A Developmental Cascade Model of Neurocognitive Functioning: Risk, Resilience, and Implications for Children's Mental Health

By

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A thesis submitted in conformity with the requirements for the degree of Doctor of Philosophy
Department of Applied Psychology and Human Development
University of Toronto

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Abstract

Theory of Mind (ToM) and executive functioning (EF) are two neurocognitive abilities that develop rapidly over the preschool period. ToM and EF are highly interrelated, both behaviourally and neurologically, and are predictive of a host of psychosocial outcomes across the lifespan. This dissertation delineates a developmental cascade model of ToM and EF in which key social-cognitive skills in the second year of life are examined as precursors to ToM and EF through their impact on children's nascent language skills. Further, both cumulative social disadvantage and biomedical risk are investigated as risk factors that increase vulnerability to cognitive morbidity over the early years. Finally, it is suggested that these social and biomedical risks are non-deterministic, and that positive postnatal socialization experiences with caregivers may protect children against their deleterious influence. The implications for prevention and intervention will be discussed with the overarching suggestion that early programming may help to mitigate the negative cascading effects of poor early adaptation on later psychosocial health and development.
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General Introduction

Healthy neurocognitive functioning is essential for children’s development, with deficits in neurocognition associated with a wide range of psychosocial impairments across the lifespan (Blair, 2001; Clark, Chamberlain, & Sahakian, 2009; Mesholam-Gately, Giuliano, Goff, Faraone, & Seidman, 2009). Neurocognition is broadly defined as any cognitive ability that is linked to particular brain structures, neural circuits, or cortical networks that, if damaged, would have a deleterious effect on that function. Two neurocognitive abilities that are important for adaptation in childhood include theory of mind (ToM) and executive functioning (EF). ToM is the capacity for representing the mental states (i.e., beliefs, desires, intentions, and emotions) of oneself and others in order to understand human behavior (Astington, 2003). EF describes a collection of skills involved in goal-direct action and problem solving, such as working memory, cognitive flexibility, and inhibitory control (Garon, Bryson, & Smith, 2008). Importantly, ToM and EF are subserved by both distinct and overlapping brain regions (Perner & Aichhorn, 2008; Rothmayr, et al., 2011), show robust behavioral associations across development (Hughes & Ensor, 2007; Milligan, Astington, & Dack, 2007), and are related to a number of functional outcomes, including social adjustment, academic achievement, and mental health (Blair & Razza, 2007; Lysaker, et al., 2014; Robinson, et al., 2014). Thus, ToM and EF are good candidates to index neurocognition in early childhood.

Given the importance of ToM and EF for children’s psychosocial health, and given that these abilities are interrelated both behaviorally and neurologically, we might expect similar mechanisms to be operating in their development. The current dissertation aims to identify a subset of these mechanisms by examining a constellation of biopsychosocial factors hypothesized to support or impede their development. These include early social-cognitive precursors and linguistic mediators of ToM and EF, as well as environmental (e.g. cumulative social disadvantage) and biomedical (e.g. birth weight, maternal pregnancy hypertension) risks for poor neurocognitive functioning. Further, in line with risk-resilience models of development (Jenkins, Madigan, & Arsenault, in press; Luthar, Cicchetti, & Becker, 2000; Masten, Cutuli, Herbers, & Reed, 2009), the protective effect of enriched socialization experiences with caregivers is assessed with respect to a subset of these risks.
In the current dissertation, three related themes are organized across three chapters. Chapter 1 explicates a neurocognitive cascade model in which early emerging social-cognitive skills measured at 18 months are hypothesized as important precursors for later ToM and EF at age 4.5. Fundamental to this chapter is the concept of ‘developmental cascades’. These refer to the cumulative interactional and transactional processes within a developmental system that lead to the distribution of effects across levels, across specific domains at the same level, or across systems (Masten & Cicchetti, 2010). Developmental cascades have assumed many names in the field of developmental psychology, such as chain reactions, snowball or amplification effects, and spillover or progressive influences (Burt, Obradović, Long, & Masten, 2008; Dodge & Pettit, 2003; Hanson & Gottesman, 2007; Lansford, Malone, Dodge, Pettit, & Bates, 2010; Masten & Coatsworth, 1998; Masten, et al., 2005; Rutter, Kim-Cohen, & Maughan, 2006). Several examples of developmental cascades have been advanced in the extant literature, including: genetic influences on disordered phenotypes and psychopathology (Einat & Manji, 2006); the biological embedding of experience, including gene-environment interactions and resultant consequences on endocrine or neurobiological systems (Gunnar & Quevedo, 2007); marital dissolution as a cascade towards divorce (Gottman, 1993); contagion effects of antisocial behaviour within peer groups (Boxer, Guerra, Huesmann, & Morales, 2005); and the intergenerational transmission of behaviour (e.g. parenting, aggression) via genes, experience, or their interaction (Beaver & Belsky, 2012; Conger, Neppl, Kim, & Scaramella, 2003; Shaffer, Burt, Obradović, Herbers, & Masten, 2009).

Thus, ‘developmental cascade’ is a broad term used to describe, either conceptually or empirically through well-designed longitudinal studies, the cumulative downstream consequences of a particular social-environmental risk, prior level of adaptation, or constitutional factor in either supporting or stymieing a discrete ability, process, or condition (Masten & Cicchetti, 2010). Most relevant to Chapter 1 is the notion that competence in one domain of functioning at one period of development promotes skill acquisition in newly emerging domains of competence at later periods of development (Masten & Coatsworth, 1998; Masten & Wright, 2009). Specifically, Study 1 specifies a longitudinal model of ToM and EF development in which early social-cognitive precursors measured at 18 months (joint attention, empathy, cooperation, and self-recognition) are hypothesized to predict ToM and EF at age 4.5. This particular kind of cascade has been variably termed skill formation (Heckman, 2006) or a
positive chain reaction (Rutter, 1999). Moreover, cascade effects may be unidirectional or bidirectional, and direct or indirect through various pathways (Masten & Cicchetti, 2010). The cascade model presented herein tests a series of indirect effects through children’s nascent language skills which, it is argued, provide a crucial cognitive substrate that helps to scaffold later ToM and EF.

Chapter 2 outlines how certain biomedical risks are associated with ToM and EF, with the overarching suggestion that exposure to pre/perinatal complications make children vulnerable to cognitive difficulties owing to their effect on brain development. This may, in turn, perpetuate a downstream sequelae of cognitive morbidity across childhood. Specifically, Study 2 examines whether maternal pregnancy hypertension – a factor known to be associated with in utero development – is associated with lower ToM and EF at ages 3 and 4.5, as well as social cognition at 18 months. Study 3 tests whether birth weight variability (within the normal range) is another biomedical risk associated with ToM and EF at age 4.5. As in the cascade model of Study 1, this study examines whether language has a mediating role in linking birth weight to ToM and EF. The primary argument of Study 2 and 3 is that discrete biomedical risks may create vulnerability to postnatal cognitive difficulties, with language as a significant mediator in this chain of development.

Finally, Chapter 3 investigates how contextual factors moderate the association between biomedical risk and certain neurocognitive abilities contained within the the proposed cascade. Specifically, Study 4 examines whether responsive parenting buffers the association between low birth weight and language ability at age 3, while Study 5 examines whether responsive parenting protects against cumulative biomedical risk on social cognition at 18 months. The focus of Chapter 3 is social cognition at 18 months and language at age 3, as it is argued that these early abilities are important for the development of more sophisticated ToM and EF skills. This is consistent with intervention cascade models which posit that targeting the upstream and/or mediating processes of a given outcome has the potential to interrupt negative cascades and promote positive ones (Cicchetti & Curtis, 2007; Cicchetti & Gunnar, 2008; Masten, Desjardins, McCormick, Kuo, & Long, 2010). In other words, by enhancing the postnatal socialization factors that foster early social cognition and language, it is presumed that negative cascades can
be counteracted, and improvements in early functioning will lead to postliminary advantages in later ToM and EF.

In summary, the current dissertation maps out a cascade model of ToM and EF development. Important components of this model include: (1) the precursory importance of early social cognition for ToM and EF; (2) the role of various social and biomedical risks in creating vulnerability to poor ToM and EF; (3) the mediating role of language in this developmental cascade; and (4) the buffering effect of parental socialization processes on early social cognition and language, which are believed to be important couriers of environmental and biomedical risk. Figure 1 below provides a conceptual summary of these studies. The following Chapters provide a thorough account of the studies delineated above.

**Figure 1.** Conceptual model for all five studies currently included in the dissertation. Numbers reflect the study number (1-5), as outlined in-text. Black boxes represent neurocognitive outcomes, while gray boxes are various risk and protective factors.
It is important to note that the studies presented below were derived from an ongoing project by my supervisor, Dr. Jennifer Jenkins. Two important points deserve attention: First, I was not responsible for the design of the study, choice of measurement, or data collection, as this was a multi-wave longitudinal study that was designed and initiated prior to my joining Dr. Jenkins’ lab. I have been involved in study conceptualization, data analyses, interpretation, and writing/publication for the five studies that make up this thesis, as well as 20 manuscripts that have been published during my PhD. I have been responsible for the development of observational coding schemes, training coders and research assistants, and maintenance and testing of reliability on mother-child interaction measures (in the current dissertation) and sibling interactions (not in the thesis). Second, the projects that make up my thesis built upon one another iteratively. As the coding of constructs was completed in the lab, and as data became available within the framework of a longitudinal study, I was able to use these data. That is, each study was an extension of previous work, and the process was iterative and cumulative.
Chapter 1

1 Study 1: Cumulative risk disparities in children’s neurocognitive functioning: A developmental cascade model

1.1 Introduction

Two important capacities that mature over the preschool period are theory of mind and executive functioning, and these neurocognitive skills are associated with a range of school-age outcomes, including academic ability (Blair & Razza, 2007; Hughes & Ensor, 2011), social competence (Razza & Blair, 2009), behavioral difficulties (Hughes & Ensor, 2008; Olson, Lopez-Duran, Lunkenheimer, Chang, & Sameroff, 2011), and emotional, hyperactive, conduct, and peer problems (Hughes & Ensor, 2008; 2011). Theory of mind (ToM) is the capacity for mentalization – the ability to understand behavior in terms of the underlying mental states that guide others’ actions, such as beliefs, emotions, desires, and intentions. Executive functioning (EF) refers to the cognitive processes that facilitate goal-directed action and problem solving, such as working memory, cognitive flexibility, inhibition, planning, and self-monitoring (Garon, et al., 2008). EF is important for the conscious, effortful control of thoughts and behavior (Oh & Lewis, 2008). The goal of the current study was to examine whether there are cumulative risk disparities in ToM and EF across early childhood, and whether a particular mechanism of ToM and EF development can be differentiated on the basis of children’s social risk status.

1.1.1 Social disadvantage in children’s neurocognitive development

Contextual and social-environmental factors have been shown to be influential in the development of ToM and EF. For instance, socioeconomic status (SES) has been independently linked to both ToM (Cole & Mitchell, 1998; Cutting & Dunn, 1999) and EF (Noble, McCandliss, & Farah, 2007; Noble, Norman, & Farah, 2005; Sarsour, et al., 2010), with the overarching suggestion that socioeconomic deprivation may impinge on healthy neural development and thus compromise neurocognitive functioning (Noble, Houston, Kan, & Sowell, 2012). Recent findings of a shared cortical architecture between ToM and EF (Rothmayr, et al., 2011) support
the idea that the deleterious effects of psychosocial stress on brain development may function similarly for these cognitive outcomes. However, few studies have examined the socioeconomic correlates of both ToM and EF simultaneously. In one notable study by Noble and colleagues (2005), large and stable differences were found between low- and middle-SES children on a battery of EF tasks ($d = .68$), whereas deficits in ToM performance in low-SES children only trended towards significance. However, since the age of participants in their study (mean of nearly 6 years) represents a stage of sophisticated ToM reasoning, the presence of unintended ceiling effects could account for this lack of association. More research into the role of socioeconomic and social stress on ToM and EF, as well as the cognitive precursors of these abilities, is needed.

It is important to emphasize that, although SES is most commonly measured using indicators such as education, income, and parental occupation (Ensminger & Fothergill, 2003; Farah, et al., 2006), these factors do not capture the full extent of risk exposure for children. Other critical social constructs such as quality of the home environment, neighbourhood factors, parental mental illness, and abuse history also vary systematically with SES and have been shown to predict children’s developmental outcomes (Burchinal, Vernon-Feagans, Cox, & Investigators, 2008). In fact, these social risks tend to cluster together, with the presence of one risk substantially increasing the likelihood of other co-occurring risks. Consequently, treating risks in isolation may under-represent children’s risk exposure (Dong, et al., 2004). Cumulative risk indices have been constructed to test the idea that development is affected by the accumulation of environmental risks rather than the level of a single and specific risk (Evans, Li, & Whipple, 2013). There is evidence that these indices are useful for relating social risk to developmental patterns (Burchinal, Roberts, Hooper, & Zeisel, 2000), and they also explain more variance in child outcomes than any single factor (Flouri & Kallis, 2007).

Building on previous studies showing that independent socioeconomic factors are associated with ToM and EF, the current study aimed to examine whether there are cumulative risk disparities in these neurocognitive abilities. Further, we aimed to determine whether a specific mechanism of ToM and EF development differed for advantaged versus disadvantaged children. In particular, we tested a developmental cascade model wherein children’s emergent social cognition at 18 months was hypothesized to predict ToM and EF in the preschool period through
intermediary receptive language skills. *Cascade* in this regard is operationalized as the unfolding of key cognitive abilities over time, emerging from, or dependent on, earlier abilities which support their development. This mechanism is outlined in detail below.

### 1.1.2 A mechanism of ToM and EF development: social cognition as a precursor

One capacity that emerges early in development and may serve to support later ToM and EF is *social cognition*, broadly defined as the cognitive abilities that support social behavior. Social cognition undergoes rapid development at around 18 months (Nielsen & Dissanayake, 2004; Warneken et al. 2006), at which point a host of ‘precursor’ abilities are observed in children, including joint attention (Charman, et al., 2000), empathy (Seyfarth & Cheney, 2013), cooperation (Dunn, Brown, Slomkowski, Tesla, & Youngblade, 1991; Perner, Ruffman, & Leekam, 1994), and self-recognition (Gallup, 1998). Recent theoretical models suggest that children’s nascent capacity for self-other differentiation and intention understanding may be key faculties underlying the execution of these social-cognitive behaviors in the second year of life (Knoblich & Sebanz, 2008; Moore, 2007). Indeed, previous studies have shown that these four competencies – joint attention, empathy, cooperation, and self-recognition – form a coherent construct that can be used to represent children’s latent social cognition at 18 months (Wade, Hoffmann, & Jenkins, 2014; Wade, Moore, Astington, Frampton, & Jenkins, 2014).

Supporting the link between early social cognition and later ToM is evidence from several longitudinal studies showing that intention understanding measured in the first two years of life is associated with later forms of social reasoning, such as false belief understanding (Csibra & Gergely, 1998; Wellman, Lopez-Duran, LaBounty, & Hamilton, 2008; Yamaguchi, Kuhlmeier, Wynn, & VanMarle, 2009). Alternatively, social cognition as a precursor to later EF has garnered relatively less attention. However, Perner and colleagues (Perner & Lang, 1999; 2000; Perner, Stummer, & Lang, 1999) make the argument that understanding the causal effect of mental states is required to exert executive control over interfering or unwanted action tendencies. Although scarcer, recent evidence is accruing which suggests that early social-cognitive abilities may also be related to later EF. For instance, Hughes and Ensor (2007) showed that elements of social cognition at age 2, such as understanding deception and pretend play, predicted EF at age 4 over and above the effects of age, verbal ability, and social
disadvantage. Moreover, Müller et al. (2012) recently demonstrated an association between social-cognitive precursors at age 2 and EF ability at age 4. Further, these authors demonstrated that this relationship was fully mediated by children’s language ability at age 3. However, no study has examined whether social-cognitive precursors such as joint attention, empathy, cooperation, and self-recognition are longitudinally associated with both ToM and EF simultaneously, nor the mediational role of language in these pathways.

1.1.3 Language as a mediator between early social cognition and later ToM and EF

Longitudinal evidence suggests that early language is predictive of later ToM (Astington & Jenkins, 1999) and EF (Hughes & Ensor, 2007). For ToM, language acquisition may facilitate the internalization of multiple perspectives that come about through interpersonal exchanges, and it is the accommodation of these various perspectives that affords children the ability to represent and reason about others’ mental states (Fernyhough, 2008; Vygotsky, 1997). Similarly, for EF, language may instigate a reformulation of cognitive activity in which children achieve control over thoughts and behaviours by internalizing words and semiotic cues that previously functioned to control the behaviour of others, or were otherwise used to regulate the child’s behaviour (Fernyhough et al., 2009). From this perspective, language serves the purpose of fostering the internal, verbal representation of mental states required for ToM (Astington & Baird, 2005), and the capacity for verbal self-regulation that underlies EF (e.g. Müller, Jacques, Brocki, & Zelazo, 2009). Moreover, it may be the case that early social cognition itself facilitates language development by recruiting children into rich communicative exchanges that afford them the linguistic material required for verbal reasoning, reflection, and private speech that supports more advanced ToM and EF abilities (Carpendale & Lewis, 2004; 2010; Hammond, Müller, Carpendale, Bibok, & Liebermann-Finestone, 2012; Lewis & Carpendale, 2009).

1.1.4 Summary and goals of the current study

The goals of the current study were three-fold: (1) to examine cumulative risk disparities in children’s ToM and EF during early development; (2) to map out a developmental cascade model in which social cognition at 18 months (joint attention, empathy, cooperation, and self-recognition) was hypothesized to predict ToM and EF at age 4.5 through children’s receptive language ability at age 3; and (3) to determine whether this cascade mechanism varied as a
function of social risk status. In testing this model, it is important to control for two other pathways suggested by the literature. First, intermediary levels of ToM and EF may play a role in their own development. For instance, early social cognition may relate to later EF through intermediary levels of EF, rather than language specifically. This proposal may be intuitive if we expect early skills to predict later skills of the same kind (e.g. Colonnesei, Rieffe, Koops, & Perucchini, 2008). Here, we refer to this as the ‘previous skills’ pathway. Second, there is evidence that ToM and EF reciprocally predict one another longitudinally (Carlson, Mandell, & Williams, 2004; Hughes & Ensor, 2007; McAlister & Peterson, 2012; Müller, Lieberman-Finestone, Carpendale, Hammond, & Bibok, 2012), making it important to account for so-called ‘reciprocal effects’ pathways (EF to later ToM, and vice versa). Thus, the current study aimed to elucidate whether receptive language per se represents a key pathway through which early social cognition influences later ToM and EF while controlling for pathways related to previous skills and reciprocal effects. This conceptual model is presented in Figure 2. On the basis of previously documented socioeconomic disparities, we did expect the pathways from social cognition to later ToM and EF to differ for children in low and high risk circumstances; however, with an absence of literature, we did not make explicit hypotheses about how the specific paths would vary.

1.2 Method

1.2.1 Participants

Participants came from the intensive sample of the Kids, Families, Places Study (iKFP; http://kfp.oise.utoronto.ca/). All women giving birth in Toronto and Hamilton, Ontario, between April 2006 and September 2007 were considered for participation. Families were recruited through a program called Healthy Babies Healthy Children. Parents of all registered newborns were contacted within several days of the child’s birth. Inclusion criteria for the iKFP study (which involved a sibling design longitudinal follow-up and intensive observational measurement) included the presence of an English-speaking mother, a newborn >1500 grams, at least two children who are < 4 years, and families agreeing to be filmed in the home. The University of Toronto Research Ethics Board approved all procedures for this investigation, including informed consent.
At study entry, the iKFP sample \((N=501)\) was compared to the general population of Toronto and Hamilton using 2006 Census Data, limiting the census to women between 20-50 years and having at least one child. Families were compared on immigrant status, number of persons in the home, family type, maternal personal income, and educational level. Based on these comparisons, iKFP was similar to the general population on family size \((M = 4.52, SD = 1.01\) vs. \(M = 4.13, SD = 1.22\)) and personal income \((C$30,000-39,999 vs. census population mean = C$30,504.16, SD = C$37,808.12)\). Since our sample was recruited shortly after childbirth, there
were predictably fewer non-intact families than in the general population (5% vs. 16.8% lone-parent families; 4.3% vs. 10.3% stepfamilies). The ratio of Canadian-born to immigrants was somewhat higher in the iKFP sample (57.7% vs. 47.6%), likely due to the language requirement for participation. Also, more study mothers had earned a bachelor’s degree or higher (53.3% vs. 30.6%). Of participating mothers, 56.5% identified as being of European descent, 14.6% as South Asian, 9.2% as Black, 12.0% as East Asian and 7.7% as other. Sample demographics at study entry are presented in Table 1.

Table 1. Demographics of sample at study entry

<table>
<thead>
<tr>
<th>Measure</th>
<th>N</th>
<th>% of sample</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ethnicity of mothers</td>
<td></td>
<td></td>
</tr>
<tr>
<td>European/Caucasian</td>
<td>283</td>
<td>56.5</td>
</tr>
<tr>
<td>South Asian</td>
<td>73</td>
<td>14.6</td>
</tr>
<tr>
<td>East Asian</td>
<td>60</td>
<td>12.0</td>
</tr>
<tr>
<td>Black</td>
<td>46</td>
<td>9.2</td>
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<tr>
<td>Other</td>
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<td>7.7</td>
</tr>
<tr>
<td>Teen mom</td>
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<td>6.2</td>
</tr>
<tr>
<td>Single parent family</td>
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<td>6.4</td>
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<tr>
<td>New-immigrant family (&lt;10 years)</td>
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<td>29.1</td>
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<tr>
<td>Low income family (&lt;$20,000)</td>
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<td>9.5</td>
</tr>
<tr>
<td>Mother’s years of education (&lt;high school)</td>
<td>34</td>
<td>6.2</td>
</tr>
<tr>
<td>Mothers scoring in depressed range on CESD</td>
<td>71</td>
<td>14.4</td>
</tr>
</tbody>
</table>

Note. Total sample at wave 1, N =501

Of participating families, 74.1% of families were 2 child families, 18.8% were 3 child families, and the remaining 7.2% had 4 or more children. At Time 1 (T1; \(M_{age} = 2.0 \) months; SD = 1.06), 501 families were enlisted in the study. Due to sample attrition, 397 (79.2%) families were followed up at Time 2 (T2; \(M_{age} = 1.60 \) years; SD = .16), 385 (76.8%) were followed up at Time 3 (T3; \(M_{age} = 3.15 \) years; SD = .27), and 323 (64.5%) were followed up at Time 4 (T4; \(M_{age} = 4.79 \) years; SD = .28). The current study drew on data from all time points in order to test the
study hypotheses. Attrition analysis showed that family dropout was related to lower maternal age at first pregnancy, \( t(494) = -5.10, p < .001 \), lower socioeconomic status, \( t(498) = -5.07, p < .001 \), and lower maternal education, \( t(498) = -2.99, p < .005 \). Moreover, for outcome measures between 18 months and 4.5 years, there were variable levels of missing data due to child noncompliance, lack of visibility (e.g., child went off camera), parent intrusion (e.g., directing child), non-administration due to family constraints (e.g., time limitations) or tester administration error (e.g., not following the standardized protocol). Table 2 shows how many participants contributed data to each of the measures across time points.

1.2.2 Procedure

At each time point, a home visit of approximately two hours involved questionnaires pertaining to demographics, family life, and child behaviour. Direct measurement of child behaviour was also assessed using age-appropriate standardized and/or observational tasks.

1.2.3 Measures

Social cognition. Social cognition was measured at T2 (18 months) by four independent observational tasks assessing children’s joint attention, empathy, cooperation, and self-recognition. Each of these tasks was previously validated and widely used in laboratory studies, and we adapted these for use in the home interviews. A complete description of these tasks can be found in Supplementary Material. Briefly, in the joint attention task children were required to respond to an adult interviewer’s bids for directing their attention (Mundy et al., 2003); in the empathy task (Kochanska et al., 1994) children were tasked with responding to the feigned distress of the interviewer; in the cooperation tasks (Warneken et al., 2006) children needed to work collaboratively with the interviewer towards a shared goal; and in the self-recognition task, children were assessed for their ability to recognize the objectivity of their body using the mirror-rouge paradigm (Amsterdam, 1972). Inter-rater reliabilities across tasks were: \( \alpha = 0.94 \) for joint attention, \( \alpha = .82 \) for empathy, \( \alpha = .86 \) for cooperation, and \( \kappa = 0.79 \) for self-recognition. Scores on these measures were submitted to a confirmatory factor analysis (CFA), consistent with their theoretical coherence and position as precursors to ToM (Wade et al., in press). In accordance with the recommended cut-offs of Hu and Bentler (1999), fit indices were excellent for the latent social cognition factor: root-mean-square-error of approximation (RMSEA) = .023, comparative
fit index (CFI) = .99, and standardized root-mean-square residual (SRMR) = .021. Model-estimated loadings were also positive and significant at the $p < .001$ level for all manifest variables. Factor scores were saved and used as explanatory predictor variables in the subsequent path analysis.

**Executive functioning.** This was assessed at both T3 (3 years) and T4 (4.5 years) using two previously developed and widely used tasks that were appropriate to the age of the child. At T3 this consisted of Grass/Snow (Carlson & Moses, 2001) and Bear/Dragon (Reed, Pien, & Rothbart, 1984); and at T4 this consisted of Bear/Dragon and the Dimensional Change Card Sort (DCCS; Zelazo, 2006). The Grass/Snow task is a Stroop-like task in which the children were instructed to point to a green color chip when the experimenter said the word “snow” and to a white color chip when the experimenter said “grass.” The score was a total of correct responses on 16 total trials. For the Bear/Dragon task, children were instructed to do what they were told by the nice bear (e.g., “touch your nose”), but not to do what they were told by the mean dragon. Children were scored for total number of compliance (0–10) on five dragon and five bear trails. For the DCCS, children were required to sort a series of bivalent test cards, first according to one dimension (e.g., color), and then according to the other (e.g., shape). Children who pass the post-switch phase of the standard version of the DCCS may proceed immediately to the border version, which uses the same target cards as the standard version. The border version consists of 12 trials. Children are required to sort cards based on “border” criteria (“If there’s a border, play the color game. If there’s no border, play the shape game”). Previous studies have shown that the Grass/Snow, Bear/Dragon, and DCCS all load onto the same latent factor measuring set shifting, working memory, and inhibitory control (Bernier, Carlson, Deschênes, & Matte-Gagné, 2012).

In the present study, T3 Grass/Snow and Bear/Dragon were significantly correlated, $r(309) = .28$, $p < .001$; and at T4 Bear/Dragon and DCCS were significantly correlated, $r(299) = .34$ $p < .001$. Thus, at each time point the two tasks were z-scored and combined into a composite EF variable. Higher scores represented better EF ability.

