

Social Influences on Children's Learning

by

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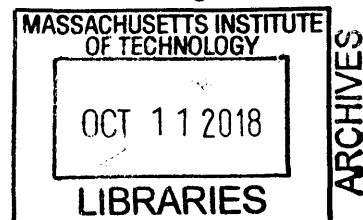
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Abstract

Adults greatly impact children's learning: they serve as models of how to behave, and as parents, provide the larger social context in which children grow up. This thesis explores how adults impact children's learning across two time scales. Chapters 2 and 3 ask how a brief exposure to an adult model impacts children's moment-to-moment approach towards learning, and Chapters 4 and 5 look at how children's long-term social context impacts their brain development and capacity to learn. In Chapter 2, I show that preschool-age children integrate information from adults' actions, outcomes, and testimony to decide how hard to try on novel tasks. Children persist the longest when adults practice what they preach: saying they value effort, or giving children a pep talk, in conjunction with demonstrating effortful success on their own task. Chapter 3 demonstrates that social learning about effort is present in the first year of life and generalizes across tasks. In Chapter 4, I find that adolescents' long-term social environments have a selective impact on neural structure and function: socioeconomic-status (SES) relates to hippocampal-prefrontal declarative memory, but not striatal-dependent procedural memory. Finally, in Chapter 5 I demonstrate that the neural correlates of fluid reasoning differ by SES, suggesting that positive brain development varies by early life environment. Collectively, this work elucidates both the malleable social factors that positively impact children's learning and the unique neural and cognitive adaptations that children develop in response to adverse environments.

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My research interests lie in how the social environment shapes children's development and as I near the end of my PhD, I'm lucky to have the opportunity to reflect back on all the amazing people that have positively shaped *my* development.

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Chapter 1

Children develop in a social context

As adults, we have a great impact on children's learning. We serve as models of how to behave, teach moral values, and as parents, provide the broader ecological context in which children grow up. These factors impact children's development on different time scales: in the short-term, adult behavior can influence children's moment-to-moment decision making, whereas repeated exposure to a specific behavior can cause long-term restructuring of children's brains, attitudes, and actions. For example, if an adult demonstrates they are untrustworthy as a source of information on a given task, children won't rely on them on a subsequent task. However, if a child is exposed to repeated instances of unpredictable adults, he or she will update their long-term expectations of reliability in the world at large.

This thesis explores how the social environment impacts children's learning on both of these timescales. Specifically, I address how the social environment 1) shapes children's moment-to-moment approach towards learning and 2) over time, affects children's brain development and capacity to learn. With the first question, I look at how potentially malleable social input can causally impact children's decisions to persist through challenges, a fundamental part of learning. With the second question, I explore the unique neural and cognitive adaptations children develop in response to long-term adverse social contexts. Understanding both the malleable social factors that positively impact development and children's adaptations to adverse environments are key for developing novel interventions to help children from all backgrounds succeed in school and beyond.

In this Chapter, I lay out foundational research that has inspired this work. First, I review the literature on how the social environment impacts children's proclivity to persist through challenges. Then I consider work on how children's long-term social and economic environment impacts their brain development, cognition, and educational outcomes. I conclude Chapter 1 with a roadmap discussing how this dissertation aims to contribute both theoretically and empirically to the understanding of how children grow and thrive.

1.1 How the social environment shapes children's approach to learning.

1.1.1 Persistence: a key ingredient in children's learning

Work in cognitive development has shown that children are efficient, rational learners, capable of generalizing abstract concepts from just a few examples (Bonawitz et al., 2011; Griffiths, Sobel, Tenenbaum, & Gopnik, 2011; Gweon & Schulz, 2011; Schulz, Bonawitz, & Griffiths, 2007; Tenenbaum, Kemp, Griffiths, & Goodman, 2011; Xu & Tenenbaum, 2007). Yet, learning is not always easy – we have all watched children get frustrated and give up when they encounter a difficult learning situation. Thus, in order for children to fully utilize their incredible learning abilities, they must be able to persist in the face of challenge.

Indeed, throughout development, children's persistence correlates with academic outcomes when controlling for IQ (Duckworth, Peterson, Matthews, & Kelly, 2007; Eskreis-Winkler, Shulman, Beal, & Duckworth, 2014). For example, high school juniors who displayed high passion and perseverance for long-term goals were more likely to graduate from high school, even when controlling for academic conscientiousness, demographic variables, and standardized achievement scores (Eskreis-Winkler et al., 2014). Even the way children think

about the relationship between effort and outcome is important: children with a “growth” mindset, who believe effort determines outcomes, academically outperform children with a “fixed” mindset, who believe that ability is an inherent trait (for a review, see Yeager & Dweck, 2012).

1.1.2 Social factors that impact persistence

Children’s theories about and behaviors related to persistence are malleable and greatly impacted by their social environment. For example, adults can significantly affect children’s persistence through the use of directed speech. Specifically, adult praise for children’s effort, rather than ability, has been shown to increase children’s persistence. Praising children for ability implies that traits are fixed, making subsequent failures demoralizing. Praising children for their process, on the other hand, helps children believe that effort and deliberate practice fuel their accomplishments. This focus on the process encourages children to try harder and take on challenges, even after setbacks. For example, Mueller and Dweck (1998) found that 5th graders praised for effort (“You must have worked hard at these problems”), were more inclined to seek challenging tasks and had greater task persistence after failure on matrix reasoning problems than children praised for ability (“You must be smart at these problems”). This effect has also been found in younger children. When 5-6-year-olds were praised for effort rather than outcome, they were more persistent on a role-playing task after a setback (Kamins & Dweck, 1999). Similarly, preschoolers who were given non-generic praise that invokes process (“You did a good job drawing”) had greater task persistence than children given generic praise, which implies inherent ability (“You are a good drawer”; Cimpian, Arce, Markman, & Dweck, 2007).

While these studies demonstrate the short-term impact of adult language on children's persistence, Gunderson and colleagues (2013) found that parents' praise for effort at 14-38 months predicted their child's mindset at 7-8 years old. Specifically, the more children were praised for effort in early childhood, the more likely they were to endorse a 'growth mindset' later in development. Thus, adult's language early in life causally impacts their children's beliefs about the relationship between effort and outcome.

Furthermore, intervention experiments have shown that explicitly teaching children that intelligence can grow through hard work improves their academic performance and response to challenges. College students who were given a growth mindset intervention that involved learning about the brain's malleability and teaching this message to a struggling middle school 'pen pal' had significant increases in overall grade point averages at the end of the year compared to a control group (Aronson, Fried, & Good, 2002). Similar effects were found in middle school students. Math grades usually drop during the transition from elementary school to middle school, but this pattern was reversed for students in a mindset intervention, although not for those in a study skills intervention (Blackwell, Trzesniewski, & Dweck, 2007). Furthermore, these interventions are scalable and easy to implement: short, one-time online mindset interventions have been shown to be effective at raising first-year full-time college enrollment and grades in a large-scale, double-blind study (Yeager et al., 2016). Thus, providing children with an expansive mindset can help them make sense of challenges and take steps to overcome them.

