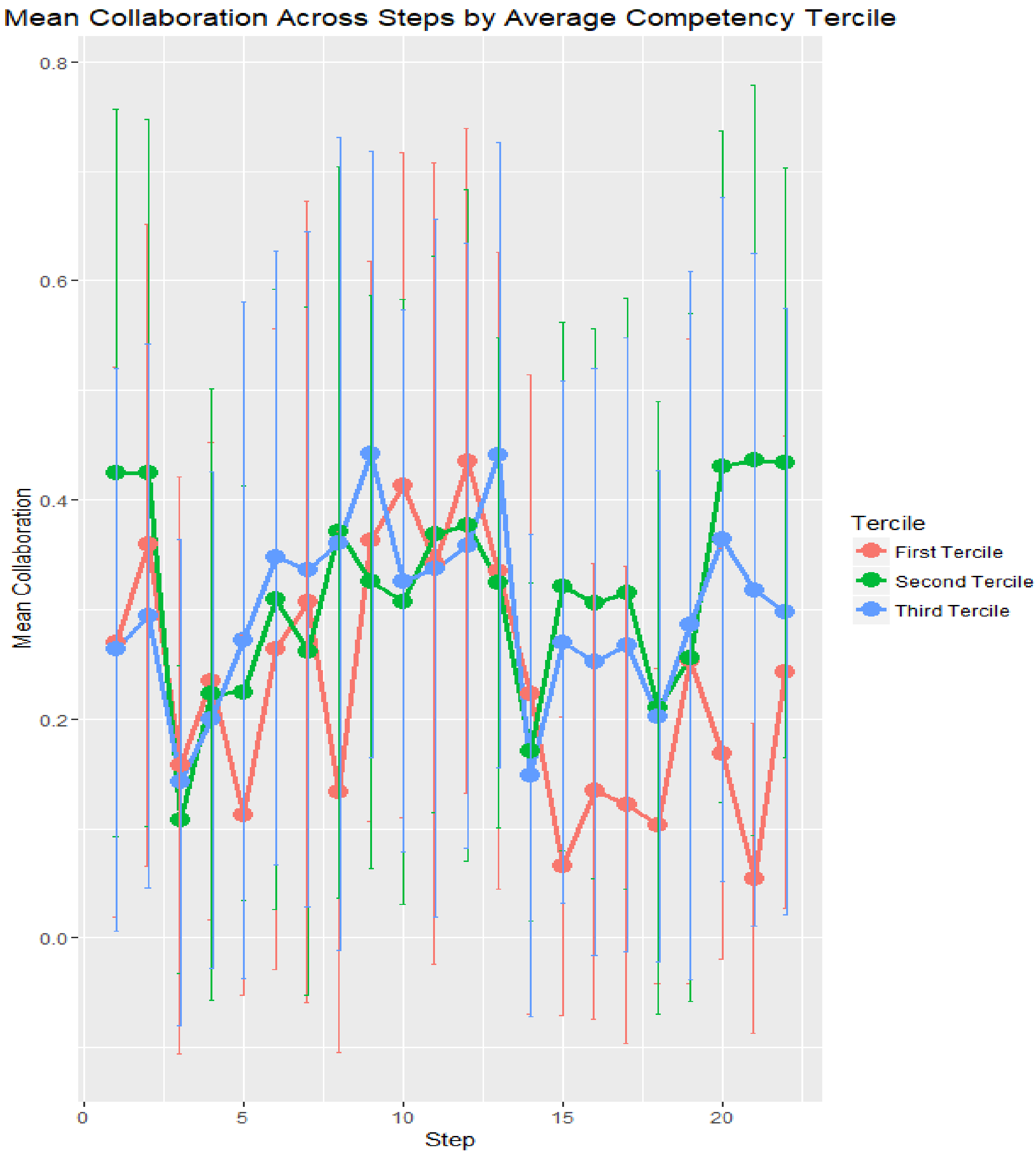

Figure 2.18: This figure complements Figure 2.16 by showing the Average

Competency terciles' mean collaboration rates across the steps. Overall, dyadic Average Competency corresponded to increased collaboration in a multilevel analysis across steps that was continuous (i.e. did not break the sample into competency terciles).