**Theory of mind.** This was assessed at T3 and T4 using the scale described by Wellman and Liu (2004). This scale presents various tasks in a sequential format that map closely onto the development of children’s theory-of-mind understanding. As children move through the scale, tasks become conceptually more difficult. Thus, progression further along the scale reflects more
sophisticated theory-of-mind understanding. The first three tasks assessed children’s understanding of diverse desires and beliefs, and knowledge and ignorance. This is followed by tasks that assessed more sophisticated ToM understanding such as belief-based emotion, and real-apparent emotion. If children failed two consecutive tasks on the scale, testing was stopped. For all ToM tasks, stories were enacted for children with the use of puppets and props. For each of the tasks, the child is given a score of 0 (fail) or 1 (pass). A total score across all tasks was computed, with higher scores representing higher ToM ability. Internal consistency was high at T3 ($\alpha = .85$) and T4 ($\alpha = .87$).

Receptive language. At T3, the Peabody Picture Vocabulary Test (PPVT; Dunn & Dunn, 1997) was used to assess children’s receptive vocabulary skills. This standardized measure is suitable for children aged 2 years and above, and as a result could not be used at previous time points in the current study. The PPVT has been shown to have good reliability and validity (Dunn & Dunn, 1997). We focused on receptive language, as this has been widely associated with children’s ToM and EF in the preschool period (Fuhs & Day, 2011; Hughes & Ensor; 2005; Müller et al., 2012; Perner, Lang, & Kloo, 2002).

Cumulative risk index. A collection of 8 psychosocial risk factors known to be associated with children’s cognitive and socio-emotional functioning were measured at T1. In the initial home visit, a trained interviewer collected information on risk factors via maternal self-report and direct observation. Risk factors consisted of caregiver factors such as history of maltreatment and depressive symptomatology; household factors such as family structure (intact versus non-intact), availability of books and toys, and household order based on the HOME scale; sociodemographic factors such as low parental education and immigrant status; and neighborhood factors such as social cohesion and trust. A full description of each measure is in Supplementary Materials. A recent review concluded that the specific risks included in these indices do not seem to matter much, and it is instead the extent of exposure that is important (see Evans et al., 2013 for a review). Measured risk factors were either naturally categorical, dichotomized based upon informative cut-points, or continuous. For continuous variables, a cut-point was identified as close as possible to the most extreme 15% of the distribution towards the risky or adverse pole. This would correspond to $+1$ standard deviation above or below the mean, based on the normal distribution. This dichotomization of risks is the typical manner in which
cumulative risk indices are constructed (Rutter, 1979; Sameroff, Seifer, & McDonough, 2004). An average of the dichotomized risk factors (0 = low risk; 1 = high risk) was computed rather than a sum score to account for the bias in a sum score that could result from potential missing data. The sample was then split at the median (50th percentile) into low or high risk. Individuals with scores at the median were assigned to the low risk group. This resulted in a low-risk group of 281 individuals (56.1% of the total sample) and a high-risk group of 220 individuals (43.9%).

1.2.4 Analytic Plan

To test the developmental cascade model, path analysis was carried out using Mplus 7.0 (Muthén & Muthén, 1998-2012) to examine total, direct, and indirect effects from social cognition at 18 months to ToM and EF at age 4.5 through receptive language, executive, and mentalization skills at age 3. These three abilities will be referred to as ‘mediators’ throughout the paper. The total effect (c path) tests the association between social cognition at 18 months and ToM/EF at 4.5 years without inclusion of any mediators. The direct effect (c’ path) is the effect of social cognition on ToM/EF at 4.5 years after inclusion of the mediator(s). The indirect effect (ab path) is the effect of social cognition on ToM/EF at 4.5 years through the hypothesized mediator. Three indirect paths were tested for each of ToM and EF at age 4.5: through receptive language, executive (EF), and mentalization (ToM) abilities at age 3 (see Figure 2). This method enabled us to determine the specificity of each of these potential mediators of cognitive functioning by accounting for all other plausible indirect paths. All indirect effects were tested using the delta method (Sobel, 1982), which calculates the standard error of the product of two variables that can then be used to determine the significance of the indirect path. This method is used to obtain standard errors and confidence intervals of parameters in path analysis (Raykov & Marcoulides, 2004). We report standardized effects. All analyses controlled for children’s concurrent age and gender.

To handle variable amounts of missing data, full information maximum likelihood estimation (FIML) was utilized. This method offers improvements over traditional approaches such as listwise deletion, pairwise deletion, and imputation with regard to parameter bias, model convergence, and model fit (Acock, 2005; Enders & Bandalos, 2001). FIML can handle up to 50% missing data without biasing the estimates (Graham & Schafer, 1999), although none of the variables in the current study showed this level of missingness. The estimator used was
maximum likelihood with robust standard errors (MLR), which generates parameter estimates with standard errors that are robust to non-normality (Muthén & Muthén, 2010).

To examine the effect of cumulative social risk on neurocognitive development, all neurocognitive skills were converted to z-scores. Significant differences were tested by examining non-overlapping confidence intervals and the standardized mean difference \( (d) \) across groups. Finally, we applied a multi-group analysis to the specified path model in order to examine model differences across low and high cumulative risk groups. As noted above, we did not make \textit{a priori} hypotheses about which paths would differ between groups; instead, we evaluated this empirically by initially constraining the parameter estimates across the two groups to equality, and then systematically freeing parameters based on recommended modification indices. Unconstrained paths across the two groups were tested for significant differences by creating new parameters representing these differences, thereby enabling the derivation of associated \( p \)-values across parameters (Muthén & Muthén, 2010). Also, chi-square difference testing was used in order to determine whether the model with freed parameters offered an improvement in model fit over the model with all parameters constrained across groups (Satorra & Bentler, 2001). Together, these tests give an indication of path differences across low and high risk groups (i.e., moderation).

1.3 Results

1.3.1 Descriptive statistics and mean differences across risk groups

Descriptive statistics for the entire sample, as well as the low and high cumulative risk groups independently, are provided in Table 2. Mean comparisons in neurocognitive skills between the low and high risk groups are also presented in Table 2, and can be viewed graphically in Figure 3. Group differences were observed for children’s social cognition at T2, receptive language at T3, and ToM and EF at T4, with the high risk group having significantly lower scores across all cognitive domains. Modest group differences emerged for ToM, but not EF, at T3. As seen in Figure 3, group differences appeared to increase in strength over time, with relatively larger differences observed between groups as children got older.
Table 2. Descriptive statistics and mean comparisons for low and high risk groups

<table>
<thead>
<tr>
<th>Measure</th>
<th>Total sample</th>
<th>Low Risk</th>
<th>High Risk</th>
<th>Standardized Mean Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M</td>
<td>SD</td>
<td>N</td>
<td>M</td>
</tr>
<tr>
<td>Cumulative risk (T1)</td>
<td>.20</td>
<td>.18</td>
<td>501</td>
<td>.06</td>
</tr>
<tr>
<td>Social cognition (T2)</td>
<td>.00a</td>
<td>.14</td>
<td>373</td>
<td>.10a</td>
</tr>
<tr>
<td>Language (T3)</td>
<td>94.8</td>
<td>15.5</td>
<td>304</td>
<td>97.0</td>
</tr>
<tr>
<td>Theory of mind (T3)</td>
<td>1.38</td>
<td>.90</td>
<td>361</td>
<td>1.45</td>
</tr>
<tr>
<td>Executive function (T3)</td>
<td>-.01a</td>
<td>.81</td>
<td>356</td>
<td>.04a</td>
</tr>
<tr>
<td>Theory of mind (T4)</td>
<td>3.68</td>
<td>1.53</td>
<td>301</td>
<td>3.91</td>
</tr>
<tr>
<td>Executive function (T4)</td>
<td>.00a</td>
<td>.82</td>
<td>311</td>
<td>.10a</td>
</tr>
</tbody>
</table>

*aValues are either saved factor scores or z-scores with a mean of zero and standard deviation of one.
This was especially true of ToM and EF, in which group differences became more differentiated from T3 to T4 for ToM ($\Delta d_{T4-T3} = .19$) and EF ($\Delta d_{T4-T3} = .15$). Zero-order correlations between study variables are presented in Table 3. For the interested reader, we present the relation of individual risks within the cumulative risk index with each of the outcomes in the Supplementary Materials.

### 1.3.2 Cascade model for the entire sample

The path model for the entire sample (not split by risk group) can be seen in Figure 4. Model fit for the specified path model was adequate per the recommendations of Hu and Bentler (1999): RMSEA = .075, CFI = .92, and SRMR = .04. As seen in Figure 4, social cognition at T2 was a

![Figure 3](image-url)
Table 3. Bivariate associations between study variables

<table>
<thead>
<tr>
<th>Measures</th>
<th>1.</th>
<th>2.</th>
<th>3.</th>
<th>4.</th>
<th>5.</th>
<th>6.</th>
<th>7.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Child age</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Female gender</td>
<td>-.01</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Social cognition (T2)</td>
<td>.40***</td>
<td>.15'</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Executive functioning (T3)</td>
<td>.25***</td>
<td>.05</td>
<td>.21**</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. Theory of mind (T3)</td>
<td>.09†</td>
<td>.06</td>
<td>.11†</td>
<td>.25***</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. Language (T3)</td>
<td>.06</td>
<td>.09†</td>
<td>.21**</td>
<td>.23***</td>
<td>.25***</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>7. Executive functioning (T4)</td>
<td>.24***</td>
<td>.01</td>
<td>.21**</td>
<td>.15*</td>
<td>.13*</td>
<td>.33***</td>
<td>-</td>
</tr>
<tr>
<td>8. Theory of mind (T4)</td>
<td>.23***</td>
<td>.16**</td>
<td>.12†</td>
<td>.17**</td>
<td>.18**</td>
<td>.29**</td>
<td>.33***</td>
</tr>
</tbody>
</table>

† p < .10. †† p < .05. ††† p < .01. *** p < .001

Note. Age correlations are concurrent with the given neuropsychological skill.

significant predictor of receptive language ability at T3, \( \beta \) (SE) = .20 (.07), \( p = .003 \), but not ToM at T3, \( \beta \) (SE) = .10 (.07), \( p = .16 \). There was a marginal association between social cognition and ToM at T4 \( \beta \) (SE) = .13 (.07), \( p = .06 \). Social cognition was marginally associated with EF at both T3, \( \beta \) (SE) = .12 (.06), \( p = .06 \), and at T4, \( \beta \) (SE) = .15 (.06), \( p = .01 \). As hypothesized, receptive language ability at T3 was significantly associated with both T4 ToM, \( \beta \) (SE) = .23 (.07), \( p = .001 \), and T4 EF, \( \beta \) (SE) = .33 (.08), \( p < .001 \). Stability in ToM and EF from T3 to T4 was modest and non-significant once all other effects in the model were controlled, despite the significant bivariate associations revealed in Table 3. Neither ToM nor EF at T3 were predictive of each other at T4, though there was a trend for T3 EF predicting T4 ToM, \( \beta \) (SE) = .12 (.07), \( p = .08 \).

1.3.3 Total, direct, and indirect effects from T2 social cognition to T4 EF and ToM

Total, direct, and indirect effects from T2 social cognition to T4 EF and ToM are presented in Table 4. For the entire sample (not split by risk group), the total effect of T2 social cognition on T4 EF (i.e., with no mediators in the model) was significant, \( \beta \) (SE) = .22 (.06), \( p < .001 \). This effect was reduced, but remained significant, upon inclusion of the mediators, \( \beta \) (SE) = .15 (.06),
$p = .012$, suggesting partial mediation. Similarly, the total effect of T2 social cognition on T4 ToM was significant, $\beta$ (SE) = .19 (.07), $p = .005$. This effect was reduced to non-significance upon inclusion of the mediators, $\beta$ (SE) = .13 (.07), $p = .06$, suggesting a mediated effect. The specific nature of these indirect effects is evaluated below$^1$.

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$^1$ In the Supplementary Materials we provide a complementary analysis that uses cumulative risk as a latent construct and relates this latent variable to ToM and EF at age 4.5 through social cognition at 18 months and receptive language at 3 years. This analysis is consistent with the cumulative risk disparities in neurocognitive skill development outlined in-text.
Table 4. Total, direct, and indirect effects for EF and ToM across risk groups

<table>
<thead>
<tr>
<th>Effect</th>
<th>Overall sample</th>
<th>Low Risk</th>
<th>High Risk</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>EF</td>
<td>ToM</td>
<td>EF</td>
</tr>
<tr>
<td>Total (β)</td>
<td>.22***</td>
<td>.19**</td>
<td>.09</td>
</tr>
<tr>
<td>Direct (β)</td>
<td>.15*</td>
<td>.13†</td>
<td>.03</td>
</tr>
<tr>
<td>Total indirect (z)</td>
<td>2.49*</td>
<td>2.47**</td>
<td>2.20†</td>
</tr>
<tr>
<td>Indirect via T3 language (z)</td>
<td>2.23*</td>
<td>2.01*</td>
<td>2.01†</td>
</tr>
<tr>
<td>Indirect via T3 ToM (z)</td>
<td>-.27</td>
<td>.82</td>
<td>-.25</td>
</tr>
<tr>
<td>Indirect via T3 EF (z)</td>
<td>1.26</td>
<td>1.26</td>
<td>1.18</td>
</tr>
</tbody>
</table>

Standardized effect size (a*b) for indirect effect through language

.07    .05    .06    .04    .05    .05

† *p < .10. **p < .05. ***p < .01. ****p < .001

1.3.4 Language-mediated pathway

As hypothesized, the indirect effect from T2 social cognition to T4 EF through T3 receptive language was significant after controlling for the ‘previous skills’ and ‘reciprocal effects’ pathways, z = 2.23, p = .026. Further, consistent with the results for EF, the indirect effect from T2 social cognition to T4 ToM through T3 receptive language was also significant after controlling for the ‘previous skills’ and ‘reciprocal effects’ pathways, z = 2.01, p = .044. Thus, for both EF and ToM at age 4.5, the effect of social cognition at 18 months operated through children’s receptive language ability at age 3.

1.3.5 Previous skills and reciprocal effects pathways

After controlling for the language-mediated pathway, the indirect effects of T2 social cognition on T4 EF through T3 EF (i.e. ‘previous skills’ pathway; z = 1.26, p = .21) and T3 ToM (i.e. ‘reciprocal effects’ pathway; z = -.27, p = .79) were not significant. The same pattern emerged
for T4 ToM: after controlling for the language pathway, neither indirect through T3 ToM (i.e. ‘previous skills’ pathway; $z = .82, p = .41$) or T3 EF (‘reciprocal effects’ pathway; $z = 1.26, p = .21$) was significant. These results suggest that the ‘previous skills’ and ‘reciprocal’ effects pathways were relatively less influential than the language pathway for both EF and ToM development at age 4.5.

1.3.6 Testing the cascade model across risk groups

We then fit the path model for both the low and high risk groups separately using a multi-group analysis. Model fit for the multi-group model was slightly better than that for the entire sample reported above: RMSEA = .050, CFI = .93, and SRMR = .066. In order to achieve this degree of model fit, certain parameters were freed across the two groups in accordance with recommended modification indices. Parameters were freed based on critical values (highest values first) until no further indices were suggested. Compared to the model with the parameters constrained to equality across groups, chi-square difference testing revealed that the model with freed parameters was a better fit to the data, $\Delta \chi^2 = 16.7 (df = 3)$, $p < .005$. This suggested that, as hypothesized, certain paths indeed differed across the two groups (described below). Contrary to hypotheses, however, we did not observe differences in the indirect effects across the low and high risk groups. As seen in Table 4, the effect of T2 social cognition on T4 EF and ToM operated solely through T3 receptive language for both groups, whereas the indirect effects through T3 EF and ToM (i.e. the ‘previous skills’ and ‘reciprocal effects’ pathways) were not significant. Thus, the mechanism linking social cognition at 18 months to EF and ToM at age 4.5 operated specifically through children’s receptive language ability at age 3, regardless of cumulative risk status.

1.3.7 Individual path differences across risk groups

As noted above, certain parameters were shown to differ across the low and high risk groups, despite no differences in the indirect effects linking early social cognition to later ToM and EF. Specifically, three paths were shown to differ across groups: the first was the direct path between T2 social cognition and T4 ToM, with $\beta$ (SE) = -.033 (.08), $p = .67$ in the low risk group and $\beta$ (SE) = .36 (.10), $p = .001$ in the high risk group. Parameter difference testing revealed that this association was indeed significantly stronger in the high risk compared to low risk group ($z = -$
3.00, \( p = .003 \)), suggesting that earlier social cognition is a stronger predictor of later ToM in high-risk compared to low-risk children. The second parameter that differed across groups was the direct path from T2 social cognition to T4 EF, with \( \beta \) (SE) = .03 (.06), \( p = .67 \) in the low risk group and \( \beta \) (SE) = .30 (.10), \( p = .001 \) in the high risk group. As with ToM, this association was statistically stronger in the high risk group (\( z = -2.94, p = .003 \)), again showing that earlier social cognition is a stronger predictor of later EF in high-risk compared to low-risk children. The third and final path that differed across groups was the association between T3 ToM to T4 ToM, with \( \beta \) (SE) = .20 (.08), \( p = .008 \) in the low risk group and \( \beta \) (SE) = -.17 (.11), \( p = .10 \) in the high risk group. This association was significantly stronger in the low risk group (\( z = 3.07, p = .002 \)). In summary, low and high-risk groups did not differ on the language-mediated pathways to EF and ToM, but they nonetheless differed on other pathways linking these skills over time. We discuss these pathways more extensively in the Supplementary Material. In general, these results show that children from high risk environments are at greater risk of later problems when they show early neurocognitive difficulties.

1.4 Discussion

The current study tested a developmental cascade model in which children’s social cognition at 18 months was hypothesized to predict ToM and EF at age 4.5 through their intermediary receptive language skills at age 3. We also examined cumulative risk disparities in neurocognitive skill development by: (1) testing overall mean differences in skill development; and (2) examining whether the developmental mechanism linking these skills over time varied as a function of children’s cumulative risk status. First, it was demonstrated that, in the overall sample, the effect of social cognition at 18 months – operationalized as a collection of precursory skills including joint attention, empathy, cooperation, and self-recognition – was indirectly associated with children’s ToM and EF at age 4.5 through their receptive language ability at age 3. There were no independent effects that operated through children’s interceding executive or mentalization abilities. Owing to this level of specificity, these results suggest that receptive language may be a critical cognitive ability that links early-emerging social-cognitive abilities in the second year of life to later cognitive capacities such as ToM and EF (Müller, et al., 2012). However, while it can be reasonably stated that language abilities partially mediated the association between early social cognition and later ToM and EF, residual effects of social
cognition on these skills (i.e., after inclusion of mediators) is suggestive of other mediating variables not measured in the current study. Future research examining additional neurocognitive and/or contextual factors linking early social-cognitive capacities to later ToM and EF would prove useful in elucidating these as-yet unidentified mechanisms of development.

Second, with regard to the effects of cumulative social disadvantage on neurocognitive development, it was shown that children from high risk backgrounds demonstrated lower overall skill development across domains. Importantly, these effects can be detected as early as 18 months, when children’s social-cognitive abilities are rapidly developing (Moore, 2007). The effect of cumulative risk also appears to be operative for children’s receptive language ability at age 3, as well as their ToM and EF at age 4.5. These results are consistent with a wealth of evidence from social neuroscience suggesting that socioeconomic gradients are predictive of individual differences in neurocognitive development across childhood (Noble et al., 2005, 2006, 2007). Previous studies have documented the deleterious effects of cumulative risk on outcomes such as effortful control and social competence (Lengua, Honorado, & Bush, 2007), socio-emotional functioning (Cabrera, Fagan, Wight, & Schadler, 2011), and internalizing and externalizing problems (Trentacosta et al., 2008). The current study extends these harmful consequences of cumulative risk to EF and ToM in the preschool period, effects not previously demonstrated.

Interestingly, the size of the group differences in neurocognitive functioning appeared to increase over time. This finding suggests that, although we see differences in neurocognitive ability as a function of risk exposure early in development, these effects may become more pronounced as children mature. One explanation for the modest differences across risk groups on ToM and EF at age 3 is that these competencies are still quite emergent at this time, and there has been less opportunity for risk to impede normative development. A certain level of postnatal neural pruning and/or organization of functional brain networks (Kelly et al., 2009; Power et al., 2010) may be necessary in order for the effects of social disadvantage to become fully realized. As prefrontal connections are enhanced and functional connectivity across brain regions that support ToM and EF are established (e.g. Casey, Tettenham, Liston, & Durston, 2005), the cumulative effects of social disadvantage on neurocognitive development may surface in the preschool period. Indeed, recent brain imaging studies show that the effects of socioeconomic disadvantage
on particular cortical regions – including the superior temporal gyrus and inferior frontal gyrus – increase as a function of age (Noble et al., 2012). These brain regions have been shown to support children’s language, ToM, and EF abilities (Brunet, Sarfati, Hardy-Bayle, & Decety, 2000; Fan, McCandliss, Fossella, Flombaum, & Posner, 2005; Gallagher & Frith, 2003). It may be the case that accumulating social risks have the effect of creating wider gaps in children’s neurocognitive functioning as they age. Future research on the extent and timing of risk exposure, and their relationship to brain development, are crucial to our understanding of how disparities in neurocognitive functioning are shaped across early development.

The third major finding of the present study was that, despite overall group differences in neurocognitive functioning, the developmental cascade linking social cognition at 18 months to ToM and EF at age 4.5 operated similarly for children from both low and high risk backgrounds. That is, in both groups there was a specific indirect effect through receptive language at age 3, but no separate effect through intermediary executive or mentalization abilities. Thus, language may represent a core mechanism applicable to both low and high risk children that links early social-cognitive capacities to later EF and ToM. The implication of this is that poor receptive language functioning at age 3 has knock-on consequences for subsequent cognitive skills. As language abilities are readily and reliably measured in primary care settings, they represent a good candidate for early screening and targeted intervention. Future research should consider whether such early assessment and intervention can reduce subsequent cognitive morbidity.

Despite a similarly operative mechanism connecting early social cognition to later ToM and EF through receptive language in both low and high risk children, there were also discrete path differences that existed between groups. These paths were not components of the language-mediated pathway discussed above, and hence had no bearing on its functioning in either risk group. Rather, two of these discrepant paths were the direct effect of social cognition at 18 months on ToM and EF at age 4.5 – that is, the non-mediated, residual effect of social cognition on ToM and EF (after accounting for indirect effects). The third path that differed was the stability in ToM from age 3 to age 4.5. The specific nature of these results is explicated in the Supplementary Material, but these effects were generally consistent with the notion that poor early cognitive abilities in the context of high risk environments may have a deleterious effect on later ToM and EF. A common finding in the resiliency literature is that child functioning is more
compromised when risks combine – in this case early cognitive difficulties and high cumulative risk (Luthar, Cicchetti, & Becker, 2000; Masten et al., 2009). This suggests that improved outcomes may be most effectively achieved by targeting children where risks are coupled.

The current study demonstrated that children from low risk backgrounds, who demonstrate relatively more advanced early skill development, also show more advanced neurocognitive abilities later in development than their high risk peers. The processes that account for this advantage are not yet fully understood; however, it may be the case that low risk children, owing to their higher social-cognitive abilities, recruit themselves into cognitively stimulating environments that facilitate neurocognition from a young age (e.g. Lewis & Carpendale, 2009). For instance, these children may engage in more sophisticated communicative exchanges with caregivers that foster their language skills, which in turn promote later ToM and EF. More studies are needed to substantiate whether early social interactions put children on a trajectory towards positive and stable neurocognitive development, and how these transactional patterns mediate or moderate the effects of social disadvantage on neurocognitive development.

Central to the current study is the mediating role of receptive language in the association between social cognition and later ToM and EF. Müller and colleagues (2012) also recently demonstrated that the relationship between early social-cognitive precursors and EF at age 4 was fully mediated by children’s verbal ability at age 3. Together, these results are suggestive of both a constitutive and possible executive role of language in the ability to control one’s thoughts and actions (Müller et al., 2009). The current study expands on these findings in three important ways: first, it shows a similar pathways from early social cognition to both later EF and ToM through children’s intermediary receptive language ability; second, it emphasizes the specificity of this relationship by ruling out an auxiliary role of interceding executive and mentalization skills (i.e. previous skills and reciprocal effects pathways); and third, it demonstrates the mediational role of receptive language in both low and high risk children. Although our theoretical and empirical model focused on social cognition as a key precursor skill in development, future models examining competing pathways, perhaps with early language, behavioral inhibition, or general cognitive abilities as antecedents, would advance our understanding of the mechanisms to ToM and EF.
Neuroimaging studies suggest that ToM and EF may be supported by an overlapping, distributed neural network that includes the anterior cingulate cortex, medial prefrontal cortex, temporoparietal junction, and lateral prefrontal areas (Gallagher & Frith, 2003; Lie, Specht, Marshall, & Fink, 2006; Rothmayr, et al., 2011; Spreng, Mar, & Kim, 2009). Indeed, fascinating evidence is now emerging that links socioeconomic disparities to children’s neural functioning, particularly in the prefrontal brain regions that support EF and ToM (Kishiyama, Boyce, Jimenez, Perry, & Knight, 2009; Lawson, Duda, Avants, Wu, & Farah, 2013; Noble et al., 2012). Consistent with the suggestion that language is an important constituent in cognitive development, a recent study by Sheridan and colleagues (2012) showed that the association between socioeconomic factors and children’s prefrontal functioning may be accounted for by increased complexity of language use in the home. Taken together, these results suggest that enriched environments that contribute to children’s linguistic competence may have the effect of fostering other brain-based neurocognitive abilities over early childhood. Thus, efforts to promote the early skills that carry these pathways of social risk in young children may prove effective in mitigating the negative consequences of poor neurocognitive development, especially in socially disadvantaged children who may require extra support to catch up to their more fortunate peers.

**Strengths and Limitations**

The current findings should be considered in light of several strengths and limitations. Strengths included the large and diverse sample, longitudinal follow-up, and detailed observational data across time points. With respect to limitations, the first is that our measure of language at age 3 was a single measure of receptive vocabulary. Although the PPVT is one of the most widely used measures of language in the developmental literature (especially in relation to ToM and EF), it is not a diagnostic tool, nor does it allow for the assessment of different aspects of language. Future studies with more comprehensive language assessment are encouraged. Likewise, future studies with documentation of clinical diagnoses of language delay and/or neurodevelopmental disorders may be useful in uncovering whether these cascades operate similarly for typically compared to atypically developing children. Second, there was a variable amount of missing data on risk indicators and outcomes due to attrition and non-response. Best practice approaches to handle missing data were used (Graham, 2009), but caution should be exercised when interpreting these results. Finally, though not a limitation per se, it is important
to emphasize that construction of the cumulative risk index was based on the summation (and averaging) of 8 specific dichotomous risk factors, followed by a median split into high and low risk groups. These methodological nuances should be considered as potential sources of variation, and should be highlighted in order to promote clarity and facilitate replication. Nevertheless, that we demonstrated disparities in neurocognitive skills and discrete paths linking these skills based on this relatively conservative partitioning of the sample speaks to the significance of these results.