Adults can also impact children's persistence by providing verbal strategies. Patterson and Mischel (1975) had preschoolers do a repetitive copying task alone in a room with a distracting clown toy. Children were either provided strategies to resist this temptation (e.g., "No

I can't, I'm working!" or "I'm going to keep working so I can play with the fun toys and Mr. clown box later.") or given no strategies. The children who were given strategies persisted on the task for longer in the face of a distraction than children in a control group. In other words, if children are provided with a clear plan of attack to deal with distraction, they can apply it and increase their persistence. However, some strategies are more successful than others. Teaching children to work on dampening their attention to temptation is more effective than instructing children to increase their attention to the task at hand (Mischel & Patterson, 1976; Patterson & Mischel, 1976). Taken together, this suggests that adults can provide strategies to help children persist through challenges.

In addition to adults' words, adults' actions also impact children's behavior. Children learn a great deal from watching how adults behave. They use adult models to learn both information that is causally relevant to their goals (Bekkering, Wohlschläger, & Gattis, 2000; Gergely, Bekkering, & Király, 2002; Meltzoff, 1995; Schulz, Hooppell, & Jenkins, 2008) and behaviors that, although causally unnecessary, may be plausibly relevant to norms, conventions or broader social practices (Harris, 2012; Kenward, Karlsson, & Persson, 2011; Lyons, Young, & Keil, 2007; McGuigan, Whiten, Flynn, & Horner, 2007). Further, just a few examples from adult models suffice for young children to draw rich, abstract generalizations (e.g., Tenenbaum et al., 2011). Especially in pedagogical contexts, where adults make eye contact, say the child's name, use child-directed speech, and perform intentional actions, even infants can draw broad, generalizable inferences from adult models (Gergely et al., 2002; Gergely, Egyed, & Király, 2007).

Recent work has shown that children interpret others' intentional actions through the lens of a "naïve utility calculus" – expecting agents to minimize costs and maximize rewards (Jara-

Ettinger, Gweon, Schulz, & Tenenbaum, 2016). For example, 5-year olds infer that if an agent climbs up a tall tower to get a cookie when a cracker was available on a shorter tower, that the agent must prefer cookies over crackers (Jara-Ettinger, Gweon, Tenenbaum, & Schulz, 2015). This same form of reasoning about the value of outcomes based on costs incurred has been demonstrated even in 10-month olds (Liu, Ullman, Tenenbaum, & Spelke, 2017). Furthermore, children utilize their sensitivity to others' costs to decide how to engage socially. Toddlers prefer to play with agents who achieve goals quickly and easily, presumably because this demonstrates competence (Jara-Ettinger, Tenenbaum, & Schulz, 2015). This work shows that young children can use other people's costs to make inferences about the agent (i.e., their desires and competence). But do children also use others' costs to inform their own costly action?

At least some work suggests that children persist more on their own tasks after watching other people persist through challenges (Brown & Inouye, 1978; Zimmerman & Blotner, 1979; Zimmerman & Ringle, 1981). This learning can happen through watching peers (Schunk & Hanson, 1985; Schunk, Hanson, & Cox, 1987) or adults (Zimmerman & Ringle 1981; Zimmerman & Blotner, 1979). These studies have found that children persist more after watching an adult persist and succeed both immediately after the demonstration (Zimmerman & Ringle, 1988) and a day later on a different task (Zimmerman & Blotner, 1979). However, the impact of adult models of effort on children's persistence has not been studied in children younger than first grade.

1.1.3 The importance of persistence in early childhood

Most work on children's persistence has focused on school-age children, but there is reason to believe that examining persistent behavior before children enter formal schooling is

particularly important. A number of studies have found relationships between infants and toddler's persistence and later cognitive outcomes, ranging from IQ scores to willingness to take on difficult challenges (Belsky, Friedman, & Hsieh, 2001; Frodi, Bridges, & Grolnick, 1985; Kelley, Brownell, & Campbell, 2000; Messer et al., 1986; Yarrow et al., 1983; Yarrow, Morgan, Jennings, Harmon, & Gaiter, 1982). The particular behaviors operationalized as "persistence" varies by study and the age of the child. Studies with young infants tend to focus on sustained attention while manipulating simple objects; studies with older infants and toddlers may focus on the discovery of object functions, or perseverance in problem solving, as with a shape-sorter toy. Overall, however, researchers have suggested that a suite of temperamental and cognitive factors involved in executive function and "effortful control" (see Kochanska, Murray, & Harlan, 2000 and Rothbart, 2007 for reviews) may mediate correlations between infant persistence and later cognitive outcomes. Thus, understanding how effortful behavior forms early in life is critical as early persistence sets children on a path for later cognitive success.

Furthermore, income and race achievement gaps are present by the time children enter school (Duncan & Magnuson, 2011; Phillips, Crouse, & Ralph, 1998), suggesting the necessity of early interventions related to motivation. Two studies found that children (preschool to grade 8) who grow up in poverty are less persistent than those who do not (Brown, 2009; Evans, Gonnella, Marcynyszyn, Gentile, & Salpekar, 2005). While no study has yet directly tested whether persistence mediates the relationship between poverty and educational outcomes, it may be a contributing factor. Early interventions targeted toward low-income preschool children that encourage engaging in cognitively challenging tasks (e.g., Tools of the Mind) have shown moderate success (Barnett et al., 2008; Diamond, Barnett, Thomas, & Munro, 2007). This

suggests that finding ways to encourage children to take on challenges early in life, before formal schooling, might be an effective way to narrow achievement gaps.

There are many open questions related to children's persistence before they start formal schooling. For example, are young children rational and selective with their persistence? What sources of evidence in their environment do they use to make decisions related to effort? Perhaps most pressing is the question of whether motivational behavior is at all malleable in early childhood. And if so, in what ways can we intervene? This is not to suggest that the goal is for children to persist at everything. Indeed, effort is a limited resource and we can't expect children to try hard at everything, nor would that be a good idea. Rather, we would like to understand how to boost persistence when it matters most, such as in learning contexts.

1.2 How the social environment shapes brain development and one's capacity to learn.

1.2.1. The social environment gets "under our skin"

The long-term social environment we grow up in has a powerful impact on both our brain and behavior. This 'biological embedding' of early life experiences has been most clearly demonstrated in animals. Studies with rodents show that individual differences in maternal care (in the form of licking and grooming) cause genetic changes in offspring's glucocorticoid receptor gene promoter in the hippocampus, affecting how these pups respond to stress later in life (Meaney & Szyf, 2005; Weaver et al., 2004). Specifically, the offspring of higher licking and grooming mothers develop more robust stress reactivity (Meaney, 2001). This effect is not genetic, but rather epigenetic (genetic changes induced by environmental context), as it is fully reversed in cross-fostering studies (Meaney & Szyf, 2005; Weaver et al. 2004).