APPENDIX B: CHAPTER 3 ADDITIONAL TABLES AND FIGURES

Figure 3.4

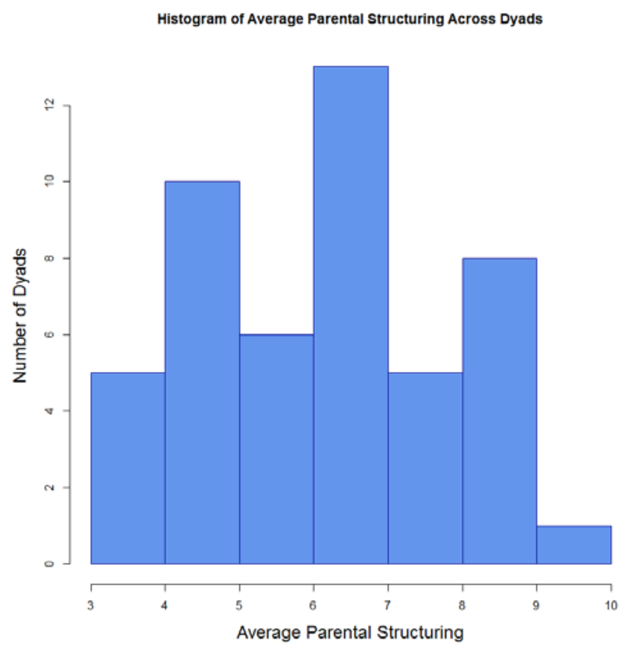

Figure 3.4: This figure depicts the dyadic index of Average Parental Structuring.

Figure 3.5

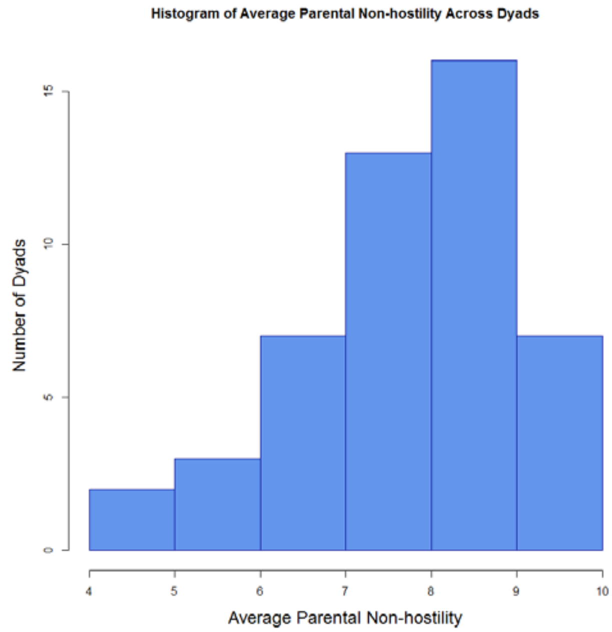

Figure 3.5: This figure depicts the dyadic index of Average Parental Non-hostility.

Figure 3.6

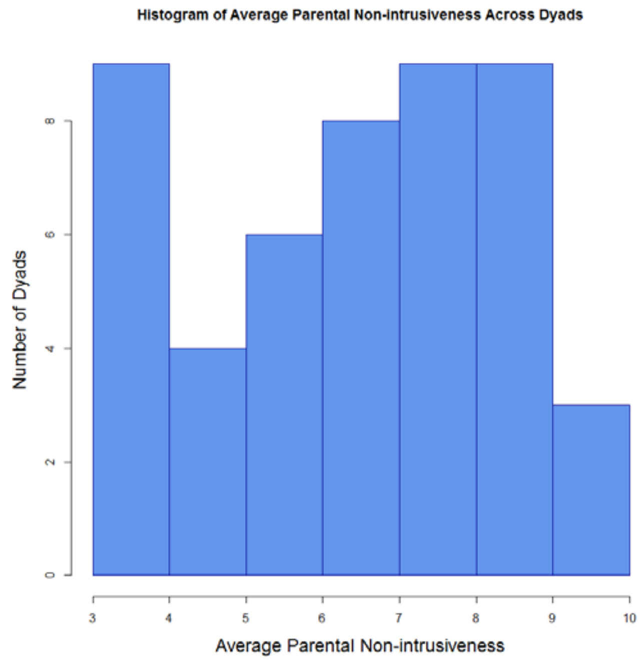

Figure 3.6: This figure depicts the dyadic index of Average Parental Non-intrusiveness.