1.5 Acknowledgements

We are grateful to the families who give so generously of their time, to the Hamilton and Toronto Public Health Units for facilitating recruitment of the sample, and to Mira Boskovic for project management. The grant ‘Transactional Processes in Emotional and Behavioural Regulation: Individuals in Context’ was awarded to Jennifer M. Jenkins and Michael Boyle from the Canadian Institutes of Health Research and covered data collection. We are also grateful to the Connaught Global Challenge Fund for providing financial support to the contributors of this study. The study team, beyond the current authors includes: Janet Astington, Cathy Barr, Kathy Georgiades, Greg Moran, Chris Moore, Tom O’Connor, Michal Perlman, Hildy Ross, Louis Schmidt.

1.6 References - Study 1


Raizada, R. D., & Kishiyama, M. M. (2010). Effects of socioeconomic status on brain development, and how cognitive neuroscience may contribute to levelling the playing field. *Frontiers in Human Neuroscience, 4*.


1.7 Supplementary Material for Study 1

Measurement Information on Social Cognition and the Cumulative Risk Index

For the Social Cognition factor, four independent observational tasks were used to assess children’s joint attention, empathy, cooperation, and self-recognition at T2 (18 months). These tasks were administered during the home visit. Each task is described below:

<table>
<thead>
<tr>
<th>Measure</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Joint Attention</td>
<td>This was measured in terms of children’s ability to follow the gaze of an adult interviewer (Carpenter, Nagell, &amp; Tomasello, 1998), using a gaze-following task from the Early Social Communication Scale (ESCS; Mundy, et al., 2003). The child sat with his or her mother across from the experimenter. Two colorful pictures were placed beside the child, and two behind the child. The tester first ensured she had the attention of the child by calling the child’s name, tapping the table, or gently touching the child. She then proceeded to point to the four posters in a systematic order: tester’s left, left-behind, right, right-behind. The point consisted of the tester turning her entire torso, visually orienting to a poster and keeping her elbow in contact with body. During the pointing trial, if the child did not immediately redirect his or her attention to the poster, the tester proceeded to say the child’s name three times. If the child still did not redirect his or her attention, the tester paused before redirecting attention to the child. This task was administered twice throughout the home visit, separated by another activity, for a total of 8 possible ‘respond-to-joint-attention’ (RJA) observations for each child. A trained coder viewed videotapes and coded children’s ability to redirect attention to the focal object along a 4-point scale. If the child immediately redirected attention to the poster after the tester’s point, the child received a score of 4. If the child redirected attention after the tester said his or her name, the child received a score of 3. If the child delayed redirection of attention until after the tester’s point was finished, but before the next trial commenced, the child received a score of 2. If the child failed to redirect attention to a poster, he or she received the lowest score of 1. Inter-rater reliability was $\alpha = .94$. A task analysis revealed significant mean differences between side point ($M = 3.90$, $SD = .27$) and behind point ($M = 3.30$, $SD = .91$) trials ($t(279) = 11.84$, $p &lt; .01$), suggesting that following side points is a simple task for most 18-month-olds. Furthermore, only behind points correlated significantly with children’s concurrent vocabulary ($r = .22$, $p &lt; .01$), indicating more robust construct validity for the behind-point trials in the current sample. Thus, for each child, only the four observations of the behind trials were used as the measure of RJA. We took the mean score for each of the four trials, resulting in a maximum score of 4 (perfect score of 4 on all four trials).</td>
</tr>
<tr>
<td>Empathy</td>
<td>This was measured as the child’s responsiveness to the feigned distress of an adult interviewer. At standard points during the home interview, the interviewer pretended to hurt her knee and finger, as well as to drop and...</td>
</tr>
</tbody>
</table>
ostensibly break her favourite toy (‘Mickey’, a magnetic toy monkey, whom the child met at the beginning of the testing session). Two coders watched all empathy events and rated children on six statements based on their reaction to the interviewer’s distress. A thin-slice coding method was used (Ambady, Bernieri, & Richeson, 2000; Ambady & Rosenthal, 1992), which is a global or impressionistic rating of the child’s behaviour. This method has been used successfully in rating child behaviour (Prime, Perlman, Tackett, & Jenkins, 2011). Based on the thin-slice methodology, coders are encouraged to make general judgements about children using all available information from the empathy events, and their final ratings are averaged to decrease the impact of a single observer’s judgment (Ambady, et al., 2000). Empathy ratings were based on an adaptation of an empathy scale developed by Kochanska and colleagues (Kochanska, DeVet, Goldman, Murray, & Putnam, 1994). Five items were removed from that scale because they referred to elicitors for which our raters had no information (reactions to movie characters or animals being hurt). Items rated included ‘Will try to comfort or reassure another in distress’; ‘Likely to offer toys or candy to crying playmate even without parental suggestion’; ‘Can tell at just one glance how others are feeling’; ‘Likely to ask what’s wrong when seeing someone in distress’; ‘Will feel sorry for other people who are hurt sick or unhappy’; and ‘Is not likely to become upset if a playmate cries’, each of which was rated on a 7-point scale from 1 (‘extremely untrue’) to 7 (‘Extremely true’). The internal consistency was .98 for coder 1 and .96 for coder 2. Although inter-rater agreement in thin-slice methodology is not normally reported, agreement between coders was high (α = .82).

| Cooperation | Children’s cooperation skills were measured with two previously developed cooperation tasks: trampoline and double tubes (Warneken, Chen, & Tomasello, 2006). These tasks assess the extent to which children cooperate with the tester towards a goal, requiring the child to change his/her behaviour to succeed. Four cooperation measures were taken: (1) In the trampoline task, the child was invited by the tester to help make a bear dance on a hand-held trampoline. Failure to cooperate by holding up their end led to the collapse of the trampoline. The first 10 seconds of the task were allowed as a learning phase, and were not coded. Subsequently, discrete 10-second intervals were coded on a 5-point scale, up to a maximum of 80 seconds (8 total intervals). The scale ranged from 1 (no success) to 5 (high engagement), and the mean of the intervals was taken. (2) In the double tubes tasks, the child was invited to help the experimenter complete a sequence of actions in which she rolled a ball down one of two tubes and asked the child to catch it at the bottom. In contrast to the trampoline task, the child was required to engage in different but complementary behaviour to the tester to achieve the goal. Therefore, to be successful, the child cannot simply imitate the tester. The first catch trial was allowed as a learning phase, and was not coded. Subsequently, each catch invitation was coded on a 5-point scale, with a maximum of 8 trials coded. The scale ranged from 1 (no attempt) to 5 (complete success), and the mean of the 8 trials were computed for each child. (3) After the trampoline and double tubes tasks were completed, coders rated a global cooperation score for each |
task. The global cooperation score was coded along a 4-point scale, based on percentage of the task the child was cooperative (0-25%, 26-50%, 51-75%, 76-100%). A mean global score on these two tasks was computed. Finally, coders rated the number of times a child was uncooperative throughout the (4) trampoline and (5) double tubes tasks independently, from ‘none’ (0) to ‘3 or more times’ (3). These items were reverse coded. Ten percent of videotapes were double coded by independent coders and the mean inter-rater reliability across all cooperation tasks was \( \alpha = .86 \) (ranging from .68 to .96). All of the items loaded significantly onto the same factor, explaining 47% of the variance, with item loadings ranging from .54 to .76. A composite cooperation variable was constructed by taking the mean of the standardized scores across all cooperation measures. Scores were z-scored because each measure was on a difference scale but combined into a single composite measure of cooperation. Individual measures were as follows: (1) Trampoline \((M = 2.39, SD = 1.07)\); (2) Double Tubes \((M = 3.41, SD = 1.06)\); (3) Global rating \((M = 1.47, SD = .73)\); (4) Uncooperative trampoline \((M = 1.86, SD = .99)\); Uncooperative double tubes \((M = 1.89, SD = 1.06)\). All bivariate correlations were significant at \( p < .01 \). Internal consistency of the items making up the composite was \( \alpha = .71 \).

**Self-Recognition**

During the cooperation task, the interviewer surreptitiously marked the child with a large coloured sticker at the front of their head on the hair (so that they could not feel it being placed). The child was then placed in front of a mirror and allowed to look at themselves for 30 seconds. If the child demonstrated any self-directed behaviour (either reaching for the sticker or verbally acknowledging its presence, with or without prompting), the child received a score of 1. If the child did not recognize the sticker at all, they received a score of 0. Thus, this score was a conservative estimate of the child’s ability to recognize him/herself in the mirror. Reliability on this task was \( \kappa = 0.79 \).
For the *Cumulative Risk Index*, a trained interviewer conducted initial home visits when children were 2 months old. Information on risk factors was collected via maternal self-report and interviewer observation. Measured risk factors were either naturally categorical, dichotomized based upon informative cut-points, or continuous. For continuous variables, a cut-point was identified as close as possible to the most extreme 15% of the distribution (towards the risky or adverse pole). This corresponded to +1 standard deviation above or below the mean, based on the normal distribution. Each risk factor is described below:

### Cumulative Risk Index

<table>
<thead>
<tr>
<th>Measure</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maternal History of Adversity</td>
<td>Maternal history of adversity was assessed using an adapted adult-version of the Childhood Experience of Violence Questionnaire (Walsh, MacMillan, Trocmé, Jamieson, &amp; Boyle, 2008.) Mother’s rated their witnessing of verbal and physical abuse (e.g. parents abusing one another or a sibling) and direct experience of physical and sexual abuse. Severity items (e.g. “How many times before the age of 16 did an adult caregiver slap you on the face...”) were scored on a scale of “never” to “more than 10 times.” As scales were highly skewed with most mothers reporting few or no experiences of abuse, we recoded the scales to be dichotomous, following the natural cut point of the distribution. A cut-off of 2 was used for witnessing verbal abuse (representing 21% of sample), 1 (9.6% of sample) for witnessing physical abuse, 2 (14.2% of sample) for experiencing physical abuse, and 1 for experiencing sexual abuse (9.8% of sample). These cut-points were based on the distribution of the scale, but in all cases risk was classified as anything beyond the lowest category (i.e. anything beyond ‘no abuse’ or the lowest possible score).</td>
</tr>
<tr>
<td>Non-intact Family</td>
<td>The family was coded as being “non-intact” if the mother described: (a) parents were separated or divorced; (b) child was living in a stepfamily; or (c) if the child’s father was not present (11.8% of the sample was coded as 1 ‘non-intact’).</td>
</tr>
<tr>
<td>Maternal Depression</td>
<td>Maternal depression was evaluated using the Center for Epidemiological Studies Depression Scale (CES-D), a widely used self-report scale that assesses depression in nonclinical populations (Radloff, 1977). Mothers rated the frequency of 20 depressive symptoms over the past week on a 4-point scale. Higher scores represented higher depression levels. Internal consistency from the original study was high: α = .85 for the general population and α = .90 for clinical patients. In the current sample, α = .84. Items were summed and a cutoff of ≥ 16 was used to index persons who would likely meet criteria for clinical depression (16.8% of mothers were depressed), as suggested by Radloff and colleagues (Radloff, 1977; Sawyer, Radloff, &amp; Teri, 1986).</td>
</tr>
<tr>
<td>Parental Education</td>
<td>Maternal education was measured by asking the mother how many years of formal education they have received, excluding kindergarten. A natural cut-point was observed in the distribution and selected as the dichotomization target. Mothers with &lt; 13 years of education (i.e. 0 to 12 years) were categorized as having “low education”. This cut-point is reflective of the absence of post-secondary education, assuming 12 years of compulsory schooling (i.e. high-school diploma or less). Based on this, 18.0% of mothers did not have any post-secondary education.</td>
</tr>
<tr>
<td><strong>Home Order</strong></td>
<td>Trained interviewers used an adapted version of the HOME scale to assess the quality of the home environment (Bradley, 1994). The standard HOME scale is a mixture of observer and parental report. We only used the observer items in order to avoid any parental response bias. In total, observers rated 12 items on a 3 or 4-point scale. Preliminary factor analysis revealed two factors with eigenvalues greater than 1, which explained 44% of the variance. The first factor (including 4 items) represented order, cleanliness, and safety of physical environment. The scale was reverse-coded to represent the underlying construct of household chaos (α = .78). A cut-off of 1.76 or higher was used to define families with low home order (16.3% of families).</td>
</tr>
<tr>
<td><strong>Books and Toys in the Home</strong></td>
<td>The same HOME scale used for Home Order was used. The second factor that emerged with an eigenvalue greater than 1 (including 6 items) represented the amount of playing and learning tools available to the children (α = .69). A cut-off of 1.18 or higher was used to define families with few learning materials (10.8% of families).</td>
</tr>
<tr>
<td><strong>Immigrant Status</strong></td>
<td>Mothers reported on whether they were born outside of Canada. Based on this, 46.5% of mothers were coded as immigrants.</td>
</tr>
<tr>
<td><strong>Neighborhood Trust</strong></td>
<td>Parental perceptions of neighborhood trust were derived using Sampson and colleagues’ (1997) study of collective efficacy. The trust scale was comprised of five items such as: “people around here are willing to help their neighbors”. Parents responded on a five-point scale ranging from 1 (‘strongly agree’) to 5 (‘strongly disagree’). This scale demonstrated reliability in the original Sampson study (α = .92). In the present study, reliability was α = .82. Neighborhood trust was dichotomized at 3.0, which resulted in 15.8% of families living in neighborhoods characterized by lower levels of trust.</td>
</tr>
</tbody>
</table>
Supplementary Analysis
Individual Risks and Neurocognitive Outcomes

Table S-1: Effect of individual risks in the cumulative risk index on each neurocognitive outcome

<table>
<thead>
<tr>
<th>Individual Risk Measure</th>
<th>Social cognition (18 m)</th>
<th>ToM (3 years)</th>
<th>EF (3 years)</th>
<th>Receptive language (3 years)</th>
<th>ToM (4.5 years)</th>
<th>EF (4.5 years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>History of adversity</td>
<td>-0.02 .87</td>
<td>-0.13 .33</td>
<td>-0.01 .94</td>
<td>.09 .52</td>
<td>.08 .56</td>
<td>.02 .91</td>
</tr>
<tr>
<td>Non-intact family</td>
<td>0.26 .20</td>
<td>0.01 .97</td>
<td>0.13 .46</td>
<td>.32 .07</td>
<td>.06 .78</td>
<td>.55 .01</td>
</tr>
<tr>
<td>Maternal depression</td>
<td>-0.03 .86</td>
<td>0.00 .98</td>
<td>-0.04 .80</td>
<td>.16 .33</td>
<td>.34 .04</td>
<td>.08 .62</td>
</tr>
<tr>
<td>Low maternal education</td>
<td>0.17 .33</td>
<td>.39 .01</td>
<td>0.25 .11</td>
<td>.40 .02</td>
<td>-.01 .95</td>
<td>.10 .53</td>
</tr>
<tr>
<td>Low home order</td>
<td>.43 .01</td>
<td>.13 .34</td>
<td>.25 .07</td>
<td>.01 .94</td>
<td>.21 .18</td>
<td>.12 .44</td>
</tr>
<tr>
<td>Low books and toys</td>
<td>0.23 .30</td>
<td>.12 .48</td>
<td>.15 .40</td>
<td>.49 .01</td>
<td>.69 &lt;.01</td>
<td>.74 .01</td>
</tr>
<tr>
<td>Immigrant</td>
<td>0.12 .33</td>
<td>.24 .03</td>
<td>.11 .28</td>
<td>.62 &lt;.01</td>
<td>.24 .04</td>
<td>.32 .01</td>
</tr>
<tr>
<td>Low neighborhood trust</td>
<td>.37 .04</td>
<td>.31 .05</td>
<td>.38 .01</td>
<td>.48 .01</td>
<td>.15 .40</td>
<td>.29 .10</td>
</tr>
</tbody>
</table>

Interpretation:

Certain individual risks were more strongly associated with certain outcomes. Some risks (e.g. immigrant status; low neighbourhood trust) were associated with multiple outcomes, whereas history of adversity was not associated with any. It is important to note, however, that just because a certain variable is not, on its own, significantly associated with an outcome, the cumulative risk approach permits the possibility that, in conjunction with other risks, there may be an effect on the outcomes (i.e. potentiation of effect as risks accumulate). Thus, while Table-S1 suggests that individual risks may be differentially related to the outcomes, this does not contest the cumulative risk approach. Rather, these should be considered complementary analyses that offer two alternative perspectives to the question of how risk operates on children’s neurocognitive functioning.
Cumulative Risk as a Predictor of Neurocognitive Outcomes

The association between cumulative risk and each outcome was also examined. Here, the 8 psychosocial risk factors were combined into a latent variable reflecting risk status. This latent variable can be seen in Figure S-1. Model fit was adequate: \( \chi^2 (df = 20) = 64.8, p < .001 \), RMSEA = .06, CFI = .84, and WRMR = 1.23. All model-estimated loadings were significant and in the expected direction.

We examined the relation of this latent factor to ToM and EF at age 4.5 through social cognition at 18 months and receptive language at age 3. For ToM, there was a significant indirect effect from cumulative risk through receptive language at age 3 (\( z = -2.31, p = .021 \)) and a marginal effect through social cognition and language (\( z = -1.69, p = .092 \)). A similar pattern emerged for EF at age 4.5: there was a significant indirect effect of cumulative risk through receptive language at age 3 (\( z = -2.27, p = .023 \)) and a marginal effect through social cognition and language (\( z = -1.71, p = .087 \)). No indirect effect from cumulative risk through just social cognition on either ToM or EF was observed. These results are consistent with the cumulative risk disparities in neurocognitive development reported in the main text. Together, these results suggest that cumulative risk is associated with compromised neurocognitive development, and moderates the paths that connect these skills over early childhood.

Figure S-1. Latent cumulative risk factor with each individual risk variable as a manifest indicator variable. Loadings are standardized coefficients.
Path Differences Across Low and High Risk Groups

As noted in the main text, there were three parameters that differed between the low and high risk groups: (1) T2 social cognition to T4 ToM; (2) T2 social cognition to T4 EF; and (3) T3 ToM to T4 ToM. For the first parameter, post hoc moderation analysis of this effect revealed that the relatively weak association in the low risk group actually reflected a pattern of high ToM at T4 regardless of T2 social cognition levels (see Figure S-2). Alternatively, those in the high risk group who had low social cognition tended to also have lower ToM at T4. The same pattern emerged for the second freed parameter, between T2 social cognition and T4 EF. Here, the relatively weak association in the low risk group reflected high levels of EF regardless of T2 social cognition (Figure S-3), whereas children in the high risk group who also had low social cognition at T2 showed more EF difficulties at T4. Importantly, if children in the high risk group showed relatively high social cognition at T2, their ToM and EF at T4 did not appear to be compromised, and was comparable to their low risk peers. Finally, for the third freely estimated parameter, it was shown that there was more stability in ToM from T3 to T4 in the low risk group: if they started high they remained high, and if they started low they remained low (Figure S-4). Conversely, in the high risk group, children performed relatively low on T4 ToM regardless of their T3 ToM. Thus, high risk children did not show the same gains at T4 as their low risk peers, even if they demonstrated comparable ToM levels at age 3.

Figure S-2. Plotted interaction of social cognition at T2 (+/- 1 SD) by cumulative risk (CR) group (high versus low) on theory of mind at T4. Solid line represents the low risk group, and the hashed line represents the high risk group. These results are meant to complement the primary path model-estimated differences presented in the main text.
Figure S-3. Plotted interaction of social cognition at T2 (+/- 1 SD) by cumulative risk (CR) group (high versus low) on executive functioning at T4. Solid line represents the low risk group, and the hashed line represents the high risk group. These results are meant to complement the primary path model-estimated differences presented in the main text.

Figure S-4. Plotted interaction of theory of mind at T3 (+/- 1 SD) by cumulative risk (CR) group (high versus low) on theory of mind at T4. Solid line represents the low risk group, and the hashed line represents the high risk group. These results are meant to complement the primary path model-estimated differences presented in the main text.
Interpretation

These path differences across risk groups (i.e., moderation effects) are consistent with the interpretations made in text regarding the advantage of low risk children in neurocognitive functioning compared to high risk children. Specifically, these results show that children with high risk backgrounds who have relatively underdeveloped social cognition at 18 months demonstrate lower ToM and EF skills at age 4.5; and only at high levels of early social cognition do high-risk children show comparable ToM and EF to their low-risk peers. These results are consistent with so-called ‘compensatory risk/resiliency’ models of development, or what Luthar et al. (2000) call a ‘protective-stabilizing’ effect. Here, children’s development suffers in the presence of multiple risks, such as low social cognition at 18 months in combination with high cumulative risk. Alternatively, exposure to only one of these risks is less strongly associated with negative ToM/EF outcomes (Masten et al., 2009). Thus, if a child shows poor early development within the context of a stimulating environment, subsequent developmental outcomes are less likely to be compromised than in high-risk environments (hence the term ‘compensatory’). In general, these results are consistent with the overarching proposal that children in high risk environments are at a greater risk for later ToM and EF difficulties, especially when they show problems with social cognition early in development.

The third parameter – from T3 ToM to T4 ToM – showed a different pattern of results. Here, high risk children showed relatively low ToM levels at age 4.5 regardless of ToM competency at T3, whereas those from low risk backgrounds with high ToM at age 3 demonstrated higher ToM ability at age 4.5. These results are consistent with the notion that a combination of factors (i.e. low risk and high social cognition) is needed to demonstrate elevated competence in a given area. This pattern is generally consistent with what Luthar et al. (2000) call a ‘protective-reactive’ mechanism, where a given attribute (e.g. high social cognition) confers an advantage on later development (e.g. EF and/or ToM), but less so in the presence of increased social stress. Thus, when the child is in a high-risk environment, ToM abilities at age 3 may not have the same positive effect on later ToM at age 4.5 than when they are exposed to more stimulating (or less risky) environments.
Two overarching themes can be extracted from these findings. First, children with relatively low risk backgrounds may be set up for success early in development due to mastery of previous milestones. That is, low risk children who have high ToM at T3 show higher ToM at age 4.5, but this is not true of the high risk group, who show continued problems. In high risk children, there appears to be more stagnancy in skill development, as many are not developing the skills required for later success. Second, low risk children may be buffered against low social-cognitive skill development in the second year of life. This means that, even in the context of low social cognition at 18 months, low-risk children may be able to make the transition into a higher neurocognitive bracket at later stages of development. On the other hand, children from more disadvantaged backgrounds are more vulnerable to the effects of low social cognition in the second year, which places them at risk for neurocognitive difficulties later in childhood. That is, if high risk children have low social cognition at 18 months, they show lower ToM and EF at age 4.5. Critically, however, if high risk children manage to accrue these early competencies (i.e. if they have high social cognition at 18 months), they show comparable ToM and EF compared to their low risk counterparts.
Chapter 2

2 Study 2: Pregnancy hypertension and the risk for neuropsychological difficulties across early development: A brief report

2.1 Introduction

Maternal hypertension during pregnancy is a significant risk for the physical health of her child, and has been linked to intrauterine growth restriction, cerebral palsy, and preterm birth (McIntyre et al., 2013; Sato et al., 2013). In addition, hypertension during pregnancy has been shown to predict mental health problems in 8-14 year-olds (Robinson et al., 2009). Gestational hypertension has also been associated with lower verbal ability at age 10 (Whitehouse, Robinson, Newnham, & Pennell, 2012), the effects of which appear to persist into early and late adulthood (Tuovinen, Räikkönen, Kajantie, Henriksson et al., 2012; Tuovinen, Räikkönen, Kajantie, Leskinen et al., 2012). Investigations with young children are scarce. However, van Wassenaer and colleagues (2011) showed that 4.5-year-old children of mothers with severe hypertension demonstrated more cognitive problems compared to a standardization sample. Moreover, Robinson et al. (2013) demonstrated that mothers who were diagnosed with either gestational hypertension or preeclampsia were more likely to report that their children had problematic temperaments at year one compared to mothers who did not experience hypertension. Despite these intriguing findings, a recent review published in the journal Child Neuropsychology concluded that the effect of pregnancy hypertension on neuropsychological morbidity has been understudied (Gerner & Baron, 2014). This brief report provides a preliminary investigation of the effect of maternal hypertension during pregnancy on children’s social cognition (including theory of mind; ToM) and executive functioning (EF) – two critical neuropsychological skills – across the first 5 years of life.

2.2 Method

All women giving birth to infants in the cities of Toronto and Hamilton, Canada, between February 2006 and February 2008 were considered for participation. Families were recruited through a program called Healthy Babies Healthy Children, run by Toronto and Hamilton Public Health Units. Inclusion criteria included an English-speaking mother, a newborn >1500 grams,
two or more children <4 years old, and the family agreeing to being videotaped. The current study was embedded within a larger project (http://kfp.oise.utoronto.ca/). At Time 1 (T1; infants were 2 months old), 501 families took part in data collection. Due to sample attrition, the following number of families was followed up at subsequent time points: T2 (18-months-old), N=397 families; T3 (3-years-old), N=385; and T4 (4.5-years-old), N=323.

All testing was done in the participants’ homes across waves. Additional details about the sample are provided in the Supplementary Materials. Pregnancy hypertensive was measured at T1 by a single item which asked ‘During your pregnancy with this child, did you suffer from high blood pressure?’ with mothers answering no (0) or yes (1). Of the 501 mothers reporting, 23 (4.6%) endorsed hypertension as a prenatal complication, which is comparable to that found in other community samples (James & Nelson-Piercy, 2004). Social cognition was measured at T2 (18 months) using previously validated laboratory tasks that assessed children’s cooperation, empathy, joint attention, and self-recognition (see Wade, Moore, Astington, Frampton, & Jenkins, 2014). A complete description of these tasks is in Supplementary Materials of Study 1. Executive functioning was assessed at T3 and T4 using widely used, well-validated tasks. At T3 this consisted of Grass/Snow (Carlson & Moses, 2001) and Bear/Dragon (Reed, Pien, & Rothbart, 1984); and at T4, Bear/Dragon and the Dimensional Change Card Sort (DCCS; Zelazo, 2006). In the present study, T3 Grass/Snow and Bear/Dragon were significantly correlated, \( r(309) = .28, p < .001; \) and at T4 Bear/Dragon and DCCS were significantly correlated, \( r(299) = .34 p < .001. \) Thus, at each time point the two tasks were z-scored and combined into a composite EF variable. Theory of mind was assessed at T3 and T4 using the well-validated scale described by Wellman and Liu (2004). Higher scores for ToM and EF represented higher abilities. A more in-depth description of EF and ToM tasks is in Study 1 and 3. Finally, covariates included: child age, gender (0 = male, 1 = female), birth weight (kg), gestational age, maternal age at pregnancy, socioeconomic status (a composite of family income and maternal education), smoking during pregnancy (0 = no, 1 = yes), and whether the mother experienced diabetes or thyroid problems during pregnancy (each coded 0 = no, 1 = yes).