Besides the amount of maternal care, exposure to novelty and environmental enrichment are also important factors for positive development. Rodents exposed to novelty early in life have enhanced spatial working memory, social dominance, and plasticity of the stress response later in life (Akers et al., 2008; Tang, Akers, Reeb, Romeo, & McEwen, 2006). Environmental enrichment in rodents leads to increases in brain weight, the number of new neurons in the hippocampus and in turn, greater learning and memory (Henderson, 1970; van Praag, Kempermann, & Gage, 2000). Similar effects have been found in rhesus monkeys, with environmental enrichment leading to increased cross-hemispheric projections and cognitive performance (Sánchez, Hearn, Do, Rilling, & Herndon, 1998). In adult marmosets, even a brief, month-long stay in a complex environment enhances spine density and synaptic protein levels in the hippocampus and prefrontal cortex (Kozorovitskiy et al., 2005).

In humans, differential early life experiences also get “under the skin.” Correlational studies show that humans with more adverse childhood experiences (negative experiences ranging from physical and sexual abuse to chronic poverty) are more likely to have increased inflammatory tone, blunted HPA axis response to stressors, depression, and decreased prefrontal cortex functioning and executive function (see Danese & McEwen, 2012 for review). A harsh family climate and chaos in the home also leads to marked health effects: increased inflammatory tone and poor self-regulation (Evans et al., 2005; Miller & Chen, 2010). Furthermore, early social life deprivation (such as being raised in an orphanage or institution) leads to decreased gray matter volume and thickness, atypical amygdala structure and function, increased anxiety and decreased cognitive functioning (Gee et al., 2013; McLaughlin et al., 2014; Nelson et al., 2007; Sheridan, Fox, Zeanah, McLaughlin, & Nelson, 2012; Tottenham, 2012). While each of these risk factors may present separately, growing up in a low

socioeconomic-status (SES) environment increases the likelihood of exposure to all of them. Low-SES is associated with less exposure to enriching cognitive experiences (Bradley, Conyn, Burchinal, McAdoo, & Coll, 2001; Bradley, Corwyn, McAdoo, & Coll, 2001) and linguistic input (Hart & Risley, 1995) and increased exposure to conditions conducive to chronic stress, such as a chaotic home environment (Baum, Garofalo, & Yali, 1999; Evans & English, 2002; Evans & Kantrowitz, 2002).

SES is a multifaceted construct that indexes one's status in society through their education, income, job status, neighborhood quality, or some combination of these factors. While SES itself is complex and imprecise, it is highly predictive of many important life outcomes, particularly cognition and academic achievement (see Farah, 2017 for review). This has led to the so-called "income-achievement gap" (Bradley & Corwyn, 2002; Reardon, 2011), whereby students from higher-SES backgrounds academically outperform their peers from lower-SES backgrounds. This gap is present at the beginning of formal schooling and continues to widen (Duncan & Magnuson, 2011). Thus, exploring how SES "gets under the skin" and impacts cognition is of great societal and economic importance.

1.2.2. The relationship between socioeconomic-status, the brain, and cognition

A growing body of research has taken a neuroscientific approach to exploring the income-achievement gap. This method has gained traction for a few reasons. First, the impact of SES on the brain can be seen as a causal pathway by which SES affects behavior. SES is associated with many factors (as reviewed above) that impact brain development, such as increased exposure to stress and reduced environmental enrichment (Hackman & Farah, 2009). Thus, researchers are interested in exploring how the brain might mediate relationships between

SES and cognition/academic achievement in order to better understand how to intervene. A second benefit of studying SES effects on the brain is that neural measures can sometimes be more sensitive than behavioral measures (Gabrieli, Ghosh, & Whitfield-Gabrieli, 2015). While two groups may have matched behavioral performance on a task, differences in neural activity could indicate group differences in resource availability or use. Finally, neuroscience can help pinpoint distinct neurocognitive systems that may be more or less impacted by SES. For example, differences in math performance by SES could be related to underlying differences in executive function rather than pure mathematics ability. This causal difference could be demonstrated using behavioral measures, but neuroscience tools add a confirmatory layer: an fMRI study could reveal executive function related prefrontal differences by SES during a math task, rather than math related parietal cortex differences.

I now review the literature on the relationship between SES and the brain, focusing on three cognitive systems most consistently shown to be impacted by SES: language, executive function, and declarative memory (Fernald, Marchman, & Weisleder, 2013; Hart & Risley, 1995; Herrmann & Guadagno, 1997; Hoff, 2013; Lawson, Hook, & Farah, 2018; Noble et al., 2015; Noble, McCandliss, & Farah, 2007; Noble, Norman, & Farah, 2005; Raver, Blair, & Willoughby, 2013). Then, I review literature that looks specifically at how the brain might mediate relationships between SES and cognition/academic achievement.

Numerous studies have found that the behavioral and neural correlates of language processing vary by SES. Children from lower-SES backgrounds have less linguistic input and in turn, lower language processing and production abilities (Fernald et al., 2013; Hart & Risley, 1995; Hoff, 2013; Noble et al., 2007). Even at the elementary level of auditory processing, children from lower-SES backgrounds have more variable brain stem-related neural activity

during speech processing (Skoe, Krizman, & Kraus, 2013). For higher-level language processing, SES has been most notably related to the function and structure of two language-related brain areas: left inferior frontal gyrus (IFG, which includes Broca's area) and left temporal cortex (which includes auditory cortex and Wernicke's area). SES moderates the association between left IFG activation and performance during a phonetic discrimination task (Conant, Liebenthal, Desai, & Binder, 2017) and relates to asymmetry of IFG activation and left IFG and middle temporal gyrus activation during a rhyming task (Demir, Prado, & Booth, 2015; Raizada, Richards, Meltzoff, & Kuhl, 2008). Structurally, SES is negatively related to both left IFG and left superior and middle temporal thickness in 6-9-year-olds (Romeo et al., 2017). However, this relationship may not be consistent across development: a cross-sectional study of 5-17-year-olds found SES by age interactions for both left IFG and superior temporal gyrus thickness, whereby individuals from lower-SES backgrounds showed thinning over time, while individuals from higher-SES backgrounds exhibited thickening (Noble, Houston, Kan, & Sowell, 2012).

Beyond language abilities, children's self-regulatory behaviors, or executive functions, are also greatly impacted by SES. Executive functions refer to a set of cognitive processes that support planning and regulation, including shifting, updating (working memory), and inhibition (Miyake et al., 2000). Executive functions largely rely on the prefrontal cortex (PFC; Miller & Cohen, 2001). Numerous studies have found a positive relationship between SES and performance on executive function tasks (Lawson et al., 2018; Noble et al., 2015, 2005; Raver et al., 2013; Sarsour et al., 2011). This SES disparity is also reflected in neuroimaging studies. During a rule-learning task (which measures executive function), children from lower-SES backgrounds both performed worse than their higher-SES peers and had increased activation of

their right middle frontal gyrus (a part of the PFC). A similar pattern of results has also been observed during a working memory task: Finn et al., (2016) found that adolescents from lower-SES backgrounds had poorer working memory and increased frontal-parietal activation on an N-back working memory task at the easiest level. However, at more difficult working memory levels, this neural pattern reversed, with adolescents from higher-SES backgrounds recruiting more frontal-parietal areas than adolescents from lower-SES backgrounds. Thus, children from lower-SES backgrounds may have less neural resources to bring online at difficult levels in executive function tasks. Structurally, lower-SES has been related to less PFC thickness and surface area (Lawson, Duda, Avants, Wu, & Farah, 2013; Mackey et al., 2015; Noble et al., 2015). These findings showing the detrimental effect of SES on PFC structure and function are consistent with literature showing that the PFC is particularly susceptible to environmental influences due to its prolonged development (Giedd & Rapoport, 2010; Hackman & Farah, 2009).