Figure 3.7

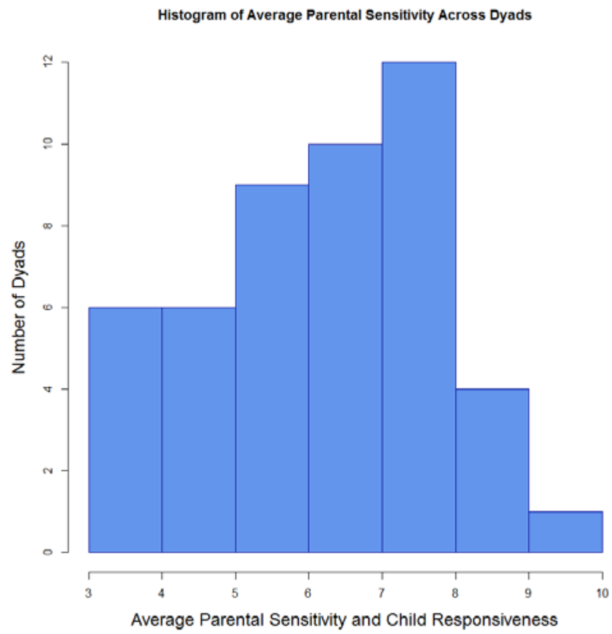

Figure 3.7: This figure depicts the distribution of the dyadic index of Average Parental Sensitivity and Child Responsiveness.