At T1, there were 23 hypertensive cases. A statistical comparison of hypertensive and nonhypertensive cases on sociodemographic and pregnancy variables is provided in the Supplementary Materials (Table S-1). This table shows that these two groups were comparable.
on most variables. Attrition in the hypertensive group was as follows: T2, N=19; T3, N= 16; T4, N= 11. Chi-square analysis showed no significant differences between hypertensive and non-hypertensive individuals on whether they participated in subsequent waves after T1: $\chi^2 = .17, p = .80$ at T2; $\chi^2 = .71, p = .45$ at T3, and $\chi^2 = 2.97, p = .12$ at T4. Data were determined to be missing at random (MAR). To handle missing data and ensure a full sample of 501 participants (and retention of the 23 hypertensive cases), we used a maximum-likelihood approach called expectation maximization (EM; Little and Rubin, 2002; Schafer, 1997). The result was a fully imputed data set of the original 501 participants.

In the primary analysis, multiple regression was carried out for each outcome using MPlus 7.0. The first step of each regression model included the covariates, and the second step included covariates plus pregnancy hypertension. In a supplementary follow-up analysis, we conducted a direct comparison between the hypertension group and a matched control group. Here, all hypertensive cases were included (n = 23), and propensity score matching was used to generate a sample of non-hypertensive ‘control’ participants (n = 23), matched as closely as possible on key confounding variables. Propensity score matching is used to balance non-equivalent groups in non-randomized studies (Rosenbaum & Rubin, 1983; Lanza, Moore, & Butera, 2013). The result was two subgroups (23 hypertension; 23 controls) that were comparable on demographic characteristics (see Table S-2).

### 2.3 Results

Descriptive statistics for study variables are presented in Table 5. Results of the regression analyses for T2, T3, and T4 outcomes are presented in Table 6. Social cognition at T2 was predicted by child age, being female, pregnancy diabetes, and thyroid problems. After controlling for covariates, hypertension was negatively associated with social cognition at T2, $\beta = -1.04, p < .001$. EF at T3 was significantly predicted by gestational age, maternal age, and child age. After controlling for covariates, hypertension was negatively associated with EF at T3, $\beta = -.62, p = .001$. ToM at T3 was significantly predicted by birth weight, maternal age, being female, and child age. After controlling for covariates, hypertension was negatively associated with ToM at T3, $\beta = -.57, p = .005$. EF at T4 was predicted by birth weight, gestational age, child age, female gender, and SES. After controlling for covariates, hypertension was negatively associated with EF at T4, $\beta = -.59, p = .001$. ToM at T4 was predicted by gestational age,
maternal age, child age, and female gender. Controlling for covariates, hypertension was negatively associated with ToM, $\beta = -.80$, $p < .001$.

### Table 5. Descriptive statistics for study variables ($N = 501$)

<table>
<thead>
<tr>
<th>Measure</th>
<th>$M$</th>
<th>$SD$</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Birth weight (T1)</td>
<td>3.42</td>
<td>.59</td>
<td>[1.6, 6.1]</td>
</tr>
<tr>
<td>Gestational age (T1)</td>
<td>38.9</td>
<td>1.4</td>
<td>[28, 40]</td>
</tr>
<tr>
<td>Maternal age at pregnancy (T1)</td>
<td>32.4</td>
<td>4.9</td>
<td>[10, 47]</td>
</tr>
<tr>
<td>Social cognition (T2)</td>
<td>.00a</td>
<td>.13</td>
<td>[-.48, .32]</td>
</tr>
<tr>
<td>Executive function (T3)</td>
<td>.06a</td>
<td>.75</td>
<td>[-2.0, 2.2]</td>
</tr>
<tr>
<td>Theory of mind (T3)</td>
<td>1.35</td>
<td>.82</td>
<td>[0, 5.0]</td>
</tr>
<tr>
<td>Executive function (T4)</td>
<td>-.01a</td>
<td>.96</td>
<td>[-2.8, 1.2]</td>
</tr>
<tr>
<td>Theory of mind (T4)</td>
<td>3.54</td>
<td>1.65</td>
<td>[0, 7.0]</td>
</tr>
</tbody>
</table>

*a* These are standardized composite or saved factor scores with a mean of zero

Results from the matched-control analyses (using propensity score matching) were analogous: compared to the non-hypertensive group ($n = 23$), children of mothers with pregnancy hypertension ($n = 23$) scored lower on nearly all neuropsychological skills: social cognition at T2, $t (44) = 3.11$, $p = .003$, $d = .84$; ToM at T3, $t (44) = 3.48$, $p = .001$, $d = .92$; EF at T4, $t (44) = 4.13$, $p < .001$, $d = 1.04$; and ToM at T4, $t (44) = 2.52$, $p = .015$, $d = .70$. For EF at T3, the difference between hypertensive and non-hypertensive cases was nearly significant, $t (44) = 1.86$, $p = .070$, $d = .53$. 

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Table 6. Regression results for Time 2 (18 months), Time 3 (3 years), and Time 4 (4.5 years) outcomes.

<table>
<thead>
<tr>
<th>Covariates</th>
<th>1. Social Cognition (T2)</th>
<th>2. EF (T3)</th>
<th>3. ToM (T3)</th>
<th>4. EF (T4)</th>
<th>5. ToM (T4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>STD (SE)</td>
<td>R²</td>
<td>STD (SE)</td>
<td>R²</td>
<td>STD (SE)</td>
<td>R²</td>
</tr>
<tr>
<td>Birth weight</td>
<td>-.06 (.05)</td>
<td>.02 (.05)</td>
<td>.11 (.05)*</td>
<td>.18 (.04)**</td>
<td>.01 (.05)</td>
</tr>
<tr>
<td>Gestational age</td>
<td>.05 (.04)</td>
<td>.14 (.05)**</td>
<td>.00 (.05)</td>
<td>-.11 (.04)**</td>
<td>.19 (.05)**</td>
</tr>
<tr>
<td>Maternal age</td>
<td>-.04 (.04)</td>
<td>.13 (.04)**</td>
<td>.09 (.05)*</td>
<td>-.01 (.03)</td>
<td>.16 (.04)**</td>
</tr>
<tr>
<td>Female gender</td>
<td>.26 (.08)**</td>
<td>.06 (.09)</td>
<td>.18 (.09)*</td>
<td>.17 (.07)*</td>
<td>.30 (.10)**</td>
</tr>
<tr>
<td>Child age</td>
<td>.42 (.04)**</td>
<td>.26 (.05)**</td>
<td>.10 (.04)*</td>
<td>.18 (.04)**</td>
<td>.18 (.04)**</td>
</tr>
<tr>
<td>Family SES</td>
<td>.11 (.07)</td>
<td>.12 (.09)</td>
<td>-.08 (.08)</td>
<td>.46 (.12)**</td>
<td>-.18 (.12)</td>
</tr>
<tr>
<td>Maternal smoking</td>
<td>-.07 (.20)</td>
<td>-.08 (.16)</td>
<td>-.08 (.20)</td>
<td>.17 (.15)</td>
<td>.34 (.19)</td>
</tr>
<tr>
<td>Pregnancy diabetes</td>
<td>-.37 (.16)*</td>
<td>-.14 (.17)</td>
<td>.01 (.19)</td>
<td>.26 (.15)</td>
<td>.13 (.14)</td>
</tr>
<tr>
<td>Pregnancy thyroid</td>
<td>-.49 (.18)**</td>
<td>-.32 (.29)</td>
<td>.35 (.23)</td>
<td>.06 (.21)</td>
<td>-.72 (.42)</td>
</tr>
<tr>
<td>Hypertension</td>
<td>-1.04 (.19)**</td>
<td>-.27***</td>
<td>-.62 (.18)**</td>
<td>-.57 (.20)**</td>
<td>-.59 (.18)**</td>
</tr>
</tbody>
</table>

*p < .05. **p < .01. ***p < .001

STD – standardized parameter estimate; SE – standard error; R² – cumulative R²

Note. Model 1 – Social cognition at 18 months; Model 2 – executive functioning at 3 years; Model 3 – theory of mind at 3 years. Model 4 – executive functioning at 4.5 years; Model 5 – theory of mind at 4.5 years.
2.4 Discussion

In summary, the current study found that the presence of hypertension during pregnancy was negatively associated with children’s social cognition at 18 months and their ToM and EF at ages 3 and 4.5. In general, these findings support the notion that an unfavourable intrauterine environment may impinge on healthy fetal brain development, thereby compromising neuropsychological functioning across early postnatal life (Geva, Eshel, Leitner, Valevski, & Harel, 2006; Padilla et al., 2011; Tolsa et al., 2004). Although the mechanisms that underpin these relationships are not fully understood, it has been suggested that fetal exposure to increased oxidative stress and hypoxia associated with hypertensive difficulties during pregnancy may contribute to suboptimal neurocognitive outcomes (de Souza et al., 2011; Luo et al., 2006; Shah, 2001). It has also been suggested that fetal protein-energy malnutrition resulting from maternal hypertension affects global and cortex-specific brain regions involved in cell proliferation, differentiation, synaptogenesis, and growth factor synthesis (Georgieff, 2007). Furthermore, neuroimaging studies suggest that infants with intrauterine growth restriction (IUGR) – a possible consequence of pregnancy hypertension – have altered patterns of grey and white matter in temporal, parietal, and frontal brain areas (Batalle et al., 2012; Padilla et al., 2011). Interestingly, social cognition (including ToM) and EF are believed to be supported by a distributed fronto-tempo-parietal network (Collette & Van der Linden, 2002; Lie, Specht, Marshall, & Fink, 2006; Rothmayr et al., 2011; Spreng, Mar, & Kim, 2009), leading to the possibility that prenatal insults such as hypertension may disrupt the optimal development of neural structures that support neuropsychological growth and development. Research linking intrauterine conditions to postnatal outcomes has proved critical to our understanding of the fetal-programmed basis of psychosocial health and development (Feldman, 2008; Gerner & Baron, 2014). The current findings suggest that social cognition and EF may be two discrete neurocognitive domains that are impacted by heightened endocrine and inflammatory mediators of maternal, placental, and fetal stressors during pregnancy (Buss, Entringer, & Wadhwa, 2012). As social cognition and EF are associated with a range of neurodevelopmental and mental health conditions across the lifespan (Geurts, Verté, Oosterlaan, Roeyers, & Sergeant, 2004; Pilowsky, Yirmiya, Arbelle, & Mozes, 2000), it is possible that these cognitive substrates provide an endophenotypic link between early intrauterine conditions and children’s psychosocial outcomes.
Further studies are needed to clarify these complex and presently unspecified mechanisms of development.

The results of this study should be considered in light of limitations, including the small number of women affected by hypertension, sample attrition, and the self-report and dichotomous measurement of hypertension. Future research should include comprehensive obstetrical records, type of hypertension (e.g. gestational, preeclampsia, etc.), timing and length of exposure to prenatal conditions (e.g. first trimester, second trimester, throughout pregnancy, etc.), and a record of prenatal care.

2.5 Acknowledgments

We are grateful to the KFP families the Hamilton and Toronto Public Health Units and to Mira Boskovic for project management. The grant ‘Transactional Processes in Emotional and Behavioural Regulation: Individuals in Context’ was awarded to Jennifer M. Jenkins and Michael Boyle from the Canadian Institutes of Health Research and covered data collection. We are also grateful to the Connaught Global Challenge Fund for providing financial support to the contributors of this study.

2.6 References – Study 2


Feldman, R. (2008). The intrauterine environment, temperament, and development: Including the


2.7 Supplementary Material for Study 2

Additional Sample and Measurement Details

Additional Sample Details

Attrition
Attrition analysis showed that family dropout was related to lower maternal age at first pregnancy, \( t(494) = -5.10, p < .001 \), lower socioeconomic status, \( t(498) = -5.07, p < .001 \), and lower maternal education, \( t(498) = -2.99, p < .005 \). For outcome measures between 18 months and 4.5 years, there was also variable levels of missing data due child noncompliance, lack of visibility (e.g., child went off camera), parent intrusion (e.g., directing child’s attention), non-administration due to family constraints (e.g. time limits) or tester administration error (e.g., not following the standardized protocol).

Sample Representativeness
On measures of demographics taken at T1, the sample was representative of the general population of Toronto and Hamilton in terms of family size (\( M = 4.52, SD = 1.01 \) in IKFP versus \( M = 4.13, SD = 1.22 \) in the Census data) and personal income ($30,000-39,999 versus $30,504.16, \( SD = $37,808.12 \)). However, the study sample had more educated mothers (53% had a Bachelor’s degree compared to 30.6% in the general population), had fewer non-intact families (lone-parent: 5% versus 16.8%; step-families: 4.3% vs. 10.3%), and had fewer immigrants (47% versus 57.7%; see Meunier et al., 2013). Sample demographics, including a comparison of hypertensive (\( n = 23 \)) and non-hypertensive (\( n = 478 \)) mothers, are presented in Table 1.

Propensity Score Matching
To generate the matched sample from the subsample of 478 non-hypertensive mothers, we used the nearest neighbor matching technique described by Lanza and colleagues (2013). Logistic regression was used with hypertension status (0 = no; 1 = yes) as the outcome, and all above covariates were included in the model to adjust the probability of being “exposed” to hypertension. These probability scores were saved. Then, individuals in the hypertension group were sorted and matched to an individual in the non-hypertension group with the closest propensity score. This process continued iteratively until all 23 hypertensive cases had a matched control. The result was a subsample of 46 participants (23 hypertension; 23 control) that were matched on demographic characteristics.

A statistical comparison of the hypertensive and non-hypertensive groups on demographic characteristics is in Table S1 below. This comparison suggests that the hypertensive (\( n = 23 \)) and non-hypertensive (\( n = 23 \)) groups were indeed “matched” on sociodemographics, supporting the inferences made in text.
Table S-1: Demographic characteristics of sample at study entry

<table>
<thead>
<tr>
<th>Measure</th>
<th>% Overall</th>
<th>% Non-hypertensive (n = 478)</th>
<th>% Hypertensive (n = 23)</th>
<th>χ² value</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ethnicity of mothers</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>European/Caucasian</td>
<td>100.0</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>South Asian</td>
<td>55.7</td>
<td>56.4</td>
<td>60.9</td>
<td>.179</td>
<td>.83</td>
</tr>
<tr>
<td>East Asian</td>
<td>14.4</td>
<td>14.7</td>
<td>8.7</td>
<td>.636</td>
<td>.56</td>
</tr>
<tr>
<td>Black</td>
<td>11.8</td>
<td>12.4</td>
<td>4.3</td>
<td>1.34</td>
<td>.34</td>
</tr>
<tr>
<td>Other</td>
<td>8.8</td>
<td>8.8</td>
<td>17.4</td>
<td>1.94</td>
<td>.15</td>
</tr>
<tr>
<td>Teen mom</td>
<td>9.4</td>
<td>7.7</td>
<td>8.7</td>
<td>.014</td>
<td>1.0</td>
</tr>
<tr>
<td>Single mother</td>
<td>6.3</td>
<td>5.7</td>
<td>17.4</td>
<td>5.09</td>
<td>.05</td>
</tr>
<tr>
<td>New-immigrant family (&lt;10 years)</td>
<td>6.4</td>
<td>6.1</td>
<td>13.0</td>
<td>1.78</td>
<td>.18</td>
</tr>
<tr>
<td>Low income family (&lt;$20,000)</td>
<td>46.5</td>
<td>47.0</td>
<td>34.3</td>
<td>1.31</td>
<td>.29</td>
</tr>
<tr>
<td>Mother’s years of education (&lt;high school)</td>
<td>18.0</td>
<td>17.6</td>
<td>26.1</td>
<td>1.07</td>
<td>.28</td>
</tr>
<tr>
<td>Mothers scoring in depressed range on CES-D</td>
<td>16.6</td>
<td>19.9</td>
<td>17.4</td>
<td>.01</td>
<td>1.0</td>
</tr>
<tr>
<td>Infant birth weight &lt;2500g</td>
<td>3.6</td>
<td>3.8</td>
<td>0</td>
<td>.904</td>
<td>1.0</td>
</tr>
<tr>
<td>Gestational age &lt;37 weeks</td>
<td>4.0</td>
<td>4.0</td>
<td>4.3</td>
<td>.01</td>
<td>1.0</td>
</tr>
<tr>
<td>Pregnancy diabetes</td>
<td>6.0</td>
<td>6.3</td>
<td>0</td>
<td>1.54</td>
<td>.39</td>
</tr>
<tr>
<td>Pregnancy thyroid problems</td>
<td>3.2</td>
<td>3.1</td>
<td>4.3</td>
<td>.103</td>
<td>.54</td>
</tr>
</tbody>
</table>

CES-D - Center for Epidemiological Studies Depression Scale
Table S-2: Comparison of matched sample on demographic characteristics

<table>
<thead>
<tr>
<th>Measure</th>
<th>Non-hypertensive (n = 23) (mean or %)</th>
<th>Hypertensive (n = 23) (mean or %)</th>
<th>t statistic or $\chi^2$ value</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mother age at child birth</td>
<td>31.4</td>
<td>31.1</td>
<td>.16</td>
<td>.87</td>
</tr>
<tr>
<td>Maternal education</td>
<td>14.3</td>
<td>14.4</td>
<td>-.06</td>
<td>.95</td>
</tr>
<tr>
<td>Family SES</td>
<td>-.39&lt;sup&gt;a&lt;/sup&gt;</td>
<td>-.37&lt;sup&gt;a&lt;/sup&gt;</td>
<td>-.09</td>
<td>.93</td>
</tr>
<tr>
<td>Income and education composite</td>
<td>-.28&lt;sup&gt;a&lt;/sup&gt;</td>
<td>-.19&lt;sup&gt;a&lt;/sup&gt;</td>
<td>-.66</td>
<td>.52</td>
</tr>
<tr>
<td>Maternal depression</td>
<td>12.7</td>
<td>11.9</td>
<td>.36</td>
<td>.72</td>
</tr>
<tr>
<td>Age of mother at first pregnancy</td>
<td>27.0</td>
<td>26.4</td>
<td>.46</td>
<td>.65</td>
</tr>
<tr>
<td>Birth weight</td>
<td>3.48</td>
<td>3.37</td>
<td>.82</td>
<td>.42</td>
</tr>
<tr>
<td>Gestational age</td>
<td>39.1</td>
<td>38.7</td>
<td>1.34</td>
<td>.19</td>
</tr>
<tr>
<td>Smoking</td>
<td>13.0%</td>
<td>17.4%</td>
<td>.17</td>
<td>1.00</td>
</tr>
<tr>
<td>Teen mother</td>
<td>4.3%</td>
<td>17.4%</td>
<td>2.02</td>
<td>.35</td>
</tr>
<tr>
<td>Immigrant</td>
<td>39.1%</td>
<td>34.8%</td>
<td>.09</td>
<td>1.00</td>
</tr>
</tbody>
</table>
3 Study 3: Normal birth weight variation and children’s neuropsychological functioning: links between language, executive functioning, and theory of mind

3.1 Introduction

Low birth weight (LBW; <2500g) is associated with a range of physical, cognitive, and neurobehavioural impairments in children and adolescents, including lower IQ (Anderson & Doyle, 2003), greater inattention and hyperactivity (Hack et al., 2009), poor motor development (de Kieviet, Pick, Aarnoudse-Moens, & Oosterlaan, 2009), lower academic achievement (Aarnoudse-Moens, Weisglas-Kuperus, van Goudoever, & Oosterlaan, 2009; Anderson & Doyle, 2003), impaired visual-spatial ability (Geldof, Van Wassenaer, de Kieviet, Kok, & Oosterlaan, 2011), and more internalizing and externalizing problems (Dahl et al., 2006; Grunau, Whitfield, & Fay, 2004). Among the most pronounced and robust deficits of LBW are problems with language and executive functioning (Aarnoudse-Moens et al., 2009). Executive functioning (EF) is the set of cognitive processes required for goal-directed action and problem-solving, including inhibition, working memory, shifting, and cognitive flexibility. However, little is currently known about the relationship between birth weight variability and neuropsychological outcomes for children weighing ≥2500g (i.e. the normal range) despite the fact that the vast majority (92%) of the population falls within this range (Martin et al., 2009). The current study was designed to address this gap in the literature by testing a developmental mechanism, namely emergent language skills, linking normative birth weight variability to two critical neuropsychological capacities that unfold over the preschool period: executive functioning and theory of mind.

3.1.1 Impact of relatively low birth weight in normative samples

Within the LBW range, there is a dose-response relationship between birth weight and neurocognitive outcomes – higher birth weight is associated with better language, spatial ability, and attention (Breslau, Chilcoat, DelDotto, Andreski, & Brown, 1996). A similar pattern emerges for children born in the normal range. In a large study of 3484 children born within the normal range of birth weight, Matte et al. (2001) showed that IQ at age 7 increased monotonically with birth weight. Other studies have since shown that normative variation in birth weight is related to academic abilities such as reading, arithmetic, and spelling at age 10.
(Kirkegaard, Obel, Hedegaard, & Henriksen, 2006), and risk of developmental disabilities such as cerebral palsy, learning disabilities, and attention-deficit-hyperactivity disorder (ADHD) in 3-17 year-old children (Boulet, Schieve, & Boyle, 2011). Thus, the effect of birth weight on broad, complex phenotypes may be more far-reaching than previously thought.

### 3.1.2 Birth weight variability and cognitive domain-specificity

One fundamental limitation of previous studies assessing the relation between birth weight and child outcomes is a lack of specificity in the neuropsychological domains that may be impacted by this perinatal factor. For instance, global measures of cognitive ability (e.g. full-scale IQ), phenomenological symptom clusters (e.g. psychiatric diagnoses), and phenotypically complex performance outcomes (e.g. academic achievement) offer little in the way of understanding the relatively discrete and modular cognitive processes that may be impacted by birth weight. Phua et al. (2012) recently showed that higher birth weight within the normal range was associated with a linear increase in EF, suggesting that this may be one critical domain-specific neuropsychological capacity linking fetal growth to a range of developmental outcomes supported by EF. Consistent with this idea, Hatch, Healey, & Halperin (2013) showed that the effect of birth weight on ADHD symptom severity operated indirectly through children’s EF. Aside from EF, however, little empirical attention has been devoted to the cognitive substrates related to birth weight differences within the normal range.

One cognitive skill that has yet to be examined in relation to birth weight differences is theory of mind (ToM) – the social-cognitive ability to interpret others’ behaviour in terms of underlying psychological states such as emotions, desires, intentions, and beliefs. There is reason to suspect that this cognitive capacity may vary as a function of birth weight differences. For instance, there is a robust behavioural link between ToM and EF in the preschool period (Carlson, Moses, & Breton, 2002; Hughes, 1998), and children with ADHD also exhibit difficulties with social cognition (Uekermann et al., 2010). Recent neuroimaging evidence points to a potential neurological link between EF and ToM that involves the medial prefrontal cortex (mPFC), temporo-parietal junction (TPJ), and lateral prefrontal areas (Gallagher & Frith, 2003a; Rothmayr et al., 2011; Spreng, Mar, & Kim, 2009). Thus, it is conceivable that birth weight is associated with both EF and ToM owing to a shared neural network that is compromised in lower birth weight children (Walhovd et al., 2013).
3.1.3 Neural correlates of low birth weight

Studies examining the cortical regions affected by low birth weight show that LBW infants exhibit regional thinning of temporal and parietal regions (Martinussen et al., 2009), areas that have long been considered important for language production and understanding (Kennison, 2013). Damage to the TPJ has also been shown to instigate deficits in ToM (Apperly, Samson, Chiavarino, & Humphreys, 2004), and has been implicated in certain executive functions (Lie, Specht, Marshall, & Fink, 2006). Moreover, it has recently been suggested that the executive dysfunctions of LBW adolescents may be attributable to white matter abnormalities in the cingulum and fronto-occipital regions of prefrontal cortex (Skranes et al., 2009). Interestingly, the cingulum connects the anterior cingulate cortex (ACC) to the dorsolateral prefrontal cortex, and there is some evidence for the involvement of these areas in ToM-based tasks (Gallagher & Frith, 2003b; Spreng et al., 2009; Stone, Baron-Cohen, & Knight, 1998). Thus, not only do ToM and EF share a common neural architecture when assessed in normative populations, but the brain regions damaged by low birth weight may be important for the development of both of these cognitive capacities. These results provide neurobiological evidence for the interconnectedness of language, EF, and ToM, warranting the exploration of birth weight correlates for all three of these neuropsychological domains amongst children ≥2500g.

3.1.4 Developmental pathways of neurocognitive impairment

Another area that has been understudied is the developmental mechanism through which fetal risk relates to specific aspects of cognitive functioning. Language has long been considered a fundamental aspect of human cognition that augments the development of other cognitive faculties (Fernyhough, 2008; Vygotskiï, 1997). Empirical evidence shows that early language skills are predictive of later ToM (Astington & Jenkins, 1999) and EF (Hughes & Ensor, 2007a). Verbal mediation of EF and ToM is further suggested by studies showing that individuals with specific language impairment have broadband difficulties with many aspects of EF (Henry, Messer, & Nash, 2012) and ToM (Farrant, Fletcher, & Maybery, 2006). These findings are consistent with the notion that EF and ToM may rely on language due to the need for verbal self-reminding (Russell, Jarrold, & Hood, 1999), conscious reflection (Marcovitch & Zelazo, 2009), and the integration of domain-specific knowledge that enables the representation, reasoning, and strategic control of thought and action (Carruthers, 2002). No study to date has examined
language as a mediating link between birth weight differences and other forms of cognition, either in low- or normal-birth weight samples. In the current study, we focused on receptive language, as this has been widely associated with children’s ToM and EF in the preschool period (Fuhs & Day, 2011; Hughes & Ensor, 2005; Müller et al., 2012; Perner, Lang, & Kloo, 2002).

3.1.5 Goals of the current study

To date, drawbacks in the examination of birth weight disparities in child neurocognition include: (a) a paucity of research examining neuropsychological outcomes within the normal range of birth weight; (b) a lack of understanding about the specific neurocognitive domains impacted by low birth weight; (c) the exclusion of key neuropsychological abilities that are critical to children’s psychosocial development, including theory of mind; and (d) little attention to the mechanisms through which birth weight differences contribute to neuropsychological functioning. The current study used a normative sample of 468 children to test the hypothesis that variability in birth weight ≥2500g would be associated with children’s EF and ToM ability at age 4.5, the latter of which has not previously been examined. Consistent with the mediating role of language in human cognition, it was further hypothesized that the relationship between birth weight and both EF and ToM would operate through children’s intermediary language ability at 3 years.