Declarative memory (also known as explicit memory and including working memory) performance is positively associated with SES (Evans & Schamberg, 2009; Farah et al., 2006; Herrmann & Guadagno, 1997; Noble et al., 2015, 2007). Hippocampal structure and function, which support explicit memory, are also positively associated with SES. During imaging of a paired-association memory task, children from lower-SES backgrounds showed less hippocampal activation (Sheridan, How, Araujo, Schamberg, & Nelson, 2013). Furthermore, many studies have reported a consistent positive relationship between SES and hippocampal volume, whereby those from higher-SES backgrounds have larger hippocampal volume than peers from lower-SES backgrounds (Butterworth, Cherbuin, Sachdev, & Anstey, 2012; Hanson, Chandra, Wolfe, & Pollak, 2011; Jednoróg et al., 2012; Noble et al., 2015; Yu et al., 2017). This

is important given the documented positive relationship between hippocampal size and memory (Biegler, McGregor, Krebs, & Healy, 2001; Yu et al., 2017). While no study to date has found that hippocampal size mediates the relationship between SES and memory performance, it presents a plausible causal pathway. Furthermore, the hippocampus is known to be sensitive to both good and bad environmental context. In mice, exposure to enriched environments causes proliferation of neurons in the hippocampus (Kempermann, Kuhn, & Gage, 1997), while exposure to stress is associated with hippocampal degeneration (see Meaney, 2001). In humans, parenting quality and exposure to stress mediate the relationship between SES and hippocampal volume in children (Luby et al., 2013).

A handful of studies directly tested whether the brain mediates relationships between SES and cognition. One functional imaging study found that neural activation during a working memory task mediated the relationship between SES and achievement on a statewide mathematics test (Finn et al., 2017). Other studies looking at this question have focused on structural measures. In some ways, brain structure is a more robust measure than brain function. Unlike brain function, brain structure is not susceptible to moment-to-moment states of mind, like motivation or hunger, which may present as confounds by SES. Furthermore, structural measures make it easier to compare across experiments, because they are not dependent on specific tasks, enabling larger samples and thus, greater reliability of findings. Noble et al., (2015) found that total surface area partially mediated the relationship between SES and executive function and working memory in a large sample (1,099 3-18-year-olds). Two studies specifically explored whether brain structure mediated relationships between SES and academic achievement. Mackey et al. (2015) found that cortical thickness in occipital, parietal, and temporal cortices accounted for almost half of the income-achievement gap found in their study,

while (Hair, Hanson, Wolfe, & Pollak, 2015) found that frontal and temporal lobe volume partially mediated the income-achievement gap found in their study. Across all of these studies, mediation effects could be due to a direct influence of the brain on behavior, or to the influence of unmeasured differences that relate to SES and are correlated with achievement and cortical thickness. Future work is necessary to fully assess whether and how the brain mediates the relationship between SES and academic achievement.

1.2.3. From “deficit model” to “adaptation model”

The SES literature discussed above primarily takes a “deficit model” approach, suggesting that children from lower-SES backgrounds have impaired brain structure and function, and reduced cognition and academic outcomes. However, this framework makes little contact with a general, cognitive theory of how all children might approach learning problems in a world of limited resources. It also largely ignores the unique neural abilities that learners might develop to adapt to high stress, unpredictable environments.

This “adaptive framework” has been well studied in the evolutionary-developmental literature (Ellis, Bianchi, Griskevicius, & Frankenhuis, 2017). For example, birds who grow up with limited and unpredictable food supplies have increased food caching and heightened memory for food locations (Hurly, 1992; Pravosudov & Clayton, 2001, 2002; Pravosudov & Grubb, 1997), rats exposed to early life stress have enhanced foraging abilities in stressful situations later in life (Chaby, Sheriff, Hirrlinger, & Braithwaite, 2015), and humans who grow up tree climbing develop longer calf muscles to enable greater foot flexibility (Venkataraman, Kraft, & Dominy, 2013).

Approaching questions concerning SES and child development from this “adaptive framework” suggests novel directions of inquiry. For example, what cognitive and neural mechanisms are enhanced growing up in a low-income environment? And, at a more basic level, what cognitive and neural systems are impacted by SES and which remain unaffected? Furthermore, does positive brain development look similar across children from diverse SES environments? Or does the brain adapt to its surroundings in such a way that it supports cognition differently by early life environment?

This approach, of course, does not mean to suggest that adapting to harsh environments is not without costs. As demonstrated from the literature reviewed above, low SES surely has a negative impact on specific cognitive functions. Furthermore, children from lower-SES backgrounds who are “resilient” and present strong self-control actually have worse cardio-metabolic health and faster epigenetic aging (Brody, Yu, Chen, & Miller, 2013; Chen, Miller, Brody, & Lei, 2015; Miller, Yu, Chen, & Brody, 2015). This adheres to the adaptive-framework and life history theory at large, which posits that resources are limited, necessitating tradeoffs in energy expenditure. However, only focusing on these “deficits” misses half of the picture. The other half is recognizing how children who grow up in lower-SES environments develop specialized neural and cognitive abilities to match this specific context. Understanding these abilities is key to developing innovative, effective intervention that works with individuals’ unique strengths by environmental context to promote success in school and life.

1.3 Thesis roadmap

This thesis addresses two broad questions probing how the social environment impacts children's learning: first, how do social factors affect children's moment-to-moment persistence (Chapters 2 and 3) and second, how does the long-term social environment, specifically SES, relate to children's brain development and cognition (Chapters 4 and 5)? Taken together, these questions address both how malleable social factors impact children's learning in the short term (their decisions to persist through challenges) and how long-term adverse social context impacts children's underlying biology (their brain development) and in turn, their cognition.

The first part of this thesis (Chapters 2 and 3) asks whether young children learn to modulate their persistence based on how hard other people try. In Chapter 2, I explore how preschoolers integrate information from adults' effort, outcomes, and testimony to decide how hard to try on a novel task. I find that children's persistence is malleable and sensitive to social information. Children tried harder after watching adults succeed vs. fail. In the instance of success, children use adults' effort to calibrate their own persistence. Furthermore, adults' testimony can boost children's persistence when adults practice what they preach, such as by saying they value hard work, or giving children a pep talk, in conjunction with demonstrating effortful success. In Chapter 3, I ask 1) whether this form of social learning about effort is present even in the first year of life and 2) whether it can generalize across tasks. I find that 15-month infants try harder on their own task after watching an adult model persist on two different tasks and that this form of learning is modulated by pedagogical cues. Collectively, this work suggests adults' actions and words causally impact children's persistence in the first few years of life.