APPENDIX C: CHAPTER 4 ADDITIONAL TABLES AND FIGURES

Figure 4.2

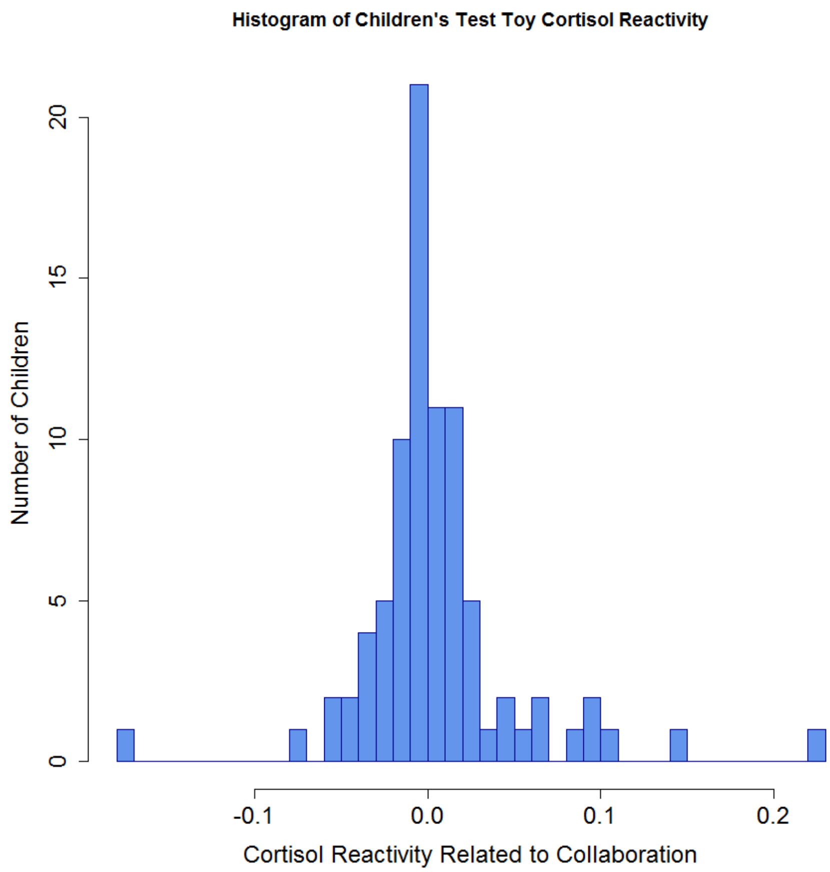

Figure 4.2: This histogram shows the distribution of children's cortisol reactivity to peer collaboration on the Test Toys, herein termed Collaboration Cortisol Reactivity.

Figure 4.4

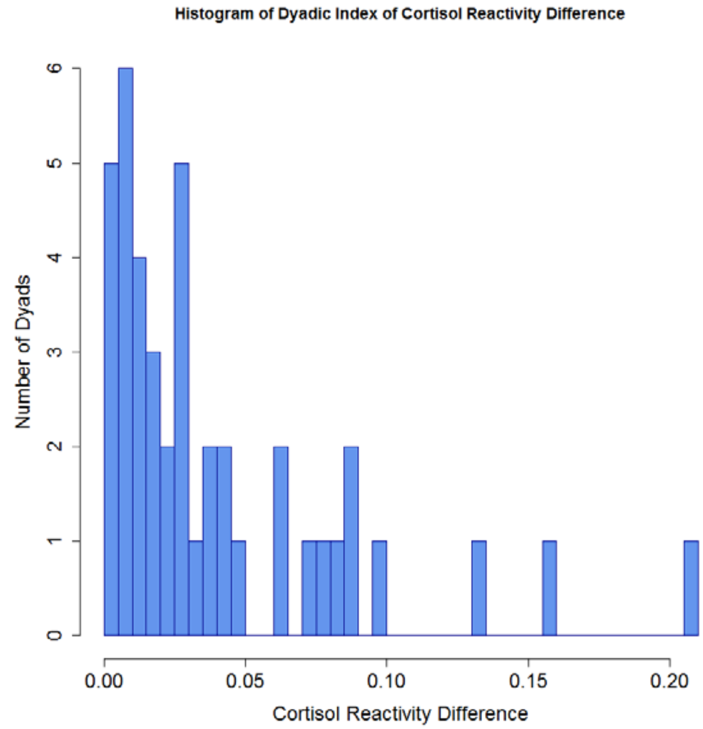

Figure 4.4: This histogram shows the distribution of the dyads' difference in cortisol reactivity, here termed Cortisol Reactivity Difference.