3.2 Method

3.2.1 Participants

All women giving birth to infants in the cities of Toronto and Hamilton between February 2006 and February 2008 were considered for participation. Families were recruited through a program called Healthy Babies Healthy Children, run by the Public Health Units of Toronto and Hamilton, which contacts the parents of all newborn babies within 7 days of the child’s birth. Inclusion criteria for the intensive sample of the Kids, Families, and Places study (iKFP) included: (1) an English-speaking mother; (2) a newborn >1500 grams; (3) a sibling <4 years old; and (4) agreement to be videotaped. Thirty-four percent of families approached agreed to take part. Reasons for non-enlistment included inability to contact families through the information given by public health, as well as refusals. The current study was embedded within a larger project, the goals of which were to examine genetic and environmental influences on
children’s socio-emotional development through the investigation of within-family differences.

As we were interested in examining neurocognition as it was unfolding, the current study focuses exclusively on the newborn children enrolled in the study. The University of Toronto Research Ethics Board approved all procedures for this investigation, including informed consent.

At Time 1 (T1; infants were ~2 months old), 501 families were enlisted in the study. Due to sample attrition, 397 of the original 501 families were followed up at Time 2 (T2; children now ~18 months old), 385 were followed up at Time 3 (T3; ~3-years-old), and 323 were followed up at Time 4 (T4; children ~4.5-years-old). The current study drew on data from all time points in order to test the study hypotheses. Sample demographics at study entry are presented in Table 7.

Table 7. Demographics of sample (\(N = 468\)) at study entry

<table>
<thead>
<tr>
<th>Measure</th>
<th>(N)</th>
<th>% of sample</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ethnicity of mothers</td>
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</tr>
<tr>
<td>European/Caucasian</td>
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<tr>
<td>South Asian</td>
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<tr>
<td>East Asian</td>
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<td>12.0</td>
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</tr>
<tr>
<td>Other</td>
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<td>9.4</td>
</tr>
<tr>
<td>Teen mom</td>
<td>29</td>
<td>6.3</td>
</tr>
<tr>
<td>Non-intact family</td>
<td>53</td>
<td>11.3</td>
</tr>
<tr>
<td>New-immigrant family (&lt;10 years)</td>
<td>213</td>
<td>45.5</td>
</tr>
<tr>
<td>Low income family (&lt;$20,000)</td>
<td>37</td>
<td>8.4</td>
</tr>
<tr>
<td>Mother’s years of education (&lt;high school)</td>
<td>78</td>
<td>16.7</td>
</tr>
<tr>
<td>Mothers scoring in depressed range on CES-D</td>
<td>73</td>
<td>15.8</td>
</tr>
<tr>
<td>Infant birth weight &lt;2500g(^a)</td>
<td>18</td>
<td>3.6</td>
</tr>
<tr>
<td>Gestational age &lt;37 weeks(^a)</td>
<td>20</td>
<td>4.0</td>
</tr>
</tbody>
</table>

CES-D – Center for Epidemiological Studies Depression Scale

\(^a\)As the sample excluded those born <2500g and at <37 weeks gestation, these values reflect the number of children in the overall sample at study entry (\(N = 501\)).
On measures of demographics taken from the entire iKFP at study entry (T1; \( N = 501 \)), the sample was representative of the general population of Toronto and Hamilton in terms of family size (\( M = 4.52, SD = 1.01 \) in IKFP compared to \( M = 4.13, SD = 1.22 \) in the Census data) and personal income ($30,000-39,999 compared to $30,504.16, \( SD = 37,808.12 \)). However, the study sample had more educated mothers (53% had a Bachelor’s degree versus 30.6% in the general population), had fewer non-intact families (lone-parent: 5% versus 16.8%; step-families: 4.3% versus 10.3%), and had fewer immigrant families (47% versus 57.7%; Meunier, Boyle, O’Connor, & Jenkins, 2013). According to the 2011 National Household Survey (NHS), the make-up of the immigrant population in Toronto (% of total population) is: 12.7% East Asian (Chinese, Korean, Japanese), 12.3% South Asian, 8.5% Black, 7.0% Southeast Asian, 5.1% Filipino, 2.8% Latin American, 2.0% West Asian, 1.1% Arab, 0.7% Aboriginal, 1.5% Multiracial, and 1.3% Other.

Only children with birth weights ≥2500g and gestational ages ≥37 weeks were included in order to limit the sample to non-premature and non-LBW children. There were 21 children (4.2%) born under 2500g and 20 children (4.0%) born under 37 gestational weeks. Exclusion of these children resulted in a final sample of 468 children (93.4% of total sample). For outcome measures at 3 and 4.5 years (child language, EF, and ToM), there were variable levels of missing data due to child noncompliance, administration error (e.g., the study interviewer did not follow the standardized protocol), or family limitations (running out of time). Table 2 shows data availability for all measures across time points.

### 3.2.2 Attrition Analysis

Attrition analysis was conducted in which participants remaining in the sample at T4 were compared to those who dropped out on key demographic variables measured at study entry. Compared to families that remained in the sample at T4, those who dropped out were comparable on family structure (i.e. intact versus non-intact family), \( \chi^2 (df = 1) = 3.30, p = .083 \), clinical levels of maternal depression, \( \chi^2 (df = 1) = 3.52, p = .080 \), whether the mother was an immigrant, \( \chi^2 (df = 1) = .85, p = .38 \), teenage motherhood, \( \chi^2 (df = 1) = 4.15, p = .067 \), and family income <$20,000, \( \chi^2 (df = 1) = 2.19, p = .15 \). Families who dropped out were more likely than those who did not participate to have mothers with less than high school education, \( \chi^2 (df = 1) = 7.05, p = .009 \). Using birth weight and gestational age as continuous measures, there were no
differences between those who remained at T4 versus those who dropped out on birth weight, \( t(466) = -0.71, p = .48 \), or gestational age, \( t(466) = 0.54, p = .59 \). Also, there were no differences on T3 language (receptive vocabulary) for those who dropped out from T3 to T4, \( t(282) = .79, p = .43 \).

3.2.3 Procedure

At each time point, a home visit of approximately two hours involved questionnaires related to prenatal and pregnancy information (T1 only) as well as demographics and family life. Children’s neuropsychological abilities (Language, ToM, and EF) were also directly assessed using age-appropriate standardized and/or observational tasks.

3.2.4 Measures

**Birth weight.** At T1, mothers reported their newborn’s birth weight in kilogram and grams. This score was normally distributed across the normal birth weight range (≥2500 g).

**Gestational age.** At T1, mothers reported the number of gestational weeks of the child.

**Language (T3).** The *Peabody Picture Vocabulary Test – Third Edition* (PPVT; Dunn & Dunn, 1997) was used to assess children’s language ability at T3. The PPVT is a standardized measure of receptive vocabulary skills for children aged ≥ 2 years. Children are required to point to a picture that corresponds to the stimulus word among a bank of four picture options. The PPVT has been shown to be adequately reliable and valid (Dunn & Dunn, 1997).

**Executive Functioning (T4).** This was assessed using the Bear/Dragon task (Reed, Pien, & Rothbart, 1984) and the Dimensional Change Card Sort (DCCS; Zelazo, 2006), two of the best-validated and most widely used tasks for the assessment of EF in the current age group (Carlson, Mandell & Williams, 2004; Carlson, 2005; Blair, Zelazo & Greenberg et al., 2005). We followed Carlson’s (2005) measurement guidelines for maximizing detection of age-dependent individual differences in inhibitory control, set shifting, and working memory. For the *Bear/Dragon* task, children were instructed to do what they were told by the nice bear (e.g., “touch your nose”), but not to do what they were told by the mean dragon. Children were scored for total number of correct responses on five dragon and five bear trails (0-10). This task has been shown to be highly correlated with other executive function tasks (Carlson et al., 2004) and to relate well to
expected child and context factors (Sabbagh, Xu, Carlson, Moses & Lee, 2006). For the DCCS, children were required to sort a series of bivalent test cards, first according to one dimension (e.g., color), and then according to the other (e.g., shape). Children who pass the post-switch phase of the standard version of the DCCS may proceed immediately to the border version, which uses the same target cards as the standard version. The border version consists of 12 trials. Children are required to sort cards based on “border” criteria (“If there’s a border, play the color game. If there’s no border, play the shape game”). Previous studies have shown that Bear/Dragon and DCCS load onto the same latent factor measuring set shifting, working memory, and inhibitory control (Bernier, Carlson, Deschênes, & Matte-Gagné, 2012) and in the current study were also significantly correlated, $r = .34 \ p < .001$. Consequently, they were z-scored and averaged into a composite measure of EF. Higher scores represented better EF ability.

Theory of mind (ToM). ToM was measured using the scale described by Wellman and Liu (2004), representing the most comprehensively validated test of ToM (Sabbagh & Seamans, 2008), including validation across cultures, languages, and in both typically and atypically developing children (Peterson et al., 2012). ToM has been found to be stable over time (Jenkins & Astington, 2000). The Wellman and Liu (2004) scale presents various tasks sequentially in a manner that maps onto the children’s theory of mind development. As children move through the scale, tasks become conceptually more difficult. Thus, progression further along the scale reflects more sophisticated ToM understanding. The first three tasks assessed children’s understanding of diverse desires and beliefs, and knowledge and ignorance, followed by tasks assessing more sophisticated ToM understanding such as belief-based emotion, and real-apparent emotion. If children failed two consecutive tasks, testing was stopped. For all tasks, stories were enacted for children with the use of puppets and props. A total score across all tasks (pass/fail) was computed. Internal consistency was high, $\alpha = .87$.

Covariates. These included the child’s current age (in years), gestational age (in weeks), and gender (0 = male, 1 = female). Socioeconomic status (SES) was assessed via both maternal education (in years) and annual family income assessed on a scale from 1 (‘no income’) to 16 (‘$105,000 or more’), reported by the mother. Also included was the Canadian-born status of the mother as a dichotomous variable (0 = no; 1 = yes), and the number of children in the home, as this has been shown to impact cognitive outcomes.
3.2.5 Analysis Plan

The analysis was carried out using Mplus version 7.0 (Muthén & Muthén, 2010). Path analysis was used to examine the total, direct, and indirect effects hypothesized above. The total effect \((c)\) path is a measure of the effect of birth weight on the outcome (EF or ToM) without inclusion of the mediator (language). The direct effect \((c')\) path is the effect of birth weight on the outcome after inclusion of the mediator. The indirect effect \((ab)\) path is the effect of birth weight on the outcome through the hypothesized mediator, and is thus the product of the effect of birth weight on language \((a)\) path and language on the outcome \((b)\) path. Indirect effects were tested using the delta method (Sobel, 1982), which is the default in Mplus. These paths were tested simultaneously for both ToM and EF, thereby providing unique estimates for each outcome. The delta method calculates the standard error of the product of two variables, which can then be used to determine the significance of the indirect path. This method is used in applied statistics to obtain approximate standard errors and confidence intervals of parameters in path analysis and basic structural equation models (Raykov & Marcoulides, 2004). Since covariates are not readily available in viewing the path model, we also present the full regression results for the path model that include all covariates. In these regression models, all variables were entered simultaneously, and thus control for all other effects in the model. We report standardized effects for all results.

Full information maximum likelihood estimation (FIML) was utilized for all analyses. This method offers improvements over traditional approaches for handling missing data such as listwise deletion, pairwise deletion, and imputation in terms of parameter bias, model convergence and fit (Acock, 2005; Enders & Bandalos, 2001). FIML can handle up to 50% missing data without biasing the estimates (Graham & Schafer, 1999). The estimator used was a maximum-likelihood with robust standard errors (MLR) estimator, which produces parameter estimates with standard errors and a chi-square that are robust to non-normality when missing data are present (Muthén & Muthén, 2010). For model fit, we report the root-mean-square-error of approximation (RMSEA), comparative fit index (CFI), Tucker-Lewis index (TLI), and standardized root-mean-square residual (SRMR).
3.3 Results

Descriptive statistics, including means, standard deviations, variable frequencies, and ranges for study variables across time are presented in Table 8. Table 9 presents the bivariate relationships between study variables. Notable associations include the relationship between family income and maternal education with all child outcomes (T3 language and T4 EF and ToM), and significant inter-relations among all neuropsychological skills. Unsurprisingly, child age was associated with all neuropsychological outcomes, with older children performing better across tasks. Females performed significantly better than males on T4 ToM tasks. The Canadian-born status of the mother was also related to all child outcomes, with the children of Canadian-born mothers having higher skills across neurocognitive domains. The number of children in the home was negatively associated with maternal education and family income, as well and children’s language ability at T3. Birth weight was positively associated with children’s language at T3, their EF at T4, and marginally associated with ToM ability at T4.

Table 10 presents the final regression results from the path analysis for child language at T3 (age 3) and EF and ToM at T4 (age 4.5). For T3 language, higher family income [$\beta$ (SE) = .30 (.10), $p = .002$], having a Canadian-born mother [$\beta$ (SE) = .20 (.08), $p = .007$], fewer children in the home [$\beta$ (SE) = -.15 (.05), $p = .005$], and being higher birth weight [$\beta$ (SE) = .17 (.07), $p = .012$] were significant predictors of higher receptive vocabulary at age 3. This model explained 24% of the variance in child language. For EF, older age [$\beta$ (SE) = .18 (.06), $p = .001$] and higher language at T3 [$\beta$ (SE) = .32 (.09), $p < .001$] were the only significant predictors of higher EF at age 4.5. This model explained 18% of the variance in EF. Finally, for ToM, female gender [$\beta$ (SE) = .19 (.06), $p = .003$] and higher T3 language [$\beta$ (SE) = .30 (.07), $p < .001$] were the only significant predictors of higher ToM at age 4.5. This model explained 15% of the variance in ToM.

Indirect effects of birth weight on EF and ToM at T4 through language at T3 were examined next. First, model fit was excellent in accordance with recommended criteria of Hu and Bentler (1999): RMSEA = .016, CFI = .99, TLI = .98, and SRMR = .014. For ToM, the total effect was significant [$\beta$ (SE) = .13 (.07), $p = .05$], meaning that, without child language in the model, higher birth weight significantly predicted higher ToM.
<table>
<thead>
<tr>
<th>Measure</th>
<th>T1</th>
<th>T2</th>
<th>T3</th>
<th>T4</th>
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<tr>
<td></td>
<td>M</td>
<td>SD</td>
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<tr>
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<td>.00-.58</td>
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<td>-</td>
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<tr>
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<tr>
<td>Theory of mind</td>
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*These variables are z-scored or standardized composites, which explains the mean centered at zero.

Note. PPVT – Peabody Picture Vocabulary Test – Third Edition
Table 9. Bivariate associations between study variables

<table>
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<tr>
<th>Measures</th>
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<td>7. Canadian-born status</td>
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<td>-.19***</td>
<td>.66</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>9. Language (T3)</td>
<td>.16**</td>
<td>.06</td>
<td>.14†</td>
<td>.07</td>
<td>.15†</td>
<td>.40***</td>
<td>.29***</td>
<td>-.12*</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>10. Executive function (T4)</td>
<td>.12*</td>
<td>-.10†</td>
<td>.24***</td>
<td>.01</td>
<td>.10†</td>
<td>.17**</td>
<td>.15†</td>
<td>-.06</td>
<td>.32***</td>
<td>-</td>
</tr>
<tr>
<td>11. Theory of mind (T4)</td>
<td>.10†</td>
<td>.09</td>
<td>.22***</td>
<td>.15†</td>
<td>.13†</td>
<td>.15†</td>
<td>.11†</td>
<td>-.04</td>
<td>.27***</td>
<td>.33***</td>
</tr>
</tbody>
</table>

† p < .10. † p < .05. ** p < .01. *** p < .001

Table 10. Regression results for mediator (language) and outcome (EF and ToM) variables

<table>
<thead>
<tr>
<th>Predictors</th>
<th>1. Language (T3)</th>
<th></th>
<th>2. Executive function (T4)</th>
<th></th>
<th>3. Theory of mind (T4)</th>
<th></th>
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<tbody>
<tr>
<td></td>
<td>STD (SE)</td>
<td>R²</td>
<td>STD (SE)</td>
<td>R²</td>
<td>STD (SE)</td>
<td>R²</td>
</tr>
<tr>
<td>Child age</td>
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<td>.18 (.06)**</td>
<td>.13 (.07)†</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Female gender</td>
<td>.04 (.06)</td>
<td>.06 (.06)</td>
<td>.13 (.06)†</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maternal education</td>
<td>-.04 (.09)</td>
<td>.06 (.08)</td>
<td>.14 (.08)†</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Family income</td>
<td>.30 (.10)**</td>
<td>-.01 (.07)</td>
<td>-.05 (.08)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Canadian-born status</td>
<td>.20 (.08)**</td>
<td>.24***</td>
<td>-.01 (.06)</td>
<td>.18**</td>
<td>-.04 (.08)</td>
<td>.15**</td>
</tr>
<tr>
<td>Number of kids in home</td>
<td>-.15 (.05)**</td>
<td>-.02 (.05)</td>
<td>.04 (.05)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gestational age</td>
<td>-.06 (.07)</td>
<td>-.11 (.06)†</td>
<td>.06 (.06)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Birth weight</td>
<td>.17 (.06)**</td>
<td>.10 (.05)†</td>
<td>.08 (.07)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Language</td>
<td>--</td>
<td>.33 (.10)***</td>
<td>.30 (.07)***</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

† p < .10. † p < .05. ** p < .01. *** p < .001

STD – standardized parameter estimate; SE – standard error
Model 1 – Language at T3; Model 2 – Executive function at T4; Model 3 – Theory of mind at T4
Upon inclusion of child language at T3, the direct effect from birth weight to ToM was reduced to non-significance \( \beta \) (SE) = .08 (.07), \( p = .23 \). Also, the indirect effect of birth weight on ToM through child language was significant \( (z = 2.05, p = .041) \), suggesting that language at age 3 mediates the relationship between birth weight and ToM at age 4.5. The standardized indirect effect size \((a*b)\) was .050, which corresponds to a small to medium effect.

For EF, the total effect was significant \( \beta \) (SE) = .15 (.06), \( p = .008 \), meaning that birth weight shows an association with EF when language is not included in the model. Upon inclusion of language at T3, the direct effect was reduced to non-significance, but continued to show a marginal association with EF \( \beta \) (SE) = .10 (.06), \( p = .08 \). The indirect effect of birth weight on EF through child language was significant \( (z = 2.07, p = .038) \), suggesting that the effect of birth weight on EF at age 4.5 operates (at least partially) indirectly through language ability at age 3 (see Figure 1). The standardized indirect effect size \((a*b)\) was .054, which is a small to medium effect.

\[\text{Newborn} \quad \longrightarrow \quad \text{3 years} \quad \longrightarrow \quad \text{4.5 years}\]

**Figure 5.** Path model for the hypothesized indirect effect of birth weight on theory of mind (ToM) and executive functioning (EF) at age 4.5 through child language (receptive vocabulary) measured at 3 years. Estimates are standardized coefficients (standard errors presented in brackets). All parameters control for covariates. Effects from birth weight to ToM and EF are direct effects after inclusion of mediator (i.e. language); see in-text for total and indirect effect estimates. \( \dagger p < .10 \), \( \ast p < .05 \), \( \ast\ast p < .01 \), \( \ast\ast\ast p < .001 \).
3.4 Discussion

The current study used a prospective community birth cohort to examine the relationship between normal birth weight variation (≥2500g) and children’s neuropsychological outcomes, and a potential mechanism linking the development of these skills over time. After controlling for a variety of potential confounding variables, it was demonstrated that birth weight was positively associated with children’s language ability (indexed their receptive vocabulary) at age 3, as well as their EF and ToM abilities at age 4.5. These results are consistent with previous reports showing that birth weight variation within the normative range is associated with a host of child outcomes such as IQ, academic abilities, and executive control (Kirkegaard et al., 2006; Matte et al., 2001; Noble et al., 2012; Phua et al., 2012). The current study builds on past findings by showing that the effect of birth weight on children’s EF and ToM in the preschool period is mediated by their language skills at age 3, suggesting that lower birth weight within the normal range may disrupt the optimal development of key language skills that serve as important predictors of emerging neuropsychological abilities.

The acquisition of language, EF, and ToM is especially salient in the preschool period, as this coincides with the transition of most children into kindergarten. This is important because children entering this stage of life who have mastered these neuropsychological skills are more likely to show favorable social outcomes (Razza & Blair, 2009), academic competence (Blair & Razza, 2007; Hughes & Ensor, 2011), lower levels of aggression (Olson, Lopez-Duran, Lunkenheimer, Chang, & Sameroff, 2011), and fewer internalizing and externalizing problems (Hughes & Ensor, 2007b, 2008, 2011). Many previous studies have documented the deleterious effect of LBW on various psychiatric conditions and developmental disorders, and recent studies have extended these findings into the normal birth weight range. The current study continues efforts to uncover the neuropsychological endophenotypes that potentially underpin these adverse outcomes (Hatch et al., 2013; Phua et al., 2012). Although more research is needed, this study supports previous findings and further implicates ToM as another cognitive ability that may be influenced by perinatal factors such as birth weight. As such, children with birth weights at the lower end of the normal range who have greater difficulty with EF and ToM may show difficulties across a range of associated psychosocial outcomes that rely on these critical neuropsychological skills.
Moreover, the current results speak to the important mediating role of language in EF and ToM development. The robust effect of birth weight on children’s language, in conjunction with the foundational role of language in the development of other cognitive abilities (Bickerton, 2005; Fernyhough, 2008), is consistent with these findings. Indeed, intervention studies show that language-based training programs have the effect of fostering both linguistic knowledge and ToM ability (Hale & Tager-Flusberg, 2003), which speaks to the causal role of language in ToM development (also see Astington & Jenkins, 1999). In addition, the provision of early verbal input from caregivers has been shown to influence later executive processing skills through children’s intermediary language ability in early and middle childhood (Landry, Miller-Loncar, Smith, & Swank, 2002; Matte-Gagné & Bernier, 2011). Taken together, these results suggest that language may be an essential cognitive ability linking birth weight variability to individual differences in EF and ToM in the preschool period.

In general, the current results are consistent with the notion that birth weight variability and resultant neuropsychological competencies should be considered along a phenotypic continuum. Importantly, however, the mechanisms connecting birth weight to neurocognitive outcomes may be different for children within the normative range compared to those classified as (V)LBW, who typically face more medical complications such as hypoxia-ischemia, infection, and periventricular leukomalacia (Stoll et al., 2004; Vohr et al., 2000). These conditions are characterized by cortical gray matter and white matter reductions (Inder et al., 1999), which are believed to underlie the cognitive and behavioral deficits observed in these infants (Rezaie & Dean, 2002). Interestingly, studies of normal birth weight children also show that that higher birth weight is related to increases in gray and white matter volume (Raznahan et al., 2012; also see Davis et al., 2011 for similar effects across the normal gestational age range). Further, for normal birth weight children, findings are suggestive of cortical variability in brain regions that have been previously implicated in language, ToM, and EF, including anterior cingulate, orbitofrontal, and temporo-parietal areas (Walhovd et al., 2013). Thus, relatively small differences in birth weight across the normal range may represent critical sources of inter-individual variability in neural functioning that support neuropsychological development. Nevertheless, it remains unclear whether the precise neural and physiological mechanisms linking birth weight to neurocognitive functioning are the same or different for (V)LBW compared to normal birth weight children. Additional factors such as antenatal stress, nutrition,
parity, and lifestyle factors including smoking and alcohol use may be important contributors for children in either the (V)LBW or normative range (Breeze & Lees, 2007). Future studies specifying and differentiating these mechanisms will improve our understanding of the unique pathways to children’s neuropsychological health and development.

Strengths and Limitations

The current findings should be considered in light of study strengths and limitations. The strengths included a prospective, longitudinal design, large and diverse sample, and use of well-validated, standardized tasks. Inclusion of potential prenatal and postnatal confounding variables also adds to the robustness of the current findings. Importantly, the effects demonstrated in the current study were significant and in line with study hypotheses, but were generally small in magnitude. Thus, the effect of birth weight on neuropsychological skills in the normative range of development should be considered small. Further replication is important. Regarding limitations, the first is that our measure of language at age 3 was a single measure of receptive vocabulary, and this may not approximate the complexity of children’s language at this stage. Although PPVT is one of the most widely used measures of language in the developmental literature (especially in relation to ToM and EF), future studies using a more comprehensive measure could provide a more nuanced view of the language functions affected. We also cannot rule out the possibility that this measure of language was indexing more general cognitive abilities (e.g. overall IQ) at this stage, and future studies that control for additional verbal and non-verbal cognitive skills may prove useful in determining the specific role of language as a mediator of the link between birth weight and ToM/EF. Second, our sample enlisted and retained families that were more educated than the general population (de Graaf et al., 2000). We also recruited families with at least one older child. These sampling factors may limit the generalizability of our findings. Also, there was a variable amount of missing data on the outcome measures due to attrition and non-response. Best practice approaches to the handling of missing data were used (Graham, 2009), but caution should still be exercised when interpreting these results.
3.5 Acknowledgements

We are grateful to the families who give so generously of their time, to the Hamilton and Toronto Public Health Units for facilitating recruitment of the sample, and to Mira Boskovic for project management. The grant ‘Transactional Processes in Emotional and Behavioural Regulation: Individuals in Context’ was awarded to Jennifer M. Jenkins and Michael Boyle from the Canadian Institutes of Health Research and covered data collection. We are also grateful to the Connaught Global Challenge Fund for providing financial support to the contributors of this study. The study team, beyond the current authors includes: Janet Astington, Cathy Barr, Kathy Georgiades, Greg Moran, Chris Moore, Tom O’Connor, Michal Perlman, Hildy Ross, Louis Schmidt. There are no known conflicts of interest for any of the authors in the current research study.

3.6 References – Study 3


Health Survey and Incidence Study (NEMESIS). *American Journal of Epidemiology, 152*(11), 1039-1047.


Grunau, R. E., Whitfield, M. F., & Fay, T. B. (2004). Psychosocial and academic characteristics of extremely low birth weight (< 800 g) adolescents who are free of major impairment compared with term-born control subjects. *Pediatrics, 114*(6), e725-e732.


Chapter 3

4 Study 4: Birth weight variability and language development: Risk, resilience, and responsive parenting

4.1 Introduction

In addition to being more medically fragile and at greater risk of mortality, research has consistently demonstrated that low birth weight (LBW) is associated with both short- and long-term social, behavioral, and neurological deficits (Aarnoudse-Moens, Weisglas-Kuperus, van Goudoever, & Oosterlaan, 2009; Eryigit Madzwamuse, Baumann, Jaekel, Bartmann, & Wolke, in press). In the United States, approximately 8% of infants are classified as LBW (<2500g; Martin, et al., 2009). Most past research has focused on this population. Comparatively little empirical attention has been devoted to exploring whether variability in birth weight is linked to compromised neurodevelopment amongst the 92% of infants within the normal range (2500-5000g). The current longitudinal study used a prospective community birth cohort to test the hypothesis that birth weight variability within the normal range is associated with inter-individual differences in language ability at 36 months. Further, we examined whether the postnatal environment of children served to protect them from the potential deleterious risk of relatively low birth weight.