The second part of this thesis (Chapters 4 and 5) explores how the long-term social environment impacts children's brains and in turn, behavior. This work takes an "adaptive framework," exploring how children from lower-SES backgrounds might develop unique neural profiles to best fit their environment. In Chapter 4, I ask if SES impacts some neural structures and functions more than others in adolescents. I find that SES has a selective influence on hippocampal-prefrontal declarative memory and little influence on striatal-dependent procedural memory. In Chapter 5, I explore whether the neural correlates of optimal learning vary by SES. I find that bilateral thickness of the rostralateral prefrontal cortex (RLPFC) differentially relates to reasoning by SES in both children and adolescents. Taken together, this work suggests that 1) SES does not impact all neural structure and function equally and that 2) the principles of positive brain development differ by SES environment.

In the final Chapter (6), I summarize and synthesize the main findings of the studies presented in Chapters 2-5. I then conclude by addressing future directions and the broader implications of this work pertaining to how we can promote positive development in children from all backgrounds.

Chapter 2

Practice what you preach: Children integrate adults' actions, outcomes with testimony to decide how hard to try

Abstract

Children's persistence in the face of challenges is key to academic success, yet we know very little about how parents and educators can help foster persistent behavior in young children. Here, we looked at how preschool-age children integrate observations of adult actions and outcomes with adult testimony to decide how hard to try on a novel task. We looked at three kinds of instructions meant to reflect common messages children hear about persistence: honest expectations ("this task might be hard"), pep talks ("you can do it!"), and statement of values ("it's important to try"), as well as one uninstructed condition. Children heard each message at baseline or after seeing an adult demonstrate either high or low effort, then either succeed or fail at a task. In total, there were 20 conditions across four experiments ($n = 520$). Children consistently attended to the outcome of adult actions: across all experiments, children tried harder after seeing the adult succeed versus fail. When the adult failed to reach her goal, adults' effort had no impact on children's persistence. However, when the adult succeeded, children paid attention to how hard she tried. In three of the four experiments, children tried harder in the high effort success conditions than the low effort success conditions. The one exception was when children were warned that the task might be hard (the honest expectations experiment): in this case children persisted equally in both success conditions. Finally, across all experiments, children persisted longest in the pep talk and moral exhortation high effort success conditions,

when the adult practiced what she preached, and it paid off. Taken together, this work suggests that children integrate evidence about outcomes, actions, and testimony in calibrating their own effort on novel tasks, and that adults can help foster children's persistence by modeling persistence in their own successful goal-directed actions and by explicitly testifying to the value of effort and encouraging children to try.

2.1 Introduction

Children's persistence in the face of challenge is key to academic success (Duckworth & Seligman, 2005; Eskreis-Winkler, Shulman, Beal, & Duckworth, 2014). Even the way children think about the relationship between effort and outcomes causally impacts academic achievement, with children who believe effort leads to change in ability outperforming those who think ability is a fixed trait (Blackwell, Trzesniewski, & Dweck, 2007). Motivation before children enter formal schooling is particularly important, as early patterns of persistence set children on a positive trajectory for future cognitive and academic achievement (Messer et al., 1986; Mokrova, O'Brien, Calkins, Leerkes, & Marcovitch, 2013; Yarrow et al., 1983; Yarrow, Morgan, Jennings, Harmon, & Gaiter, 1982). Thus, parents and educators alike are often in pursuit of how to boost persistence in young children (Tough, 2016; Smith 2014)

One way adults can impact children's behavior is through their words. Indeed, adult praise is even more effective than extrinsic rewards when reinforcing toddlers' prosocial behavior (Warneken & Tomasello, 2013). Parents' praise for effort rather than children's ability in the first few years of life, predicts children's beliefs about the relationship between effort and outcome years later (Gunderson et al., 2013). Subtle linguistic cues can also impact moment-to-moment motivation: children who are asked to "be a helper", a generic phrase that invokes

inherent identity, are more likely to help than those simply asked “to help” (Bryan, Master, & Walton, 2014). Similarly, children are less likely to cheat when told, “please don’t be a cheater” versus “please don’t cheat” (Bryan, Adams, & Monin, 2013). Yet this form of generic language, which implies trait ability, can be demoralizing after a mistake since subsequent failure here signals low ability. For example, children who were told the generic praise that they were “good drawers” were less resilient following mistakes on a drawing task than children who were told the non-generic praise that they “did a good job drawing” (Cimpian, Arce, Markman, & Dweck, 2007). Thus, subtle changes in how we speak to children can dramatically impact their motivation.

However, adults do not just convey their preferences through words – they also use their actions. Children are adept at learning from and reproducing adults’ modeled actions. They faithfully imitate elaborate actions that, although casually unnecessary, may be relevant to norms, conventions or broader social practices (Harris, 2012; Kenward, Karlsson, & Persson, 2011; Lyons, Young, & Keil, 2007; McGuigan, Whiten, Flynn, & Horner, 2007). For example, children will imitate arbitrary actions to open a box, such as tapping it with a stick, even when it is obvious that these actions are causally superfluous (Horner & Whiten, 2005; Lyons et al., 2007; Whiten, Custance, Gomez, Teixidor, & Bard, 1996). However, children are also sensitive to contextual constraints and selectively imitate actions when they demonstrate efficient ways of achieving a goal (Meltzoff, 1995; Schulz, Hoopell, & Jenkins, 2008) Children only copy an actor who turns on a lamp with their head when their hands are unavailable, but not when their hands are free (Gergely, Bekkering, & Király, 2002). Thus, children combine information about adults’ actions with prior knowledge to learn about social norms and efficient action.

In most contexts however, adults tend to combine actions and words. For instance, a parent might tell their child that it is important to give to charity while at the same time modeling this behavior. While many studies support the common adage “actions speak louder than words”, at least in the domain of altruism, (Bryan & Walbek, 1970a, 1970b; Rushton, 1975), more recent work challenges these findings (Ottoni-Wilhelm, Zhang, Estell, & Perdue, 2017). In a classic study, Rushton (1975) had 7- to 11-year-olds watch an adult play a game for tokens and either act selfishly (keeping the tokens) or generously (donating them to charity) and then preach the value of taking, donating, or provide no explanation. When it was time for children to play the game and either keep or donate their own tokens, children copied the adult’s actions, not their words. If the adult kept their tokens, so did the children, no matter whether the adult preached about taking or giving. However, one recent large-scale, nationally representative study found the opposite effect, with parents’ words, but not actions, concerning charity having an impact on their children’s giving (Ottoni-Wilhelm et al., 2017).