APPENDIX D: RESULTS OF ADDITIONAL ANALYSES

Figure 4.6

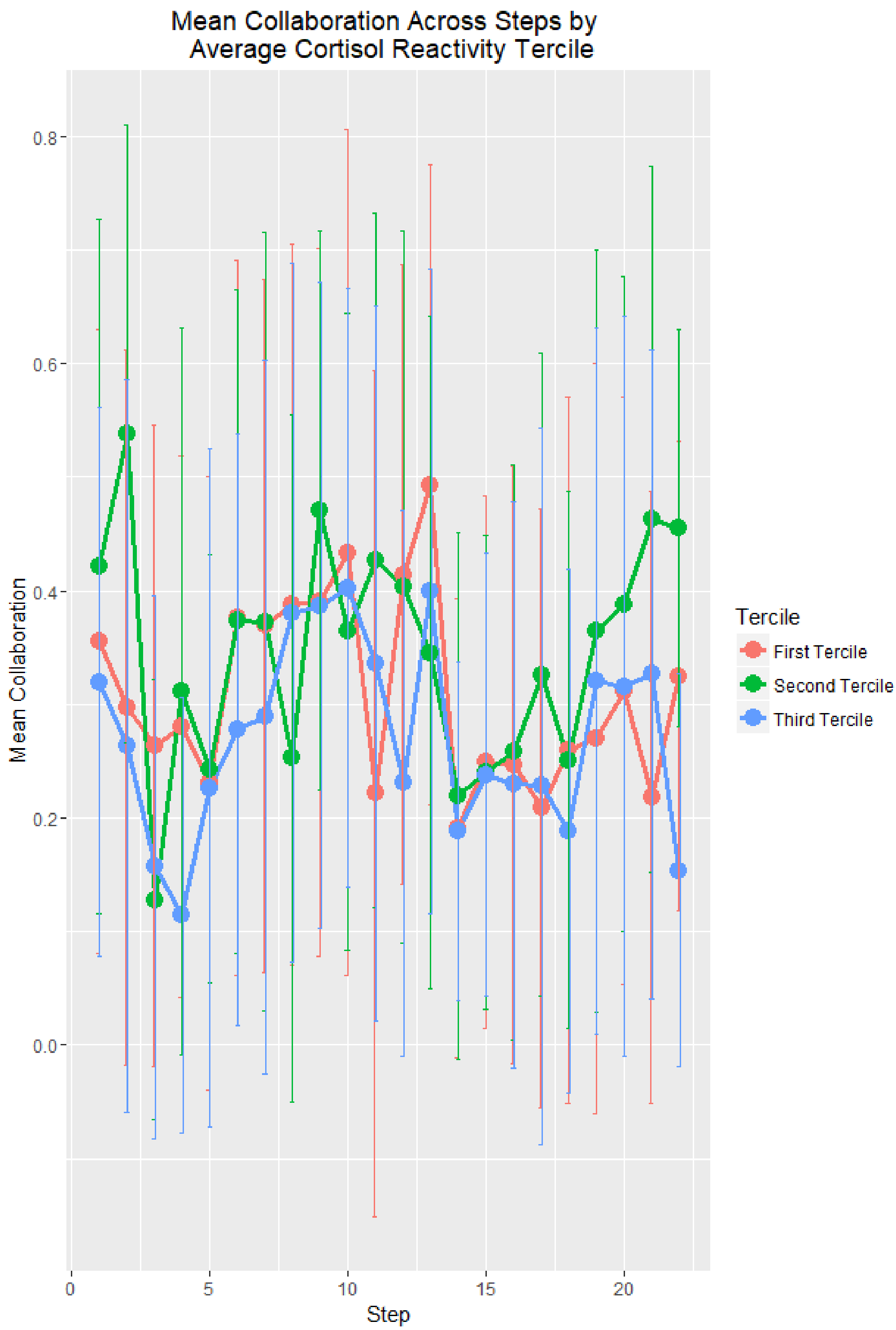

Figure 4.6: This figure complements Figure 4.5 by showing the Average Cortisol Reactivity terciles' mean collaboration rates across the steps. Overall, Average Cortisol Reactivity corresponded to decreased collaboration in a multilevel analysis across steps that was continuous (i.e. did not break the sample into cortisol reactivity factors).

APPENDIX E: ADDITIONAL ANALYSIS OUTCOMES

Table 3.2

Factor (Dyadic Index)	Factor Type	Level	Parameter Estimate	T-Statistic	P-Value
(Average Competency * Average Age)	Cognitive	2	0.0055	0.77	0.43
(Competency Difference * Average Age)	Cognitive	2	0.0063	1.12	0.27
(Average Theory of Mind * Average Age)	Cognitive	2	0.0043	0.75	0.46
(Physical Step Difficulty * SqRt(Step Difficulty))	Cognitive	1	0.0061	0.88	0.38
(Average Cortisol Reactivity * Average Age)	Physiological	2	0.00091	0.16	0.87
(Emotional Availability * Average Age)	Environmental	2	0.0037	0.82	0.41
Average Number in House	Environmental	2	0.0012	0.30	0.76
Average Number of Playmates	Environmental	2	0.0036	0.73	0.49

Table 3.2: This table shows the results of additional factors analyzed in the multilevel modeling framework used to assess relationships with children’s peer collaboration

across the steps. These additional factors were assessed as predictors at the described level and were normalized. None of these analyses indicated statistically significant relationships between the factors and children's collaboration.