4.1.1 Risk and Resilience

Resilience is conceptualized as the process of individual adaptation in spite of experiencing a biological or environmental threat that has the potential to derail optimal development relative (Masten, 2001; Rutter, 2012). In the current study, the metric of threat is relatively low birth weight. As all children in the current study are in the normal range for birth weight and since birth weight is treated as a continuous variable, we henceforth use ‘low’ and ‘high’ birth weight as relative terms. Our measure of optimal development is receptive language, considered to be a fundamental building block for later literacy and cognitive capacities (Duncan, et al., 2007). We operationalize ‘resilience’ as achieving expected language abilities despite risk factors associated with relatively low birth weight status. In particular, we test a neurobiological resiliency model in which a critical postnatal socialization input, namely responsive parenting, buffers children...
from the risk of relatively low birth weight on language skills at 36 months. This is consistent
with the notion that children who are at risk for poor cognitive outcomes by virtue of their in
utero growth may still thrive in the presence of protective socialization factor early in
development (Bale, 2012; Rutter, 2012).

4.1.2 Normative Birth Weight Variability and Neurocognitive Functioning

Across the entire birth weight range, there is a gradient relationship between birth weight and
degree of deficit. For example, Matte and colleagues (2001) reported a linear relationship
between birth weight in the normative range and subsequent intellectual functioning in a large,
nationally representative sample of 3,484 children. Specifically, they reported that mean
intelligence increased linearly with birth weight, even after controlling for a range of family
environmental variables such as ethnicity, socio-economic status, and maternal education. From
a population health standpoint, this suggests that small shifts across the entire continuum of birth
weight may impact later neurocognitive functioning. In fact, recent neuroimaging studies suggest
that subtle birth weight differences within the normal range are associated with pronounced
variability in postnatal brain maturation (Raznahan, Greenstein, Lee, Clasen, & Giedd, 2012;
Walhovd, et al., 2013). Although the specific cognitive domains impacted by normative birth
weight variation remain elusive, these studies show that temporal, parietal, and perisylvian
regions may be particularly vulnerable to perinatal factors. These brain areas are widely
implicated in receptive language ability (Catani & Jones, 2005; Sowell, et al., 2004), suggesting
that this may be a discrete neurocognitive domain that varies as a function of normative birth
weight differences. However, this link has yet to be examined in children.

4.1.3 Child Language Development

Individual differences in early language skills show remarkable predictive power for later
receptive and spoken language, academic achievement, and reading comprehension (Burchinal &
Forestieri, 2011). In contrast, language deficits in the preschool years correspond to poorer
performance on language and reading tasks throughout middle childhood (Rescorla, 2002). Thus,
early language ability is a critical proxy for later cognitive growth and academic functioning.
While there are a handful of recent studies examining the effect of normative birth weight
differences on general IQ measures (Eriksen, et al., 2013), it remains unclear how normative
birth weight variability relates to children’s language skills specifically. Enhanced understanding of this issue is critical as speech and language skills are routinely evaluated by health professionals monitoring early child development (e.g., well-baby visits). Moreover, deficits in language skills constitute one of the earliest behavioral markers of developmental risk and language delay is one of the most common reasons for referral to a developmental specialist (Forrest et al., 1999).

4.1.4 Responsive Parenting as a Putative Protective Factor

Although adverse perinatal risks are known to compromise developmental health, little is known about factors that serve to amplify or attenuate associations between early biological adversity and cognitive outcomes in children born within the normal birth weight range. Caregiver responsiveness and sensitivity has long been considered a crucial source of external input that supports children’s developmental health. For language development in particular, exposure to stimulating, rewarding, and contingently-responsive verbal and nonverbal exchanges provides opportunities for scaffolding language development by providing labels and expressions that match the object(s) of the child’s attention (Landry & Smith, 2006). Also, the ability to respond contingently to a child’s exploratory initiatives, overtures, and verbalizations with semantically relevant and interpretable speech is critical not only in providing language input, but in fostering feelings of efficacy and reinforcing communicative engagement that begets linguistic competence (Levickis, Reilly, Girolametto, Ukoumunne, & Wake, 2014).

Emerging research demonstrates that responsive parenting may moderate the association between early biological risk and later outcomes. For instance, Laucht and colleagues (2001) showed that maternal responsivity moderated the association between birth weight and children’s internalizing and hyperkinetic problems, while Tully et al. (2004) found a similar effect for attention-deficit problems. While the buffering effect of responsive parenting has been demonstrated in numerous groups of at-risk children, there are currently no existing studies on whether responsive parenting operates to protect children across the normal continuum of birth weight.
4.1.5 The Current Study

We had two central aims: (1) to determine whether normative birth weight variability (2500-5000g) relates to children’s language skills at 36 months; and (2) to examine whether responsive parenting, the theoretical protective factor, moderated the association between normative birth weight variability and language ability. Consistent with previous research on normative birth weight variability and intelligence (Matte, et al., 2001), we hypothesized that birth weight would be positively associated with language ability at 36 months, effects not previously demonstrated in children. Second, we hypothesized that children with relatively lower birth weight within the average range who experienced higher levels of responsive parenting would achieve expected language abilities despite the perinatal risk of relatively low birth weight. Building on limitations of previous research, we controlled for several child- and family-level variables that could potentially act as confounds, including maternal education and family socioeconomic status, as well as children’s gestational age and current age, and gender. We also controlled for children’s expressive language ability at an earlier time point to improve inferences around the directionality of effects.

4.2 Method

4.2.1 Study Sample

Multiparous women giving birth to infants in the cities of Toronto and Hamilton, Ontario, between 2006 and 2008, who had been contacted by the Healthy Babies Healthy Children (HBHC) public health program (run by Toronto and Hamilton Public Health Units), were considered for participation. Inclusion criteria for the intensive sample of Kids, Families, Places (KFP) was as follows: (1) English-speaking mother; (2) a newborn weighing at least 1500g; (3) one or more children less than 4 years old in the home; and (4) agreement to the collection of observational and biological data. Thirty-four percent of mothers whose information was passed by HBHC consented to participate in the study. Reasons for non-enlistment included inability to contact families, ineligibility once contacted, and refusals. A total of 501 mothers and their children were enlisted at Time 1 (T1; youngest child was a newborn). The current study was embedded within this larger project, the goals of which were to examine genetic and environmental influences on children’s cognitive and socio-emotional development. As we were interested in examining language ability in the preschool period, the current study focused
exclusively on the newborn children (and not their older siblings), who were on average 18 months (T2) and 3 years (T3) at follow-up. In the current study, only children with birth weights 2500-5000g and gestational ages ≥37 weeks were included in order to limit the sample to non-pregnate and non-LBW children. One child was also excluded because he was 5.87 SD above the birth weight mean. Exclusion of these children resulted in a final sample of 467 children (93.2% of the original 501 enlisted). The institutional Research Ethics Board approved all procedures for this investigation, including informed consent.

Attrition from T1 to T2 was 20.8%, and from T2 to T3 was an additional 3.0%. Dropout from T1 to T2 was significantly related to lower income/assets \( t(466) = -5.06, p < .001 \), lower maternal education \( t(466) = -2.67, p < .05 \), and being non-Canadian born \( \chi^2 (1) = 13.3, p < .001 \). Dropout from T1 to T3 was also related to lower income/assets \( t(466) = -3.48, p < .005 \) and moderately related to lower maternal education \( t(466) = -1.84, p < .10 \).

Mothers averaged 32.7 years of age (\( SD = 4.9 \); range = 18–48) and 15.3 (\( SD = 2.7 \)) years of education. Ninety-four percent of the sample reported that they were married or cohabitating, 2% were divorced, and 4% were single. Mean family income was between C$55,000–64,999. The ethnic distribution of children was as follows: 56.7% Caucasian, 15.6% South/West Asian, 12.5% East/South-east Asian, 6.1% Black, 3.3% Latin American, and 5.8% ‘other’. Additional sample details are available elsewhere (Meunier, Boyle, O’Connor & Jenkins, 2013). We statistically adjusted birth weight to account for ethnic heterogeneity (see below).

4.2.2 Procedure

At each time point, mothers in each family participated in a home interview and completed questionnaire measures about their neighborhood, family life, and each participating child. Data collection at T2 included mother-child observations. At T3, the home visitor assessed children’s receptive language using the Peabody Picture Vocabulary Test.

4.2.3 Measures

**Covariates:** These included children’s gestational age (in weeks), age in years at T3 (concurrent with the outcome), child gender (0 = male; 1 = female), maternal education (in years) and family income/assets, a proxy for socio-economic status (SES). The income/assets variable was a
composite of: (i) annual family income, assessed on a scale from 1 (‘no income’) to 16 (‘$105,000 or more’); (ii) number of rooms in the family’s residence; and (iii) whether the family owns/co-owns their house/apartment and/or (iv) vehicle, even if still making payments (yes/no variables). Internal consistency between items was high (α = .78), and thus these four variables were rescaled, standardized, and averaged to create a composite score for income/assets. Higher values represented higher income and assets. We also controlled for previous language using the MacArthur-Bates Communicative Development Inventories (CDI) at T2 (Fenson, et al., 1994). The CDI is a mother-reported measure of children’s expressive vocabulary that can be used with children under the age of 2. Children were coded on ‘words and sentences’. Words spoken ranged from 0 to 100 (M = 26.5, SD = 20.1). Scores used in analysis were residualized for age and gender.

**Birth weight.** At T1 (child was a newborn), mothers were asked for the child’s birth weight in kilogram/grams. Because LBW babies were excluded, the birth weight variable had a slightly right-skewed distribution, skewness = .315 (SE = .113), kurtosis = .002 (SE = .225). The range on the variable was 2.52 – 4.99 kg (M = 3.46, SD = .43). Infant birth weight was adjusted for ethnicity by computing a residual score.²

**Responsive Maternal Behavior.** Observational data were gathered at T2 (child was 18-months-old) on mother-child interactions across three 5-minute tasks: (1) unstructured free play with no toys; (2) a structured cooperative building task (using Duplo blocks to build a design from a picture); and (3) reading from a wordless picture book. For all three tasks, three domains of responsivity were coded using the Coding of Attachment-Related Parenting (CARP; Matias, 2006; Matias, O’Connor, Futh, & Scott, 2014), and the positive control scale of the Parent-Child Interaction System (PARCHISY; Deater-Deckard, Pylas, & Petrill, 1997): (i) Sensitive responding measures the degree to which the parent displays awareness of the child’s needs and shows sensitivity to his or her signals, supports the child’s autonomy, and demonstrates an ability to see things from the child’s point of view; (ii) mutuality is a dyadic code indexed by reciprocity in conversation, affect sharing, joint engagement in task, and open body posture; and (iii) positive control captures the positive aspects of the parents’ style of directing or influencing the

² **Note:** substantive results were the same when birth weight was not adjusted for ethnicity.
child’s behavior through the use of praise, explanations, and open-ended questions. Each domain was coded on a 7-point Likert scale, with higher values indicating higher levels of responsive parenting. Observational coders, who were independent from home visitors, were blind to all participant information. Internal consistency across scales was adequate ($\alpha = .87$), and a composite was created by averaging the three scales across all three tasks. Inter-rater reliability was assessed on 10% of the sample throughout the coding period to protect against coder drift. Reliability was high ($\alpha = .92$).

**Child Language.** The *Peabody Picture Vocabulary Test* (PPVT-III; Dunn & Dunn, 1997) was used at T3 (child was 3-years-old). The PPVT is a widely used and well-validated measure of receptive vocabulary skills for children aged 2 years and older (as a result, it could not be used at previous time points in the study). It estimates verbal ability. Children point to a picture which corresponds to the stimulus word among plates of four pictures. The PPVT-III has been shown to be a reliable and valid instrument for use in preschool populations (Dunn & Dunn, 1997). PPVT scores were normally distributed. We used standardized scores, which are based on age-normed (standardized) data from the PPVT-III manual.

### 4.2.4 Analyses

Analyses were performed using MPlus 7.0. As data were missing at random, we used multiple imputation (MI) in order to incorporate all 467 participants in the analyses. In MI, a model is estimated to predict observed values of a particular variable based on other variables present. This model is then used to impute missing values across a number of data sets to account for the uncertainty (i.e. error) in any single data set (Rubin, 1996). This approach restores power that could be lost due to attrition and is less biased than traditional methods for handling missing data, such as mean substitution or listwise/pairwise deletion (Graham, 2009). We report the pooled regression weights across 25 imputed data sets. MI can handle up to 50% missing data without biasing the estimates (Graham & Schafer, 1999); yet none of the variables in this study had this level of missingness.

To explicate the exact nature of the interaction effect between birth weight and maternal responsivity, we performed simple slope analyses. Simple slope analyses tests the relationship between birth weight and language at different levels of the moderator (Aiken & West, 1991). In
the case of a continuous moderator (i.e. responsive parenting), the common approach to examine
the regression relationship at high (+1 SD) and low (-1 SD) levels of the moderator (Cohen,
Cohen, West, & Aiken, 2013). This was the approach applied here.

4.3 Results

4.3.1 Descriptive Statistics

Descriptive statistics for study variables are presented in Table 11.

Table 11. Descriptive statistics for study variables

<table>
<thead>
<tr>
<th>Measure</th>
<th>Descriptive value</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Female gender, n (%)</td>
<td>230 (49.3%)</td>
<td>467</td>
</tr>
<tr>
<td>Gestational age in weeks at T1, M (SD)</td>
<td>39.15 (0.94)</td>
<td>467</td>
</tr>
<tr>
<td>Child age in years at T3, M (SD)</td>
<td>3.15 (0.27)</td>
<td>361a</td>
</tr>
<tr>
<td>Maternal age in years at T1, M (SD)</td>
<td>32.86 (4.86)</td>
<td>467</td>
</tr>
<tr>
<td>Maternal education in years at T1, M (SD)</td>
<td>15.36 (2.64)</td>
<td>467</td>
</tr>
<tr>
<td>Household income at T1 (Median)</td>
<td>$75,000 to $84,999</td>
<td>467</td>
</tr>
<tr>
<td>Number of kids at T1, M (SD)</td>
<td>2.38 (0.84)</td>
<td>467</td>
</tr>
<tr>
<td>Birth weight in kg at T1, M (SD)</td>
<td>3.46 (0.43)</td>
<td>467</td>
</tr>
<tr>
<td>PPVT-III at T3, M (SD)</td>
<td>94.9 (15.2)</td>
<td>283a</td>
</tr>
<tr>
<td>Maternal responsivity at T2, M (SD)</td>
<td>3.52 (.80)</td>
<td>354a</td>
</tr>
</tbody>
</table>

M – Mean; SD – Standard Deviation; T2 – Time 2; T3 – Time 3

*These variables are the only ones for which there was missing data, which was
due to longitudinal follow-up (i.e. attrition).

Note. Some values in this table differ slightly from those reported in
text due to differences in the total sample used in the census comparison (N = 501) compared to the current sample that was
restricted to non-premature and non-LBW infants (final N = 467).
Correlations between the main study variables appear in Table 12. Notable associations include the relationship between birth weight and receptive language at T3, maternal responsivity at T2 with child language at T2 and T3, and income/assets and maternal education with both maternal responsivity at T2 and child language at T3. Birth weight and gestational age were also significantly associated with each other. We controlled for gestational age in the primary regression analysis. A preliminary analysis revealed that there was no curvilinear relationship between birth weight and child language, $F(2, 255) = 1.87, p = .16$.

### Table 12. Bivariate correlations between study variables

<table>
<thead>
<tr>
<th>Variables</th>
<th>1.</th>
<th>2.</th>
<th>3.</th>
<th>4.</th>
<th>5.</th>
<th>6.</th>
<th>7.</th>
<th>8.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Birth weight</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Gestational age</td>
<td>.25***</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Child age (T3)</td>
<td>-.02</td>
<td>.06</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Female gender</td>
<td>-.15**</td>
<td>.11*</td>
<td>.03</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. Income/Assets (T2)</td>
<td>-.04</td>
<td>.03</td>
<td>-.02</td>
<td>.05</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. Maternal education (T2)</td>
<td>-.07</td>
<td>.02</td>
<td>.00</td>
<td>-.07</td>
<td>.43***</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7. Language (T2)</td>
<td>.03</td>
<td>.08</td>
<td>.10</td>
<td>.11*</td>
<td>.04</td>
<td>.05</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>8. Responsivity (T2)</td>
<td>.15**</td>
<td>.12**</td>
<td>-.05</td>
<td>.13*</td>
<td>.32***</td>
<td>.23***</td>
<td>.21***</td>
<td>-</td>
</tr>
<tr>
<td>9. Language (T3)</td>
<td>.13*</td>
<td>.06</td>
<td>.05</td>
<td>.07</td>
<td>.39***</td>
<td>.12†</td>
<td>.21**</td>
<td>.34***</td>
</tr>
</tbody>
</table>

*Note.†p < .10. *p < .05. **p < .01. ***p < .001
T2 – Time 2; T3 – Time 3

### 4.3.2 Moderation Model

Multiple linear regression was used to test our main hypothesis. Covariates were entered into the model simultaneously with the predictors (birth weight with responsive parenting) and the interaction term. Thus, the interaction term controls for covariates and the main effects of birth
weight and responsive parenting. The results, appearing in Table 13, showed that income/assets and child language at T2 significantly predicted language at T3. There were significant main effects of responsivity [β (SE) = .23 (.07), p < .001] and birth weight [β (SE) = .15 (.07), p = .034] on child language at T3. As hypothesized, there was also a significant interaction between maternal responsivity and birth weight [β (SE) = -.12 (.05), p = .024] after controlling for main effects and covariates. This suggests that the effect of birthweight on receptive language at T3 is contingent upon the level of responsive parenting received at T2 (see Figure 6). These effects 

Table 13. Multiple linear regression predicting receptive language scores at Time 3

<table>
<thead>
<tr>
<th></th>
<th>β [95% CI]</th>
<th>S.E.</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gestational age</td>
<td>-.05 [-.19, .09]</td>
<td>.07</td>
<td>.49</td>
</tr>
<tr>
<td>Child age (T3)</td>
<td>.07 [-.05, .19]</td>
<td>.06</td>
<td>.24</td>
</tr>
<tr>
<td>Child gender</td>
<td>.08 [-.12, .28]</td>
<td>.10</td>
<td>.44</td>
</tr>
<tr>
<td>Income/Assets (T2)</td>
<td>.32 [.16, .48]</td>
<td>.08</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Maternal education (T2)</td>
<td>-.05 [-.21, .11]</td>
<td>.08</td>
<td>.58</td>
</tr>
<tr>
<td>Child language (T2)</td>
<td>.13 [.03, .23]</td>
<td>.05</td>
<td>.01</td>
</tr>
<tr>
<td>Birth weight*</td>
<td>.15 [.01, .29]</td>
<td>.07</td>
<td>.03</td>
</tr>
<tr>
<td>Responsivity (T2)</td>
<td>.23 [.09, .37]</td>
<td>.07</td>
<td>.001</td>
</tr>
<tr>
<td>Responsivity*Birth weight</td>
<td>-.12 [-.22, -.02]</td>
<td>.05</td>
<td>.02</td>
</tr>
</tbody>
</table>

T2 – Time 2; T3 – Time 3
CI – confidence interval; S.E. – standard error
*Birth weight was residualized for ethnicity.
$R^2 = .27, p < .001.$
were significant even after controlling for earlier levels of language skills, as well as gestational and current age, gender, maternal education, and socioeconomic status.\(^3\)

---

\(^3\) We examined the data using two alternative approaches for handling missing data: listwise deletion and full information maximum-likelihood estimation (FIML). The results for listwise deletion (\(N = 283\) with complete data on the outcome) were as follows: significant main effects of responsivity [\(\beta (SE) = .24 (.08), p = .002\)] and birth weight [\(\beta (SE) = .14 (.06), p = .021\)], and a significant interaction between maternal responsivity and birth weight [\(\beta (SE) = -.13 (.06), p = .035\)], on child language at T3 (after controlling covariates). For FIML (\(N = 467\)), the results were comparable: significant main effects of responsivity [\(\beta (SE) = .23 (.07), p = .002\)] and birth weight [\(\beta (SE) = .15 (.06), p = .018\)], and a significant interaction [\(\beta (SE) = -.12 (.06), p = .039\)] on language at T3. Further, the results remained unchanged whether maternal education and income/assets were controlled at T1, T2, or T3.
4.3.3 Analysis of Simple Slopes

Compared to children with high birth weights who received low levels of maternal responsivity, children with relatively low birth weights who also received low maternal responsivity had significantly lower language scores. In contrast, there appeared to be no association between birth weight and language at T3 for children who received high levels of responsive parenting. Analyses of simple slopes confirmed that there was no association between birth weight and language at high levels of maternal responsivity ($z = -0.27$, $p = 0.79$), but there was a positive association between birth weight and language at low levels of maternal responsivity ($z = 2.93$, $p = 0.003$). These slopes were statistically different from one another ($z = 2.71$, $p = 0.007$). Finally, at both low ($z = 6.16$, $p < 0.001$) and high ($z = 3.22$, $p = 0.001$) levels of birth weight, higher maternal responsivity was associated with significantly better language ability at T3. This association was stronger at lower levels of birth weight ($z = 2.71$, $p = 0.007$).

4.4 Discussion

Consistent with study hypotheses, results revealed that birth weight was positively associated with individual differences in receptive language at 36 months for children in the normal birth weight range. The significant main effect of responsive parenting on children’s language development suggests that responsive parenting is a resource for all children in the normative birth weight range. In addition, over and above these main effects was a significant interaction between birth weight and maternal responsivity: for children at the lower end of the normative birth weight range, postnatal environments that were rich in responsive caregiving protected against the relative risk of low birth weight on language development. This interaction, which represents our resiliency effect, suggests that children facing biological risk in the form of relatively low birth weight can achieve levels of language development comparable to their higher birth weight counterparts if they are exposed to high levels of responsive parenting. This finding highlights the robust multiplicative effect of birth weight and responsive caregiving on children’s language development, and underscores the notion that optimal postnatal interpersonal exchanges with caregivers can help vulnerable children overcome the risk of compromised neurobiological development (Walhovd, Tamnes, & Fjell, 2014).
Language is an essential cognitive capacity that is not only associated with later cognitive and academic competence (Duncan, et al., 2007), but also with social, emotional, and mental health outcomes of children and adolescents (Cohen, 2001). The association of LBW with poor language development has been noted in early and middle childhood (Anderson & Doyle, 2003) as well as adulthood (Hack, et al., 2002). In comparison, only a small number of studies have shown that the normal range of birth weight is also associated with children’s neurocognitive outcomes (e.g., Boulet, Schieve, & Boyle, 2011; Matte, et al., 2001), and to our knowledge, this is the first study to demonstrate a direct link between average birth weight variability and child language development.

Although the relationship between birth weight and developmental delay is strongest in the (V)LBW range, even children weighing between 2500 to 3000g (low-average range) have been shown to be at a greater risk of mental retardation, cerebral palsy, learning disability, and attention-deficit hyperactivity disorder compared to those weighing 3500-4000g (Boulet, et al., 2011). The mechanisms linking birth weight to complex health outcomes are currently unclear. However, a recent study demonstrated a linear relationship between normative birth weight and children’s executive functioning (EF) at age 6 (Phua, Rifkin-Graboi, Saw, Meaney, & Qiu, 2012), suggesting that EF may be one discrete neurocognitive trait linking birth weight to various psychological outcomes. Adding to this literature, the current findings suggest that domain-specific language abilities may serve as another cognitive link between birth weight and global aspects of functioning such as academic, psychosocial, and psychiatric outcomes. This field would benefit from additional studies that draw explicit connections between other cognitive endophenotypes, normative variation in birth weight, and children’s developmental health.

**Clinical Implications**

Both birth weight and early language delay create vulnerability to numerous child developmental health risks, which often persist into middle childhood, adolescence, and even adulthood. Thus, early identification of risk is essential. Birth weight is an easily identifiable marker of risk for health professionals who are often responsible for routinely screening children’s speech and language development in primary care settings. Indeed, prematurity and anomalies of intrauterine growth are among the most common developmental risks encountered by pediatric psychologists (Yeates, Ris, Taylor, & Pennington, 2009). Several intervention studies show that parent-based
interventions focused on bolstering parental responsiveness and/or cognitive stimulation, are useful in enhancing children’s language development (Landry, Smith, Swank, & Guttentag, 2008; Olds et al. 2014). Such interventions aim to increase contingent responsiveness, positive emotional support, appropriate responses to the child’s focus of attention, and cognitively stimulating behaviors such as rich language input. Meaningful change in children’s outcomes can likely be achieved at a population-wide level using evidence-based parenting interventions, however, they may be of particular benefit to perinatally at-risk children, such as those with (V)LBW.

**Strengths and Limitations**

The longitudinal, multi-method design, large sample size, and rigorous controls for potential confounding variables are strengths of the study. One limitation of the current study is the focus on a single time point of observed maternal behavior during a typical day-to-day interaction that included free-play, book reading, and a structured activity. Although this interaction took place in an ecologically-valid setting, it is only a snapshot of maternal behavior during an isolated period of child development. A second limitation is our use of different measures of language at T2 and T3. The CDI, a measure of expressive language, was collected when children were 18 months of age, and the PPVT, a measure of receptive language, was assessed when children were 36 months. This variation in methodology was necessary as standard scores on the PPVT are only normed for children age 2 and above. As scores on these measures were correlated, we included the T2 language measure to improve statistical power and inferences around the directionality of these effects.

**Conclusions**

Results of the current study extend a small body of literature delineating the association between birth weight within the normal range (i.e., ≥2500g) and children’s developmental health outcomes. Specifically, lower birth weight within the normal range constitutes a risk for poor language development at 36 months. Critically, optimal caregiving behaviors can buffer children from perinatal risk and can have a significant influence on keystone language faculties. Because positive parenting protects children against the negative consequences of low average birth weight, mothers presenting with children with this perinatal risk may benefit from interventions
that focus on improving their responsiveness in order to engender positive language outcomes, which may in turn set the stage for improved life-long learning.

4.5 Acknowledgements

We are grateful to the families who give so generously of their time, to Hamilton and Toronto Public Health Units for facilitating recruitment of the sample, and to Mira Boskovic for project management. The grant ‘Transactional Processes in Emotional and Behavioural Regulation: Individuals in Context’ was awarded to Jennifer M. Jenkins and Michael Boyle from the Canadian Institutes of Health Research and covered data collection. We are also grateful to the Connaught Global Challenge Fund for providing financial support to the contributors of this study. The study team, beyond the listed authors, includes: Janet Astington, Cathy Barr, Kathy Georgiades, Greg Moran, Chris Moore, Tom O’Connor, Michal Perlman, Hildy Ross, Louis Schmidt.