As is clear from the above, myriad factors might affect children’s persistence on a task, including their prior knowledge about the task and about their own abilities, their observation of adult behavior (i.e., did they try hard?), the observed outcomes (i.e., success versus failure), and the language adults use to encourage children to attempt the task. Previous studies have looked at many of these components individually. For instance, children’s prior knowledge of a task impacts their assessment of ability: they are much more likely to indicate that they are “bad at solving puzzles” after experiencing failure than at baseline (Smiley & Dweck, 1994). Adult praise for effort, rather than ability, encourages children to persist on a previously challenging task (Mueller & Dweck, 1998). Children also learn about effort from direct observation of adult actions. Work in 1st and 2nd graders, and even 13-month olds, has shown that children try harder

at their own task after watching an adult model persist and reach her goal (Leonard, Lee, & Schulz, 2017; Zimmerman & Blotner, 1979). Children are also sensitive to adult's explicit messages during modeling of effort: they try harder at their own task after watching a confident adult persist (saying "I am sure I can separate these wires") vs. a pessimistic adult persist (Zimmerman & Ringle, 1981). However, little work has looked at how children consider multiple forms of evidence, especially those most commonly utilized by adults to encourage persistence, when presented in tandem.

A large literature on children's inductive learning suggests that children are adept at drawing conclusions by integrating multiple forms of data (see Tenenbaum, Kemp, Griffiths, & Goodman, 2011). Children are able to make rich generalizations from just a few examples of adult modeling (Bonawitz et al., 2011; Gweon & Schulz, 2011; Xu & Tenenbaum, 2007), especially when the adult engages the child pedagogically (Csibra & Gergely, 2009; Gergely, Eged, & Király, 2007). Young children are also skilled at rationally integrating their own and others' prior knowledge and data to make inferences in a range of tasks (Griffiths, Sobel, Tenenbaum, & Gopnik, 2011; Magid & Schulz, 2015; Schulz, Bonawitz, & Griffiths, 2007). Furthermore, even 10-month old infants are sensitive to the costs and rewards of others' actions (Jara-Ettinger, Tenenbaum, & Schulz, 2015; Liu, Ullman, Tenenbaum, & Spelke, 2017). Thus, children may well utilize these rich learning mechanisms to infer how to engage in costly actions by combining information from adult's actions and testimony.

Here, we test how preschool-age children integrate information from adults' actions and testimony to decide how hard to try. We looked at an uninstructed condition (Experiment 1) and three kinds of verbal instructions. The three kinds of instructions were chosen to reflect common messages children hear about persistence in the real world: an accurate calibration of the task

difficulty meant to set honest expectations (“this task is made for adults and might be hard for kids”; Experiment 2), a “pep talk” meant to encourage the children (“I have a lot of confidence in you – you’re going to do a great job”; Experiment 3¹) and a moral exhortation meant to convey the idea that the adult values effort (“I think it’s super important when something is tricky to try your best and not give up”; Experiment 4). Children heard each message in a baseline condition in which no actions were demonstrated, as well as with the actions of adults in a 2 x 2 design, crossing adult effort (high/low) and outcomes (success/failure) for a total of 20 conditions across the four experiments.

Across experiments, we hold children’s prior knowledge constant by giving them a novel task that is neither obviously within, nor outside of, their ability range. That is, all children should initially be uncertain about how difficult the task is. We also have adults and children perform seemingly identical tasks so that children should readily learn from watching and listening to the adults. (In fact, the children’s tasks are impossible in all conditions, allowing us to explore the full range of children’s persistence.) These constraints allow us to ask how adult actions, outcomes, and verbal testimony affect children’s task persistence. Given previous work suggesting that even 15-month-old toddlers’ persistence is affected by adult effort (Leonard, Lee, & Schulz, 2017), we were interested in looking at the youngest ages in which we could look at how children integrated all of these factors². We focused on four and five-year-olds for three reasons. First, pilot data suggested that four and five-year-olds, unlike toddlers, would be able to complete the task even in the conditions where they saw the adults fail to achieve the goal.

¹ Note that in the Zimmerman study with first and second grade children, the experimenter gave statements testifying to his own high or low confidence (“I know I can get this ring off the toy” versus “I don’t think I can do this”) but failed to achieve the goal in both cases; they found that children tried harder in the high confidence than low confidence condition. However, we believed that in real world contexts, adults would be more likely to communicate confidence (or cautions) to the child than their confidence in themselves so here we elected to focus on the former.

² Note also that the current design differs from the design in Leonard et al., 2017 in two respects: in the current study the adult and child performed very similar tasks and the high and low effort conditions differed with respect to how long the adult worked on the task (5 versus 30 seconds); in the earlier study the adults’ tasks differed both from each other and from the infant task, and the high and low effort modeling conditions were matched for time.

Second, we wanted to be confident that children had sufficient verbal abilities to understand the task instructions in all conditions. Finally, given the real-world importance of persistence to success, we wanted to focus on how adult behavior affected children just starting the process prior to formal education.

2.2 Experiment 1: Uninstructed

2.2.1 Methods

2.2.1.1 Participants and Materials

One hundred and forty-four 4-5 year-old children were recruited for the study, but only 130 were included in the data analysis (mean: 57.28 months; range: 48 - 71 months) due to parental interference ($n = 2$), not reaching criteria with the ‘all done playing’ bell ($n = 2$), not touching the toy box before ringing the bell ($n = 6$), successfully opening the toy box (which was supposed to be impossible; $n = 1$), or experimental error ($n = 3$). Children were randomly assigned to one of five conditions: No Effort Success, Effort Success, No Effort Failure, Effort Failure or Baseline ($n = 26$ /condition; ages were matched across conditions, $\beta = 0.08$, 95% CI [-0.28, 1.28]³). A power analysis indicated that we would need to collect 26 subjects to find large differences in planned condition contrast t-tests ($d = 0.8$, power = 0.8)⁴. Thus, we collected data on 130 children (26/condition).

Two 18.49 x 8.51 x 8.51 cm wooden boxes were used. The boxes looked like they could open in a few different ways, but they actually opened through a secret sliding notch. A marble

³ Confidence intervals reported throughout from bootstrap with 10,000 samples.

⁴ This power analysis was run for t-tests because we assumed our data would be normally distributed. This was not the case, so post-hoc comparisons were run with non-parametric Wilcoxon tests. All significant results remain significant if run with parametric t-tests on log-transformed data. For consistency across experiments, we retained this sample size throughout.

was hidden in the experimenter's box and a rubber frog was hidden in the child's box. These toys produced different sounds when the box was shaken and were used to indicate that the boxes were different. A bell was used for the child to indicate that she was 'all done playing' and a toy bear was used to demonstrate the use of the bell.

2.2.1.2 Procedure

Children were tested individually in a quiet room in an urban children's museum. In all conditions, the experimenter first introduced the child to the 'all done playing' bell. The experimenter pretended to play with the stuffed bear, and then said, "I'm all done playing" and rang the bell. The child was then asked to play with the bear and indicate when she was all done playing by ringing the bell. The procedure was repeated if the child didn't use the bell to indicate when she was done playing. If the child failed to ring the bell after three repetitions, they were excluded from the study.