4.6 References - Study 4


5 Study 5: Cumulative biomedical risk and social cognition in the second year of life: prediction and moderation by responsive parenting

5.1 Introduction

Social cognition is the set of cognitive processes related to social understanding and behavior. The capacity to understand human actions in terms of the psychological states that motivate behavior is a fundamental component of social cognition. While social cognition is broadly defined and includes a number of cognitive processes, it is generally well accepted that by the second year of life children evince many basic social-cognitive competencies, including an understanding of others’ goals (Csibra, Bró, Koós, & Gergely, 2003), intentions (Behne, Carpenter, Call, & Tomasello, 2005), desires (Repacholi & Gopnik, 1997), emotions (Moses, Baldwin, Rosicky, & Tidball, 2001), and perhaps even beliefs (Buttelmann, Carpenter, & Tomasello, 2009). The ability to understand others’ mental states manifests itself in a number of overt behaviors in the second year of life, many of which are used to index early social cognition. For instance, by 18 months children engage in regular bouts of joint attention (Tomasello & Carpenter, 2007; Tomasello, Carpenter, Call, Behne, & Moll, 2005), empathy (Roth-Hanania, Davidov, & Zahn-Waxler, 2011), cooperation (Brownell, Ramani, & Zerwas, 2006; Warneken, Chen, & Tomasello, 2006; Warneken & Tomasello, 2007), and self-recognition (Brownell, Zerwas, & Ramani, 2007; Nielsen & Dissanayake, 2004). These social-cognitive skills rely on the capacity to differentiate self from other (Asendorpf, Warkentin, & Baudonnière, 1996; Lewis, 2003), and it has been suggested that children’s emergent aptitude for understanding intentions may play a critical role in their ability to engage successfully in these behaviors (Knoblich & Sebanz, 2008; Moore, 2007).

Although social cognition develops progressively over childhood (Gergely & Csibra, 2003; San Juan & Astington, 2012; Thoermer, Sodian, Vuori, Perst, & Kristen, 2012), there are important individual differences in early social cognition that have a bearing on later skills such as theory of mind (Aschersleben, Hofer, & Jovanovic, 2008; Legerstee, 2005; Wellman, Lopez-Duran, LaBounty, & Hamilton, 2008). This variability in social reasoning can also be observed in adolescence (Dumontheil, Apperly, & Blakemore, 2010; Moriguchi, Ohnishi, Mori, Matsuda, & Komaki, 2007). Longitudinal studies show that individual differences in social cognition are
quite stable (Pons & Harris, 2005) and are related to multiple developmental outcomes (Fiske & Taylor, 2013; Frischen, Bayliss, & Tipper, 2007). For instance, theory of mind ability has been linked to children’s academic achievement (Blair & Razza, 2007), behavioral problems (Hughes & Ensor, 2006), and social competence (Razza & Blair, 2009). Accordingly, it is important to identify sources of variability in early social cognition, which may exert downstream effects on multiple domains of functioning.

To date, the preponderance of literature on predictors of social cognition has focused on contextual factors such as family processes and socioeconomic variables. For instance, Dunn and colleagues (1991) have shown that mothers’ mental state discourse and family socioeconomic status (SES) at 33 months are associated with emotion understanding at 40 months. The effect of socioeconomic factors on individual differences in theory of mind has been replicated in numerous investigations (Holmes, Black, & Miller, 1996; Shatz, Diesendruck, Martinez-Beck, & Akar, 2003). Moreover, the effect of parenting behavior on social cognition is one of the most robust findings in the literature on social cognition (de Rosnay & Hughes, 2006; Pears & Moses, 2003; Ruffman, Slade, Devitt, & Crowe, 2006). Also relevant are child-level factors such as gender, with females demonstrating overall better social cognition than males (Dunn, et al., 1991). One of the strongest factors associated with social cognition is language ability (Astington & Jenkins, 1999; Cutting & Dunn, 1999; de Rosnay & Harris, 2002; Pons, Lawson, Harris, & de Rosnay, 2003), which may play both a communicational and representational role in social cognition (see Dunn & Brophy, 2005). Thus, there appears to be a range of known environmental and child-specific factors that contribute to individual differences in social cognition across childhood.

Importantly, much of the existing literature has focused on predictors of social cognition in preschool and school-age children. Relatively less is known about the factors associated with social cognition at earlier stages of development. However, recent studies suggest that, as early as the second year of life, there may be multiple influences on social cognition, such as cumulative social disadvantage, maternal sensitivity, and language ability (Wade, Moore, Astington, Frampton, & Jenkins, 2014) as well as oxytocin genetic variability (Wade, Hoffmann, & Jenkins, 2014) and pregnancy hypertension (Wade & Jenkins, 2014). These results are consistent with the manifold biopsychosocial correlates of social cognition observed in preschool.
children. However, across all studies there remains a substantial proportion of unexplained residual variance, suggesting the presence of currently unspecified influences on social cognition. The goal of the current study was to examine whether early biomedical risk, or the occurrence of combined pre- and perinatal complications, represented another source of variability in social cognition in the second year of life. Further, supposing that such a relationship exists, and consistent with the known effects of contextual factors on social-cognitive development, we aimed to determine whether positive postnatal interpersonal experiences with caregivers (i.e. responsive parenting) protected children against these potentially adverse biomedical risks.

Specific biomedical risk factors for early social cognition have been vastly understudied. In one recent study, Wade and Jenkins (2014) demonstrated that pregnancy hypertension is associated with lower social cognition at 18 months, as well as theory of mind ability in the preschool period. Another recent study showed that birth weight was positively associated with theory of mind at age 4.5 in a typically-developing sample (Wade, Browne, Madigan, Plamondon, & Jenkins, 2014). Together, these studies provide preliminary evidence that pre- and perinatal factors may be involved in a mechanism through which early fetal stress impinges on healthy brain development that supports social cognition. Aside from these findings, however, little is known about the role of biomedical factors on social cognition in the second year of life.

Indirect evidence for a role of early medical complications on social cognition comes from research showing that such factors are related to the risk of neurodevelopmental and psychiatric disorders characterized by deficits in social cognition. For instance, a comprehensive review by Kolevzon, Gross, and Reichenberg (2007) revealed that the most prominent obstetric complications associated with risk for autism spectrum disorder (ASD) included birth weight, gestational age, as well as intrapartum hypoxia. Obstetrical complications have also been linked to the risk for schizophrenia (Geddes & Lawrie, 1995; Verdoux et al., 1997), eating disorders (Cnattingius, Hultman, Dahl, Sparén, 1999), early-onset affective disorders (Guth, Jones, & Murray, 1993), substance abuse (Sydsjö, 2011), attention-deficit hyperactivity disorder (Bhutta, Cleves, Casey, Cradock, Anand, & Phil, 2002; Milberger, Biederman, Faraone, Guite & Tsuang, 1997), and conduct, oppositional, and internalizing problems (Cohen, Velez, Brook, & Smith, 1989). In a prospective follow-up study, Buka and colleagues (1993) suggested that fetal hypoxia
was the common underlying mechanism and was the strongest predictor of later cognitive and psychiatric difficulties. Several maternal pathologies during pregnancy have been linked to perinatal hypoxia-ischemia, such as infections, diabetes, hypertension, and thyroid problems (Kurinczuk, White-Koning, & Badawi, 2010; Shah, 2001; Stanek, 2013; Teramo, 2010). Thus, it is conceivable that these biomedical factors increase the risk of hypoxic-ischemic events which compromise development in key social-cognitive domains that typify neurodevelopmental and psychiatric conditions.

Two important points deserve consideration here. The first is that early biomedical complications likely produce a continuum of postnatal biopsychosocial-health variability, rather than just the extremes of problems (Pasamanick & Knobloch, 1961). This means that we should expect to observe individual differences in discrete social, cognitive, and emotional phenotypes that characterize neurodevelopmental and psychiatric conditions as a function of biomedical risk. Second, the existing research is limited in differentiating between the effect of different types of prenatal/birth complications on developmental outcomes (Allen, Lewinsohn, & Seeley, 1998). Indeed, there are a variety of biomedical complications that can occur during the pre-, peri- and neonatal period, including those related to maternal physical health (e.g. endocrine/inflammatory diseases), intrapartum events (e.g. physical trauma), perinatal problems (e.g. low birth weight, prematurity), and immediate postpartum factors (e.g. anoxia or hematological problems demanding use of specialized care). However, it may be difficult to ascertain the effect of each individual risk on children’s outcomes, particularly in epidemiological samples where the prevalence of certain conditions may be too low to provide powerful estimates and the measurement is not sufficiently detailed to effectively partition risks. As a result, one approach that may be useful is the cumulative risk approach. The overarching idea behind cumulative risk measures is that, rather than a single and specific risk, it is the aggregation of multiple risks that compromises development (Burchinal, Vernon-Feagans, Cox, & Investigators, 2008; Dong, et al., 2004; Flouri & Kallis, 2007). Indeed, it has been repeatedly demonstrated that cumulative risk indices are more stable than individual risk measures (Burchinal, Roberts, Hooper, & Zeisel, 2000), and explain more variance in child outcomes than risks examined in isolation (Atzaba-Poria, Pike, & Deater-Deckard, 2004; Deater-Deckard, Dodge, Bates, & Pettit, 1998; Evans et al., 2013; Flouri & Kallis, 2007).
While the cumulative risk approach has been applied widely within the psychosocial domain, its application to prenatal/birth risks is far less common. Nonetheless, existing research indicates that the accumulation of biomedical risks in the pre- and perinatal period is detrimental to children’s socioemotional, intellectual, and motor functioning (Laucht, Esser, & Schmidt, 1997), as well as their visual memory (Levy-Shiff, Einat, Mogilner, Lerman, & Krikler, 1994) and attentional control (Carmody, et al., 2006). However, these studies have generally assessed the effect of medical complications in children born preterm, which represents a group of already at-risk children who may be particularly vulnerable to negative outcomes. The effect of biomedical risk (i.e. prenatal/birth complications) on social cognition in the general community remains unexplored. Further, no study has examined how enriched postnatal experiences may protect against early biomedical risk on social cognition.

Parental inputs are believed to foster social cognition owing to their role in providing children with the linguistic, representational, and reflective material needed to understand others’ minds (Fernyhough, 2008). Further, it has been demonstrated that positive experiences with caregivers exert a protective influence on children (Brody, Dorsey, Forehand, & Armistead, 2002; Burchinal, Roberts, Zeisel, Hennon, & Hooper, 2006; Rutter, 1987). Protective in this regard does not mean avoiding risk, but persevering in the face of it. These ‘moderation’ models are typically examined by determining whether the association between two variables depends on the level of a third variable, with the risk variable (e.g. biological risk) being less predictive of the outcome when the presumed protective factor is present. Surprisingly, there is little existing research on parenting as a protective factor in regard to the development of social-cognitive capacities, or as a moderator of the association between biological risk and children’s outcomes in general. The limited research to date, however, does suggest that certain aspects of parenting may buffer children against early biomedical risk. For example, Laucht et al. (2001) found that responsive parenting moderated the effect of birth weight on school-aged children’s hyperkinetic and internalizing problems, and Voigt et al. (2013) showed that the effect of neonatal distress on children’s negative affectivity at 12 months depended on the level of parenting stress, with lower levels of stress protecting against neonatal problems. Finally, another interesting study examining children’s executive functioning – a neurocognitive skill that is developmentally linked to social cognition – showed that the effect of neurobiological risk (i.e. direct measurement from neonatal medical records, e.g. need for oxygen/ventilation) on executive
functioning was most prominent in socioeconomically disadvantaged children (Ford et al., 2011). Thus, to build on this literature, and in line with risk-resiliency models of development (Jenkins, Madigan, & Arsenault, in press; Luthar, Cicchetti, & Becker, 2000; Masten, Cutuli, Herbers, & Reed, 2009), the current study aimed to determine whether, given an association between cumulative biomedical risk and social cognition, responsive parenting moderated this association. Specifically, it was hypothesized that higher levels of biomedical risk would be associated with lower social cognition at 18 months; however, if children received high levels of responsive parenting, the effect of biomedical risk on social cognition would be attenuated.

5.2 Materials and Methods

5.2.1 Participants

Participants came from the intensive sample of the Kids, Families, Places Study (iKFP; http://kfp.oise.utoronto.ca/). All women giving birth in Toronto and Hamilton, Ontario, between April 2006 and September 2007 were considered for participation. Families were recruited through a program called Healthy Babies Healthy Children. Parents of all registered newborns were contacted within several days of the child’s birth. Inclusion criteria for the iKFP study included the presence of an English-speaking mother, a newborn >1500 grams, at least two children who are <4 years, and families agreeing to be filmed in the home. Of those contacted, 34% of families agreed to take part in the study. Reasons for non-enlistment included refusals and an inability to contact families from public health’s information. The University of Toronto Research Ethics Board approved all procedures for this investigation, including informed consent.

We compared our sample (N = 501) with the general population of Toronto and Hamilton using 2006 Census Data, limiting the census to women between 20-50 years and having at least one child. Families were compared based upon immigrant status, number of persons in the home, family structure, maternal personal income, and educational level. Based on these comparisons, iKFP was similar to the general population on family size (M = 4.52, SD = 1.01 vs. M = 4.13, SD = 1.22) and personal income (C$30,000–39,999 vs. census population mean = C$30,504.16, SD = C$37,808.12). Since our sample was recruited shortly after childbirth, there were predictably fewer non-intact families than in the general population (5% vs. 16.8% lone-parent families;
4.3% vs. 10.3% stepfamilies). The ratio of Canadian-born to immigrants was somewhat higher in the iKFP sample (57.7% vs. 47.6%), likely due to the language requirement for participation. Also, more study mothers had earned a bachelor’s degree or higher in the iKFP sample (53.3% vs. 30.6%). The sample was ethnically and socio-demographically diverse (see Table 14).

**Table 14. Demographic characteristics of the sample at study entry (N = 501)**

<table>
<thead>
<tr>
<th>Measure</th>
<th>N</th>
<th>% of sample</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ethnicity of mothers</td>
<td>501</td>
<td>100.0</td>
</tr>
<tr>
<td>European/Caucasian</td>
<td>283</td>
<td>56.5</td>
</tr>
<tr>
<td>South Asian</td>
<td>73</td>
<td>14.6</td>
</tr>
<tr>
<td>East Asian</td>
<td>60</td>
<td>12.0</td>
</tr>
<tr>
<td>Black</td>
<td>46</td>
<td>9.2</td>
</tr>
<tr>
<td>Other</td>
<td>39</td>
<td>7.7</td>
</tr>
<tr>
<td>Teenage mother</td>
<td>31</td>
<td>6.2</td>
</tr>
<tr>
<td>Single parent family</td>
<td>32</td>
<td>6.4</td>
</tr>
<tr>
<td>Immigrant family (mother not Canadian-born)</td>
<td>233</td>
<td>46.5</td>
</tr>
<tr>
<td>Low income family (&lt;$20,000)</td>
<td>45</td>
<td>9.5</td>
</tr>
<tr>
<td>Mother’s years of education (&lt;high school)</td>
<td>34</td>
<td>6.2</td>
</tr>
<tr>
<td>Mothers scoring in depressed range on CESD</td>
<td>71</td>
<td>14.4</td>
</tr>
</tbody>
</table>

*Note. Total sample at wave 1, N = 501*

At Time 1 (T1; $M_{age} = 2.0$ months; SD = 1.06), 501 families were enlisted in the study. Due to sample attrition, 397 (79.2%) families were followed up at Time 2 (T2; $M_{age} = 1.60$ years; SD = .16). Attrition analysis showed that dropout, similar to other longitudinal studies, was related to higher levels of social risk: maternal depression at T1, $\chi^2 (df = 1) = 7.2, p = .01$, being in a non-intact family, $\chi^2 (df = 1) = 11.1, p = .002$, immigrant status, $\chi^2 (df = 1) = 13.5, p < .001$, teenage parenthood, $\chi^2 (df = 1) = 6.7, p = .02$, maternal education < high school, $\chi^2 (df = 1) = 10.5, p = .002$, and family income < $20,000, \chi^2 (df = 1) = 7.1, p = .01$. Of the 397 children remaining at T2, no social-cognitive data were available for 24 children due to noncompliance, lack of visibility (e.g., child went off camera), parent intrusion (e.g., directing child), non-administration due to family constraints (e.g., time limitations) or tester administration error (e.g., not following
the standardized protocol). This resulted in a final sample of 373 children providing data on social cognition.

5.2.2 Procedure

The study design combined the strengths of epidemiological methodology (large and diverse sample, multiple siblings, home visits) with the strength of developmental methodology (tasks developed in the laboratory, detailed microsocial observational data). At each time point, two trained interviewers visited each family’s residence for approximately two hours. Data collection included questionnaires, age-appropriate developmental tasks for target children at T2, and observational measures of mother-child interactions at T2.

5.2.3 Measures

Cumulative biomedical risk. At T1, mothers reported on their own pregnancy complications and a variety of infant birth problems. A single item was used to assess the presence/absence (0 = absent; 1 = present) of each of the following: (1) pregnancy diabetes; (2) hypertension; (3) thyroid problems (4) loss of fetal movement; (5) injury to the abdomen; (6) infant need for intensive care after birth; (7) infant need for oxygen/ventilation; and (8) infant need to be transferred to a specialized hospital. Further, two additional continuous perinatal risk factors were dichotomized based on pre-defined cut-points. These were: (9) low birth weight (< 2500 g); and (10) short gestation (< 37 weeks). A count of these biomedical risks was computed. The distribution of problems in the sample was as follows: 0 problems (68.0%), 1 problem (25.0%), 2 problems (4.4%), 3 problems (1.2%), 4 problems (1.2%), 5 problems (0%), and 6 problems (0.2%). No individuals reported 7 to 10 problems. Further, as few individuals existed in the upper tail of the distribution, we combined 4-6 problems into a category of ‘4 or more’ problems (1.4% of the sample). Thus, this variable represented a count of the number of biomedical risks/complications on a scale from zero to ‘4 or more’.

Maternal responsivity. Observational data were gathered at T2 on mother-child interactions across three 5-minute tasks: (1) unstructured free play with no toys; (2) a structured cooperative building task (using Duplo blocks to build a design from a picture); and (3) reading from a wordless picture book. For all three tasks, three domains of responsivity were coded using the Parent-Child Interaction System of global ratings (PARCHISY, Deater-Deckard, Pylas, & Petrill,
1997) and the Coding of Attachment Related Parenting (CARP, Matias, 2006). Sensitivity (from the CARP) measured the degree to which the parent responded to the child’s verbal and non-verbal signals, supported the child’s autonomy, showed warmth, and demonstrated an ability to see things from the child’s perspective. Mutuality (from the CARP) is a dyadic code and is compatible with the concept of the ‘goal-corrected partnership (Bowlby, 1982). Mutuality was indexed by reciprocity in conversation (e.g., a conversation that “goes somewhere” and is a genuine dialogue), affect sharing, joint engagement in task, and open body posture. Finally, positive control (from the PARCHISY) captures the parents’ positive means of getting the child to do something that she wanted him or her to do through the use of praise, explanations, and open ended questions. Each of these three domains – sensitivity, mutuality, and positive control – was rated on a 7-point scale for each of the three tasks. Internal consistency of the measures was high (α = .85). Thus, a composite measure of ‘maternal responsivity’ was created by averaging the sensitivity, mutuality, and positive control scores across all three tasks. Higher scores reflected higher levels of maternal responsivity. Coders were trained to criterion and then 10% of the interactions were double-coded. Reliability was checked throughout the coding period to guard against rater drift. Inter-rater reliability was high (α = .94). Coders were blind to the biomedical history of the children.

Social Cognition. This was measured at T2 (18 months) by four independent observational tasks assessing children’s joint attention, empathy, cooperation, and self-recognition. Each of these tasks was previously validated and widely used in laboratory studies, and we adapted these for use in the home interviews. A complete description of these tasks can be found in Supplementary Material, as well as Wade et al. (2014). Briefly, in the joint attention task children were required to respond to an adult interviewer’s bids for directing their attention (Mundy, et al., 2003); in the empathy task (Kochanska, DeVet, Goldman, Murray, & Putnam, 1994) children were assessed for their ability to respond to the feigned distress of the interviewer; in the cooperation tasks (Warneken, et al., 2006) children had to work collaboratively with the interviewer towards a shared goal; and in the self-recognition task we evaluated children’s ability to recognize the objectivity of their body using the mirror-rouge paradigm (Amsterdam, 1972). Inter-rater reliabilities across tasks were good: α = 0.94 for joint attention, α = .82 for empathy, α = .86 for cooperation, and k = 0.79 for self-recognition. Scores on these measures were submitted to a confirmatory factor analysis (CFA), consistent with their ostensible coherence as indicators of
children’s latent social cognition (Wade et al., 2014). Model fit for the social cognition factor was excellent in accordance with Hu and Bentler’s (1999) recommended cut-offs: root-mean-square-error of approximation (RMSEA) = .023, comparative fit index (CFI) = .99, and standardized root-mean-square residual (SRMR) = .021. Model-estimated loadings were also positive and significant at the \( p < .001 \) level for all indicators. Factor scores were saved and used as the primary outcome variable. The social cognition factor was normally-distributed with a mean of zero.

**Covariates.** Based on previous studies demonstrating the association between certain socio-demographic and constitutional factors and social cognition, a number of variables were controlled for: (1) child age in years; (2) child gender (0 = male; 1 = female); (3) annual family income, assessed on a scale from 1 (‘no income’) to 16 (‘$105,000 or more’); (4) maternal education, assessed as the total number of years of formal schooling, not including kindergarten; (5) immigrant status of the mother (i.e. 0 = immigrant; 1 = born in Canada); (6) maternal depression, assessed using the Center for Epidemiological Studies Depression Scale cut-off value of 16 (CES-D; Radloff, 1977). This is a widely used self-report scale that assesses depression in nonclinical populations; and (7) children’s language ability, measured concurrent with social cognition (18 months) using the MacArthur-Bates Communicative Development Inventories (CDI; Fenson, et al., 1994).

5.2.4 Statistical analysis

First, all predictor and covariate variables were standardized, and the interaction term between cumulative biomedical risk and maternal responsivity was computed by multiplying the \( z \)-scores of these two variables (Preacher & Rucker, 2003). We then performed hierarchical multiple regression using MPlus 7.0. To handle variable amounts of missing data, we used full-information maximum likelihood estimation (FIML), which produces unbiased parameter estimates and standard errors when data are missing at random (Enders & Bandalos, 2001). The model was fitted using the maximum likelihood with robust standard errors estimator (MLR), which gives parameter estimates with standard errors and a chi-square that are robust to non-normality (Yuan & Bentler, 2000). In the first step of the multiple regression analysis, the covariates were entered into the model. In the second step, the covariates plus the main effects of cumulative biomedical risk and maternal responsivity were entered into the model. Finally, in the
third step, the interaction between biomedical risk and maternal responsivity was added to the variables from all previous steps in order to determine whether the interaction term predicted social cognition above and beyond covariates and main effects.

5.3 Results

5.3.1 Preliminary descriptive analysis

Table 15 presents the descriptive statistics for all study variables, including bivariate associations. Notable associations in Table 15 include the positive relationship between social cognition and child age, female gender, family income, language ability, and maternal responsivity, as well as the negative association between social cognition and cumulative biomedical risk. Higher biomedical risk was also associated with lower socioeconomic status (family income and maternal education), as well as higher levels of maternal depression and lower levels of maternal responsivity. Maternal responsivity was associated with nearly all other study variables. A preliminary trend analysis showed that there was a significant linear association between cumulative biomedical risk and social cognition, $B (SE) = -.02 (.01)$, $p = .047$. Neither the quadratic, $B (SE) = .01 (.01)$, $p = .10$, nor the cubic trend, $B (SE) = -.01 (.01)$, $p = .22$, were significant, suggesting that as cumulative biomedical risk increases, social cognition decreases in a linear fashion (see Supplementary Figure 1 for a plot of this association). Also, Supplementary Table 15 outlines the inter-relations between individual risk variables in the cumulative risk index. This Table shows a combination of independent and inter-dependent risk variables, making the cumulative risk approach suitable (see Evans et al., 2013).

5.3.2 Primary regression analysis

We performed hierarchical multiple linear regression to examine the effect of cumulative biomedical risk, maternal responsivity, and their interaction on social cognition. These results are presented in Table 16. In the first step of the model, covariates that were shown to be significant predictors of social cognition at 18 months included age, female gender, and child language ability. Family income was marginally associated with social cognition. None of the other covariates were significant predictors. This step of the model accounted for a significant 30% of the variance in social cognition. In the second step of the model, above and beyond covariates, there was a significant main effect of cumulative biomedical risk and a marginally significant
Table 15. Descriptive statistics and correlations between study variables

<table>
<thead>
<tr>
<th>Variable</th>
<th>1.</th>
<th>2.</th>
<th>3.</th>
<th>4.</th>
<th>5.</th>
<th>6.</th>
<th>7.</th>
<th>8.</th>
<th>9.</th>
<th>M or %</th>
<th>SD</th>
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<td></td>
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<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>49.3</td>
<td>--</td>
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<tr>
<td>Family income</td>
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<td>.02</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>11.9</td>
<td>4.06</td>
</tr>
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<td>Maternal education</td>
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<td>.51***</td>
<td>-</td>
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<td></td>
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<td>15.3</td>
<td>2.68</td>
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<td>Immigrant status</td>
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<td>-.02</td>
<td>.34***</td>
<td>.13**</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>46.5</td>
<td>--</td>
</tr>
<tr>
<td>Maternal depression</td>
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<td>-.02</td>
<td>-.32***</td>
<td>-.25***</td>
<td>-.17***</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
<td>9.46</td>
<td>7.29</td>
</tr>
<tr>
<td>Language ability</td>
<td>.00</td>
<td>.00</td>
<td>.04</td>
<td>.02</td>
<td>.12*</td>
<td>.04</td>
<td>-</td>
<td></td>
<td></td>
<td>.00a</td>
<td>1.00</td>
</tr>
<tr>
<td>Maternal responsivity</td>
<td>.07</td>
<td>.14**</td>
<td>.34***</td>
<td>.26***</td>
<td>.24***</td>
<td>-.16**</td>
<td>.17**</td>
<td>-</td>
<td></td>
<td>3.51</td>
<td>.79</td>
</tr>
<tr>
<td>Social cognition factor</td>
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<td>.14**</td>
<td>.13*</td>
<td>.06</td>
<td>.02</td>
<td>-.05</td>
<td>.27***</td>
<td>.24***</td>
<td>-</td>
<td>.00a</td>
<td>.14</td>
</tr>
<tr>
<td>Biomedical risk</td>
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<td>-.02</td>
<td>-.18***</td>
<td>-.17***</td>
<td>.04</td>
<td>.10*</td>
<td>-.02</td>
<td>-.12*</td>
<td>-.10*</td>
<td>--b</td>
<td>--</td>
</tr>
</tbody>
</table>

* ***p < .001. ** p < .01. * p < .05. † p < .10.

These are either standardized scores or factor scores with a mean of zero.

See in-text for the distribution of this variable.
main effect of maternal responsivity on social cognition. This model accounted for an additional 2.1% of the variance in social cognition, or 32.1% overall. Finally, in the third step of the model, over and above covariates and main effects, the interaction between cumulative biomedical risk and maternal responsivity significantly predicted social cognition. The main effects of both biomedical risk and maternal responsivity were reduced to non-significance upon inclusion of the interaction term. This model accounted for a total of 32.8% of the variance in social cognition.

Table 16. Model results for the primary multiple regression analysis

<table>
<thead>
<tr>
<th></th>
<th>β</th>
<th>SE</th>
<th>p</th>
<th>R²</th>
<th>F change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Step 1:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Female gender</td>
<td>.30</td>
<td>.09</td>
<td>.001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Child age</td>
<td>.44</td>
<td>.05</td>
<td>&lt;.001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Family income</td>
<td>.09</td>
<td>.05</td>
<td>.10</td>
<td>.30***</td>
<td>20.49***</td>
</tr>
<tr>
<td>Maternal education</td>
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<td>.06</td>
<td>.77</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Child language ability</td>
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<td>.05</td>
<td>&lt;.001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Canadian-born</td>
<td>.10</td>
<td>.10</td>
<td>.33</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maternal depression</td>
<td>-.01</td>
<td>.05</td>
<td>.76</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Step 2:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cumulative biomedical risk</td>
<td>-.12</td>
<td>.06</td>
<td>.043</td>
<td>.32***</td>
<td>3.95*</td>
</tr>
<tr>
<td>Maternal responsivity</td>
<td>.10</td>
<td>.05</td>
<td>.051</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Step 3:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cumulative biomedical risk*maternal responsivity</td>
<td>.10</td>
<td>.05</td>
<td>.047</td>
<td>.33***</td>
<td>3.29†</td>
</tr>
</tbody>
</table>

†p < .10. *p < .05. **p < .01. ***p < .001

R² – Cumulative R²
5.3.3 Follow-up analysis of simple slopes

To explicate the pattern of the interaction between biomedical risk and maternal responsivity, we performed an analysis of simple slopes, which tests the relationship between biomedical risk and social cognition at different levels of the moderator (Aiken & West, 1991). In the case of a continuous moderator (i.e. responsive parenting), the common approach to examine the regression relationship at high (+1 SD) and low (-1 SD) levels of the moderator (Cohen et al., 2013). The pattern of this interaction can be seen in Figure 7. This figure shows that, when biomedical risk is low, there was a minimal effect of responsivity on social cognition (z = .38, p = .71). Alternatively, at high levels of biomedical risk, responsivity was positively related to social cognition (z = 2.66, p = .008). Examining the converse associations, at low levels of responsivity, biomedical risk was strongly negatively associated with social cognition (z = -2.70, p = .002), while at high levels of responsivity, biomedical risk was not associated with social cognition (z = .38, p = .70).

![Figure 7](image_url)

**Figure 7.** Plotted interaction between cumulative biomedical risk by responsive parenting on social cognition at 18 months. Solid line represents low levels of maternal responsivity (-1 SD below the mean), and hashed line represents high levels of maternal responsivity (+1 SD above the mean). Each point on the plot represents a combination of high/low biomedical risk and high/low responsivity, for a total of four possible combinations. ** denotes that that comparison between points is significant, where *n.s.* denotes that there is no difference between the points on social cognition.
5.4 Discussion

The aim of the current study was to investigate the association between cumulative biomedical risk and social cognition at 18 months, and whether maternal responsivity moderated this association. It was shown that, above and beyond covariates, both maternal responsivity and cumulative biomedical risk independently predicted social cognition at 18 months. Further, consistent with study hypotheses, maternal responsivity was shown to moderate the association between biomedical risk and social cognition, with the effect of biomedical risk only apparent at low levels of maternal responsivity. Alternatively, at high levels of maternal responsivity, there was no effect of cumulative biomedical risk on social cognition. These results provide the first empirical evidence that accumulating biomedical risk factors may be one source of inter-individual variability in children’s social-cognitive skills in the second year of life. Also, and consistent with risk-resiliency models of development, these findings suggest that postnatal socialization factors – specifically responsive caregiving – may protect against the impact of early biomedical risk on child outcomes.

Our finding that responsive parenting acts as a protective factor against early biomedical complications is consistent with intervention studies showing that cognitive and social outcomes of perinatally at-risk children may be fostered through training programs that build parents’ cognitive and affective responsiveness (Landry, Smith, Miller-Loncar, & Swank, 1997; Landry, Smith, & Swank, 2006; Landry, Smith, Swank, & Guttentag, 2008; Landry, et al., 2012). In general, these studies show that intervention effects on broad cognitive and socio-emotional competence operate through changes in parenting behaviors, and these effects are strongest in the most biologically at-risk children (e.g. very low birth weight, preterm). Within the context of these intervention studies, the current findings are noteworthy for two reasons: first, they show that, in addition to individual biological insults such as low birth weight, the accumulation of early biomedical risk factors may also compromise children’s emerging social-cognitive skill development, operationalized within a framework that posits underlying capacities for self-other differentiation and understanding of intentions (see also Moore, 2007; Wade, Moore, et al., 2014); second, they demonstrate that the protective role of responsive maternal behaviors is also present within a normative, epidemiological sample of children with varying degrees of biological risk. Within such a sample, the presence of individual biomedical risks are typically
not powerful individual predictors of child outcomes, either because these are low frequency events, or because there are a host of identified or unidentified factors that buffer the effect of isolated risks. Rather, it may be that the accumulation of multiple biomedical risks is what creates meaningful differences in children’s social cognition within the general population.

The mechanisms through which biomedical risks influence children’s social cognition are presumed to involve changes in infant brain development. However, little research exists to support the idea that prenatal/birth insults specifically impact the neural regions that support social cognition in humans. The postnatal progression following such biomedical risks may shed light on the mechanisms that underlie differences reported here. Infants born with prenatal/perinatal complications are at a higher risk for postnatal complications (e.g. metabolic complications; Hendderson et al., 2006; Lubhenco & Bard, 1971). Experimental evidence from animal models demonstrates that all these factors can stimulate or precipitate neuronal death in the infant brain resulting in volume loss in particular regions within the brain (Bhutta & Anand, 2001). This is supported by findings from Peterson and colleagues (2000), who examined brain volume differences in 8-year old children born with birth complications. This study demonstrated smaller volumes in the amygdala, hippocampus, basal ganglia, and cortical regions, all of which were associated with increased risk of ADHD and lower cognitive scores. Some of these regions have also been implicated in social cognition (Adolphs, 2001). Further, in a notable study by Carmody and colleagues (2006), cumulative medical and environmental risk was shown to be associated with lower cognitive performance in adolescence, as well distinct patterns as brain activation in temporal and parietal cortical regions. This is interesting given that social cognition, including the capacity for self-other differentiation and mental-state inference, is believed to be supported by a distributed neural network that includes temporal and parietal areas (Decety & Sommerville, 2003; Van Overwalle, 2009). By extension, it is plausible that accumulating biomedical risks are associated with social cognition by virtue of their effect on functional brain networks during in utero and early postnatal development. Moreover, recent studies suggest the possibility that the strongest associations between pre/perinatal characteristics and brain development may exist within the normal range (Raznahan, Greenstein, Lee, Clasen, & Giedd, 2012; Walhovd, et al., 2013). The current results show that, indeed, meaningful differences in social cognition may exist as a function of normal variation in summative biomedical
complications. Despite these interesting findings, the exact mechanism(s) connecting biomedical risk, neural development, and social cognition require future research.

Perhaps most interesting to the current study was the finding that responsive parenting moderated the association between cumulative biomedical risk and social cognition. These results are consistent with other observational studies on the protective effect of positive caregiving on children’s varied behavioral and mental health outcomes (Landry, et al., 1997; Laucht, et al., 1997; 2001; Raine et al., 1994; Raine et al., 1997; Voigt, et al., 2013). Schore’s regulation theory suggests that positive parent-child interactions help promote adaptive functioning through regulation of neurobiological processes, including structural and functional neuroanatomy (Schore, 1996; Schore, 2001). Moreover, regulation theory posits a maturational process from prenatal to postnatal development, consistent with the notion that there is substantial brain development over the first two years of life (Knickmeyer, et al., 2008). The developing brain is also very susceptible to both environmental insult and enrichment, the latter of which may promote some the protective effects of responsive caregiving. Interestingly, recent findings from longitudinal studies show that the provision of early responsive caregiving is associated with enhanced physiological organization and resultant cognitive functioning over the first 10 years of life (Feldman, Rosenthal, & Eidelman, 2014). The precise role of responsive parenting, including the specific forms of care that foster neurobiological development and social cognition, requires further investigation. However, collaborative evidence from the fields of pediatrics, developmental psychology, and social neuroscience point to the importance of early responsive care in ameliorating the long-term sequelae of adverse pre/perinatal events on neurological and cognitive morbidity. Indeed, small variations in biological risk may create momentous gaps in children’s social and cognitive development, and these effects may persist across the lifespan in the absence of interventions that target foundational inter-personal transactions with caregivers early in postnatal life (Walhovd, Tamnes, & Fjell, 2014).

The results of this study should be considered in light of several strengths and limitations. The strengths included the prospective, multi-method, longitudinal design, large and diverse sample, and use of detailed observational outcome data on 18-month social-cognitive measures. Inclusion of numerous socio-demographic confounding variables also adds to the robustness of the current findings. In regard to limitations, the current Canadian sample was more advantaged than the
general population, and participation was restricted to children born >1500g. These sampling factors may limit the generalizability of the results. Also, each of the 10 biomedical risks was low frequency, measured through maternal report, and typically dichotomous. Agreement between self-report and criterion-standard medical record data has been shown to be high for prenatal complications (Okura, Urban, Mahoney, Jacobsen, & Rodeheffer, 2004) and other pre/perinatal events (Lederman & Paxton, 1998; Tomeo, et al., 1999). However, future studies using more comprehensive information from obstetrical records would strengthen these findings. Moreover, additional information on the timing and severity of particular prenatal conditions (e.g. diabetes, hypertension, thyroid problems), as well as the specific reasons neonatal specialized care was needed (e.g. ischemia, anoxia, hematological problems), would improve suggestions about the mechanisms at play. More extensive records of prenatal care – which were not available in the current epidemiological study – would also shed light on the nature of these influences on child outcomes. Also, although significant, the effects documented herein were generally small in magnitude, suggesting that there are additional sources of unexplained variability in social cognition worthy of future investigation. Likewise, biomedical risk and responsive parenting were not completely independent predictors of social cognition, leading to the possibility that heightened biomedical risk may also predict variability in parenting. Possible mechanisms that link early biomedical risk to both parenting and child behaviour – for instance, through the use of longitudinal cross-lagged mediation models – may be useful in elucidating these pathways to social cognition. On a related note, the fact that social cognition and maternal responsivity were measured contemporaneously (i.e. both at 18 months) precludes inferences about causality, and additional studies are warranted to determine the directionality of effects. Finally, although cumulative risk indices are powerful measures for examining the extent of risk exposure on developmental outcomes, future studies comparing the utility of these metrics to individual risk factors (measured through client records or direct measurement of risk, e.g. degree of hypoxia, level of hyperglycemia or hypertension, length of time in specialized care, etc.), are warranted based on these preliminary results.

5.5 Acknowledgements

We are grateful to the families who give so generously of their time, to the Hamilton and Toronto Public Health Units for facilitating recruitment of the sample, and to Mira Boskovic for
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5.6 References – Study 5


## 5.7 Supplementary Material for Study 5

### Table S-2: Relationship between individual risk variables in the cumulative risk index

<table>
<thead>
<tr>
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<td>5. Injury to abdomen</td>
<td>1.52</td>
<td>.45</td>
<td>2.82</td>
<td>.93</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. Intensive care</td>
<td>.003</td>
<td>5.55*</td>
<td>.10</td>
<td>.79</td>
<td>.34</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7. Ventilation/oxygen</td>
<td>.01</td>
<td>.59</td>
<td>.69</td>
<td>.24</td>
<td>.30</td>
<td>145.7***</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8. Specialized hospital</td>
<td>.10</td>
<td>6.89</td>
<td>.07</td>
<td>2.89</td>
<td>.03</td>
<td>41.6***</td>
<td>48.2***</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>9. Low birth weight</td>
<td>.91</td>
<td>.01</td>
<td>.62</td>
<td>.01</td>
<td>.27</td>
<td>49.6***</td>
<td>41.4***</td>
<td>.08</td>
<td>-</td>
</tr>
<tr>
<td>10. Short gestation</td>
<td>.01</td>
<td>.59</td>
<td>.69</td>
<td>.89</td>
<td>.30</td>
<td>77.5***</td>
<td>52.1***</td>
<td>11.1†</td>
<td>78.8***</td>
</tr>
</tbody>
</table>

* ***p < .001. ** p < .01. *p < .05. †p < .10.

Note. These are Pearson chi-square statistics, as the variables were all dichotomous (yes/no).
Figure S-1. Scatter plot of the association between cumulative biomedical risk and social cognition at 18 months. See in-text for the statistical trend analysis documenting the linear association.
General Discussion

The current dissertation aimed to elucidate a subset of factors involved in children’s neurocognitive development, specifically their ToM and EF. First, a developmental cascade model was delineated wherein early social-cognitive precursors measured at 18 months (joint attention, empathy, cooperation, and self-recognition) were shown to predict ToM and EF in the preschool period. Importantly, these associations were specifically mediated by language ability at age 3, suggesting that early social-cognitive skill development scaffolds children’s emergent language faculties, which in turn fosters ToM and EF (Study 1; Wade, Browne, Plamondon, Daniel, & Jenkins, 2015). In other words, language appears to play an important role in ToM and EF by facilitating verbal representation and reasoning about mental states that underlies ToM, and verbal self-monitoring and self-regulation that characterizes EF (Astoning & Baird, 2005; Müller, Jacques, Brocki, & Zelazo, 2009). Second, it was shown that there are cumulative sociodemographic risk disparities in neurocognitive skill development; yet the cascade mechanism that connects these skills over time does not differ for high versus low risk children. Such findings raise the concerning possibility that children with poor early social cognition as a function of increased social risk may be vulnerable to experience continued problems in later domains of competence that rely on those abilities. Thus, promoting early skill development in social cognition may have positive postliminary effects on later neurocognitive outcomes.

There is now substantial evidence for the efficacy of universal preventative interventions to improve school-age children’s social, emotional, and cognitive skills (Catalano, Berglund, Ryan, Lonczak, & Hawkins, 2002; Weissberg & Greenberg, 1998). Programs for preschool-aged children include the Dinosaur School curriculum portion of the Incredible Years series (Webster-Stratton & Reid, 2004), the I Can Problem Solve program (Shure, 1994), and the Emotions Course (Izard, Trentacosta, King, & Mostow, 2004; Lynch, Geller, & Schmidt, 2004). In general, these programs have proven effective in fostering children’s social skills, emotion knowledge, and problem-solving skills. The Incredible Years program has components that span infancy, early childhood, preschool-age, and school-age children, with effect sizes in the small to moderate range (d = .30 to .50). Other programs, such as the Promoting Alternative Thinking Strategies (PATHS; Kusche & Greenberg, 1994) specifically target preschool children’s social-emotional skills related to self/other-awareness and self-regulation. These domains parallel the social-cognitive and executive skills investigated in this dissertation. Amongst children aged 5
and below, PATHS has been shown to improve emotion knowledge, including receptive emotion vocabulary and affect identification (Domitrovich, Cortes, & Greenberg, 2007). However, intervention effects in other areas – inhibitory control, sustained attention, and social problem-solving – have proved weak. Interestingly, language ability has been shown to moderate intervention effects on social skill development, suggesting a role of language in the ability to verbally self-regulate and communicate thoughts and emotions (Domitrovich, et al., 2007).

Prevention and intervention programs for children under 3 are relatively scarce and have been evaluated less rigorously than for school-aged children. For instance, randomized trials of the Incredible Years Parents and Babies program (age 0-12 months) has yet to be formally conducted, though planned evaluations are underway (Pontoppidan, 2015). The Incredible Years Toddler Program (12 to 36 months) has only been evaluated in one study (Gridley, Hutchings, & Baker-Henningham, 2015), which showed positive effects for increasing parental language, which is believed to have positive knock-on consequences for children’s own language development. Other short-term programs, such as the Toddlers Without Tears program, have yielded small or nil effects, with researchers suggesting brief universal programs may be insufficient to prevent behavioral problems from 18 to 36 months (Bayer, Hiscock, Ukoumunne, Scalzo, & Wake, 2010; Hiscock, et al., 2008). These findings run contrary to the widely held belief that interventions provided early in childhood are not only effective, but are more effective than remedial approaches later in life, once problem trajectories have been firmly established (Heckman & Masterov, 2007). Negative findings in infants and toddlers may be attributable to so-called “sleeper effects”, in which the advantage conferred by intervention does not manifest until later in life, possibly following a period of increased neural and biobehavioral organization (Hertzman & Boyce, 2010).

A recent meta-analysis of 123 experimental and quasi-experimental U.S. educational interventions with 3 to 5-year old children showed average effects of .23 SD for cognition (broadly defined), .14 for school progress, and .16 for socio-emotional development (Camilli, Vargas, Ryan, & Barnett, 2010). The vast majority of studies in this meta-analysis focused on disadvantaged children. While effects did not differ by income level, this may have been due to constrained variability and an overrepresentation of low-income families. That significant effects were observed suggests disadvantaged children benefit from direct skill instruction to build these
essential skills, and that receiving these interventions as early as possible may be optimal in terms of preventing cascading problems in other domains (Barnett, 2011; Guralnick, 2011; Shonkoff & Levitt, 2010; Wallace & Rogers, 2010; Wass, Scerif, & Johnson, 2012). Likewise, early cognitive functioning is an important source of human capital in that it serves as a keystone predictor of educational, occupational, and socioeconomic attainment across the life course (Coleman, 1988; Duckworth, Quinn, & Tsukayama, 2012; Sirin, 2005). Rates of return to human capital investment are exponentially higher in disadvantaged children, and economic efficiency is maximized through early intervention compared to later remedial efforts. Thus, early investment not only promotes fairness and social justice, but increases personal, familial, and societal gains for continued growth and development across the lifecourse (Cunha, Heckman, Lochner, & Masterov, 2006; Heckman, 2006).

In addition to cumulative social risk, this dissertation also isolated a set of biomedical risks that appear to confer vulnerability to cognitive morbidity. Specifically, it was demonstrated that maternal hypertension during pregnancy, birth weight, and cumulative biomedical risk were significant predictors of postnatal social cognition, language ability, ToM, and EF (Study 2, 3, and 5; Wade, Browne, Madigan, Plamondon, & Jenkins, 2015; Wade & Jenkins, 2014; Wade, Madigan, Akbari, & Jenkins, 2015). These studies contribute to a sparse literature on the role of pre- and peri-natal events in the development of ToM, EF and their developmental antecedents. These findings can be positioned within a growing literature on the role that biomedical events have on neurobiological functioning in key cortical regions that have been previously implicated in social cognition (including ToM), EF, and language (Carmody, et al., 2006; Raznahan, Greenstein, Lee, Clasen, & Giedd, 2012; Walhovd, et al., 2013). While these studies have focused on adolescence, the results of this dissertation suggest that biomedical influences on neurocognitive development may manifest as early as the preschool period, and possibly as early as the second year of life. Follow-up studies that employ neuroscientific techniques (fMRI, DTI, EEG, etc.) with young children are needed to explicitly test these hypotheses.

Perhaps more interesting than identifying several biomedical risks for neurocognitive difficulties, this dissertation also showed a strong moderating effect of postnatal maternal responsivity at 18 months on (i) children’s language ability at age 3 (Study 4; Madigan, Wade, Plamondon, Browne, & Jenkins, 2015); and (ii) social cognition at 18 months (Study 5; Wade, Madigan, et
The first effect is noteworthy since language appears to be a key mediator of early social and biomedical influences on later neurocognitive functioning. Targeting language ability for early intervention is thus consistent with cascade models that focus on mediating processes for change (Masten & Cicchetti, 2010). The second effect is important since social cognition itself is, in this cascade mechanism, the start-point of vulnerability, and may therefore confer risk for future problems if those trajectories are not shifted early in life (Shaw, Lacourse, & Nagin, 2005; Webster-Stratton & Taylor, 2001). Thus, it is proposed that early intervention may be one means of interrupting negative cascades and diminishing downstream vulnerability not only for later neurocognition, but also for the numerous psychosocial outcomes that depend on healthy neurocognition, including mental health, academic achievement, and social functioning (Blair & Razza, 2007; Hughes & Ensor, 2008; 2011; Olson, Lopez-Duran, Lunkenheimer, Chang, & Sameroff, 2011; Razza & Blair, 2009).

The current dissertation showed that children with high levels of biomedical risk—either lower birth weight or higher cumulative biomedical risk—were at an increased risk for poor language at age 3 and social cognition at 18 months, respectively, compared to children with relatively lower levels of risk, but only if they were also the recipients of lower responsive caregiving at 18 months. If responsive caregiving was high, there was no observed difference in language or social cognition as a function of biomedical risk status. These results suggest a strong protective effect of postnatal socialization experiences with caregivers on these neurocognitive outcomes. Further, it is noteworthy that children with the highest levels of biomedical risk appeared to benefit most from responsive caregiving. That is, upward mobility in skill attainment was greater for high-risk children—a result that is consistent with the abovementioned findings on socially disadvantaged children evincing more gains than advantaged children (also see Burger, 2010).

These moderated effects speak to the increased importance of early policy and programming targeting biomedically at-risk children. Indeed, several intervention and prevention-focused programs have been developed that target premature, low-birthweight, or otherwise biomedically compromised children. These program generally focus on parent education, infant stimulation, home visits, or individualized developmental care. Systematic reviews and meta-analyses suggest that these programs improve cognitive and neurodevelopmental outcomes in preschool-aged children, though maintenance of effects into school-age is more tenuous (Orton, Spittle,
Doyle, Anderson, & Boyd, 2009; Spittle, Orton, Doyle, & Boyd, 2007; Vanderveen, Bassler, Robertson, & Kirpalani, 2009). However, interventions that explicitly focus on maternal outcomes and parent-child interactions have yielded positive effects on child cognitive outcomes (Benzies, Magill-Evans, Hayden, & Ballantyne, 2013; Newnham, Milgrom, & Skouteris, 2009; Wu, et al., 2014). Some interventions, such as Kangaroo Care, have been shown not only to improve executive functions up to age 10, but also to improve sleep, reduce stress response, and increase vagal tone, suggesting that improvements in physiological organization can be maintained via dynamic cascades involving continued parental enrichment across development (Feldman, Rosenthal, & Eidelman, 2014).

The effect of developmentally-sensitive interventions targeting biomedically at-risk children is perhaps best exemplified by Susan Landry’s Playing and Learning Strategies (PALS) program (Landry, Smith, Swank, & Guttentag, 2008; Landry, et al., 2012). This program emphasises parental affective-emotional responsiveness (positive affection, high levels of warmth and nurturance, acceptance of child uniqueness) as well as cognitive responsiveness (maintaining child focus of interest, rich verbal input). The 10-session curriculum contains both an infancy and early childhood (24-26 months) component, and uses educational videotapes and coached mother-child interactions. Intervention effects on maternal behaviour are generally moderate ($d = .25$ to $.51$) for contingent responsiveness, warmth/sensitivity, maintaining and redirecting, and verbal input. Likewise, there are concomitant positive effects for several child outcomes ($d = .30$ to $.68$), including cooperation, social engagement, word use, coordinating attention, and receptive vocabulary (Landry, Smith, & Swank, 2006; Landry, et al., 2008). Effects tend to be greater among more biomedically compromised children. Moreover, the benefit of PALS on maternal and child outcomes has been shown to generalize to novel contexts not initially trained during intervention (Landry, et al., 2012). An extension of this intervention, called the My Baby & Me program, includes other components such as establishing daily routines, learning about infant health and safety, developmental milestones, and problem solving and decision making. This program has been shown to improve children’s social, emotional, and cognitive abilities at 30 months, effects that are mediated by improvements in maternal responsiveness (Guttentag, et al., 2014). In sum, fostering responsive parenting through video modeling, guided live practice of target skills, and reflective review and discussion of the parent’s video footage with her child has the potential to bolster children’s early neurocognitive skill development. It is suggested that
efforts to enhance early skill formation may help to prevent the instigation or propagation of deleterious cascades over time.

From an investment standpoint, it is fair to wonder whether early prevention/intervention programs targeting parental responsiveness are more profitable than training programs for individual neurocognitive skills. In other words, where do we get the most “bang for our buck”? While an exhaustive review of literature on ToM and EF training is beyond the scope of this dissertation, it is generally the case that these training programs generate stronger effects than parent-focused interventions (Diamond & Lee, 2011; Hale & Tager-Flusberg, 2003; Kloo & Perner, 2003; Lecce, Bianco, Devine, Hughes, & Banerjee, 2014; Tompkins, 2015). However, meta-analytic studies suggest that while short-term gains in neurocognitive skills are usually observed, long-term improvements are less reliable and tend not to generalize to other neurocognitive domains (Melby-Lervåg & Hulme, 2013). These result cast doubt on the clinical utility of these programs in enhancing cognitive functioning in healthy children and adults. Whether such programs are more beneficial for socially or biomedically at-risk children is an area that deserves attention in future research. However, other meta-analyses show that programs designed to train EF in children with ADHD also show limited efficacy, without auxiliary improvements in academic, behavioural, or cognitive functioning in other domains (Rapport, Orban, Kofler, & Friedman, 2013). Thus, interventions that are less domain-focused and more ecologically wide-reaching may espouse lasting change in several domains of competence. Although direct effect-size comparisons can be misleading and are highly prone to sampling biases, the aggregate of findings presented above (including those from experimental, observational, and intervention studies) suggest that programs focused on improving parental responsivity may be one means of promoting early neurocognitive functioning in various domains, with positive cascading effects over the course of childhood.
References for General Introduction and Discussion


Lysaker, P. H., Leonhardt, B. L., Brüne, M., Buck, K. D., James, A., Vohs, J., et al. (2014). Capacities for theory of mind, metacognition, and neurocognitive function are independently related to emotional recognition in schizophrenia. *Psychiatry research, 219*(1), 79-85.


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