In all conditions except baseline, the experimenter then brought out her wooden box and shook it, saying, "I think there's something inside of there!" In the No Effort Success condition, the experimenter took approximately 5 seconds to find the sliding notch and opened the box. In the Effort Success condition, the experimenter made repeated attempts to open the box for 30 seconds before locating the sliding notch and opening it. In the No Effort Failure condition, the experimenter manipulated the box for 5 seconds and then said, "I can't do it. Okay, I'm done." In the Effort Failure condition, the experimenter performed the same actions as in the Effort Success condition except that at the end of 30 seconds, instead of identifying the sliding notch and opening the box, she said, "I can't do it. Okay, I'm done". Thus, in both of the failure

conditions, the experimenter never successfully opens the box. In the Baseline condition, there was no experimental modeling (see Figure 2.1).

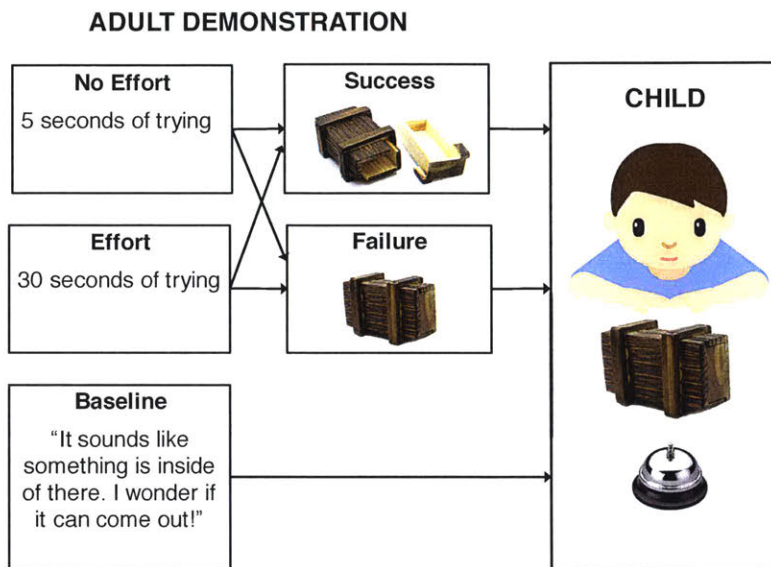


Figure 2.1. Experiment 1 schematic. Children were randomly assigned to one of five conditions: No Effort Success, Effort Success, No Effort Failure, Effort Failure, or Baseline. In the Effort conditions, the experimenter tried to open their toy box for 30 seconds. In the No Effort conditions, the experimenter spent 5 seconds trying to open the box. In the Success conditions, the experimenter successfully opened the box and in the Failure conditions, the experimenter never opened the box. In the Baseline condition the experimenter didn't model any action. Next, children were given their own box (that was secretly impossible to open) to play with. Their box was identical to the adult's box, but made a different sound when shaken, indicating that a different toy was inside. The children were told they could ring the bell when they were all done playing and were timed out at four minutes. A similar design was used for Experiments 2 and 3 with small additions.

Next, the experimenter told the child that she needed to go review some paperwork with their parents and that the child would get to play with a toy by herself. The child was also told that, because the experimenter would be on the other side of the room talking with her parents, they should ring the bell to indicate when they were done playing. Only in the Baseline condition did the experimenter introduce the child's box to them, shaking it and saying, "it sounds like something is inside of there. I wonder if it can come out!"

The child was then given a box to play with that looked identical to the experimenter's box but had a different toy inside and was impossible to open. The experimenter then moved out of the child's line of sight to talk to their parents. If the child asked a question during the free play period the experimenter always responded by saying "I'm going over some paperwork with your mom/dad right now. You can ring the bell when you're all done playing" or "This toy is just for you, so we can't help you with it. Just let us know when you are all done playing by ringing the bell". If the child stopped touching the toy for 5 seconds, the experimenter would ask "Are you all done playing?" The experiment was terminated when the child rang the bell or after four minutes, whichever came first. The experimenter always ended by saying, "Oops, I gave you the wrong box to open!" Children were given a different box, and working with the experimenter, always opened the box in the end.

2.2.2 Results and Discussion

There are many different ways to operationalize effort (number of discrete actions, number of repeated actions, force applied, time manipulating the toy, coordination of eye gaze and hand movements, etc.). None of these, however, would also include cognitive effort (planning, thinking, etc.), which may not be reflected in any overt behavior. For this reason, and for simplicity and reliability of coding across tasks and conditions, we used latency to ring the bell as the dependent measure indexing children's persistence in all conditions. The dependent measure did not adhere to a normal distribution. It was log transformed to better adhere to a normal distribution for linear models. Non-parametric analyses were used for follow-up comparisons. Results were coded from videotape by two coders blind to condition (80% of videos were double-scored with inter-rater reliability $r = .99, p < .001$).

To simultaneously explore how Effort and Outcome affected children's performance, we performed a multiple regression where seconds playing with the toy was input as the dependent variable and Effort, Outcome, and their interaction as the independent variables (model $r^2 = .30$). The regression revealed a positive effect of Outcome, with children playing with the toy for a longer amount of time in the Success conditions vs. the Failure conditions ($\beta = 0.66$ log seconds, $t(100) = 3.10, p < .001, 95\% \text{ CI } [0.25, 1.07]$). There was no effect of Effort ($\beta = 0.01$ log seconds, $t(100) = 0.03, p = .97, 95\% \text{ CI } [-0.42, 0.47]$). Finally, we found that there was a trend of an interaction between Outcome and Effort, with children trying harder than any other condition when the experimenter tried hard and succeeded ($\beta = 0.58$ log seconds, $t(100) = 1.90, p = .06, 95\% \text{ CI } [0.01, 1.14]$, see Figure 2.2 and Table 2.1 and 2.2 for means and medians across conditions).

We also ran planned comparisons on the contrasts of interest, looking at the effect of Effort separately in the Success and Failure conditions and looking at the effect of Outcome separately in Effort and No Effort conditions. To look at the directionality of any significant effects, we follow up by comparing these conditions to Baseline. In the Success conditions, there was an effect of Effort such that children tried harder in the Effort than the No Effort condition ($W = 490.5, p = .005, r = -.39$). There was a trend for children to persist more in the Effort Success condition than Baseline ($W = 242, p = .08, r = -.24$), but no difference in children's persistence in No Effort Success condition and Baseline ($W = 362, p = .67, r = -.06$). In the Failure conditions, there was no effect of effort, with no difference between Effort Failure and No Effort Failure ($W = 341.5, p = .96, r = -.008$).

Looking at Outcomes, there was an effect of Outcome in both the Effort and No Effort conditions such that children tried harder given Success than Failure (Effort: $W = 86.5, p < .001,$

$r = -.64$; No Effort: $W = 186.5, p = .006, r = -.38$). In the Effort conditions there was, as noted, a trend for children to try harder given Success than Baseline ($W = 242, p = .08, r = -.24$); given Failure, children persisted less than they did at Baseline ($W = 483.5, p = .008, r = -.37$). In the No Effort conditions, children's persistence did not differ between Success and Baseline ($W = 362, p = .67, r = -.06$) but given Failure, children persisted less than they did at Baseline ($W = 488, p = .006, r = -.38$).

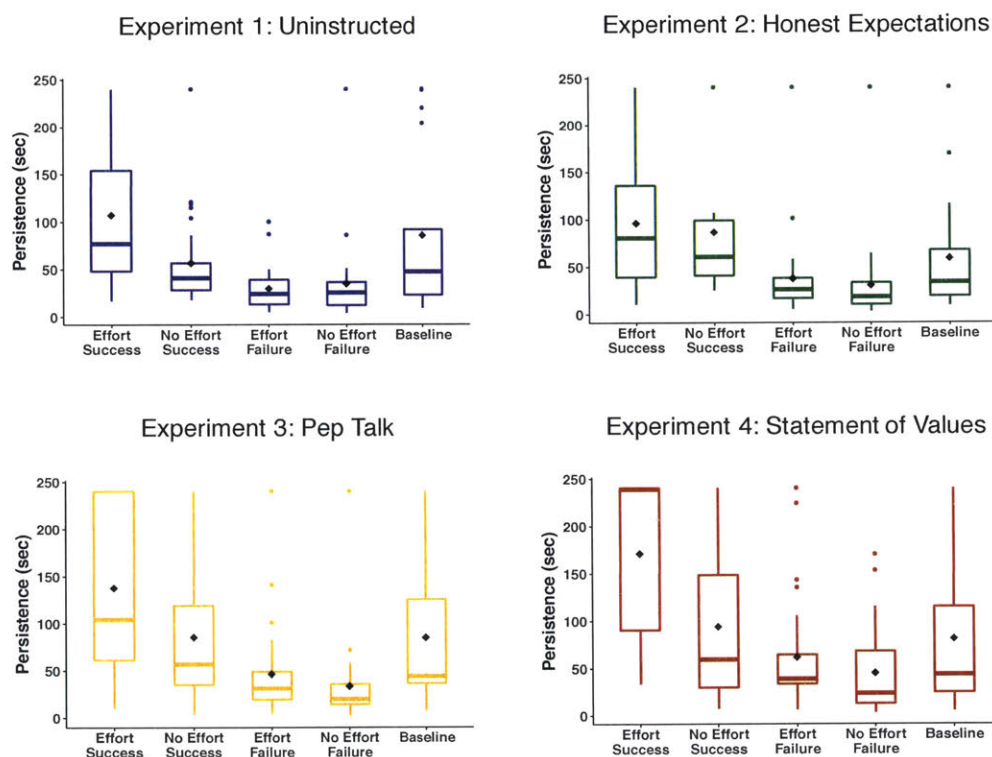


Figure 2.2. Results from Experiment 1 - 4. The top and the bottom of the boxes correspond to the first and third quartiles (the 25th and the 75th percentiles). The thick horizontal line in the middle of the boxes demarks medians. The upper whisker extends from the third quartile to the largest value no further than 1.5 interquartile ranges from the third quartile. The lower whisker extends from the 25th percentile down to the smallest value no further than 1.5 interquartile ranges from the first quartile. The dots are values more than 1.5 times the interquartile range above the third quartile. The black diamonds indicate medians. See text for statistical analyses.

The results of Experiment 1 show that children's persistence is affected jointly by the adult's persistence at a goal and whether the adult ultimately succeeds at her goal or not. Children were most likely to persist when the adult tried hard and succeeded; however, they were least likely to persist when the adult failed, regardless of whether she modeled effort or not. Indeed, seeing the adult fail pushed children's persistence below baseline. Note that this pattern of results suggests that, even given similar tasks and goals, children do not merely imitate adult actions. Rather, children integrate information about adults' effort and outcomes to guide their behavior.

2.3 Experiment 2: Honest Expectations

The results from Experiment 1 show that children calibrate their effort based on adult actions. However, adults often convey messages to children with both actions and words. One common way adults can signal that a task will require effort is simply to tell kids that the task will be hard. A parent may say to a child "This could be tricky" or a teacher might say, "We're going to try something more difficult now." Explicitly communicating that a task is hard might obviate the need for children to use adult effort to estimate the task's difficulty. If children are forewarned that a task could be difficult for them (i.e., difficult for children but not for adults), then they might persist simply because they expect the task to be challenging. Even preschoolers have some understanding that effort scales with difficulty (Gweon, Asaba, & Bennett-Pierre, 2017). Thus, children may try harder if an adult tells them that a task will be hard for them, regardless of whether the adult herself tries hard or not. Critically however, children should still be sensitive to whether the adult succeeds or fails (the adult outcome). If the adult fails on a difficult task, children might now expect the task to be out of reach for them, and thus not worth

persisting on at all. In Experiment 2 we looked at how children might integrate explicit messages about task difficulty with observations of adult effort and outcomes by replicating the design in Experiment 1, but first telling children that the task was made for adults and thus might be hard for kids.

2.3.1 Methods

2.3.1.1 *Participants and Materials*

One hundred and fifty 4-5 year-old children were recruited for the study, but only 130 were included in the data analysis (mean: 59.03 months; range: 48 - 71 months) due to parental interference (n = 3), not reaching criteria with the ‘all done playing’ bell (n = 1), not touching the toy box before ringing the bell (n = 6), or experimental error (n = 10). Children were randomly assigned to one of five conditions: No Effort Success, Effort Success, No Effort Failure, Effort Failure, or Baseline (n = 26/condition; ages were matched across conditions, $\beta = 0.36$, 95% CI [-0.36, 1.06]).

All materials were the same as in Experiment 1 except for the addition of a “latches activity board” designed for preschool children.

2.3.1.2 *Procedure*

The procedure was the same as in Experiment 1 except as follows. After introducing the “all done playing” bell, the experimenter said that they were going to play with some toys today. Then she took out two toys: the puzzle box (made for adults) and the latch activity board (made for preschoolers). She said “one of these toys is for grownups and the other is for kids your age.

Which one do you think is for kids your age? And which one is for grownups?” If the child answered incorrectly, they were corrected (105/130 answered this correctly). Then the experimenter asked the child to point to which of the people at the table (experimenter or child) was a kid and which was a grown up. The experimenter then said that they were going to get to play with the games “but as you can see, some of the toys are made for grownups, so they can be hard for kids”. The experimenter then modeled the actions and outcomes appropriate to the target condition, as in Experiment 1. Finally, she handed the child their own box to play with and again reminded them “that some of the toys will be hard for kids because they are actually made for grownups”.

2.3.2 Results and Discussion

Coding and analyses were identical to those in Experiment 1. Results were coded from videotape by two coders blind to condition (25% of videos were double scored with inter-rater reliability $r = .92$, $p < .001$). We performed a multiple regression where seconds playing with the toy was input as the dependent variable and Effort, Outcome, and their interaction as the independent variables (model $r^2 = .34$). There was a positive effect of Outcome, with children playing with the toy longer in the Success conditions vs. the Failure conditions ($\beta = 1.31$ log seconds, $t(100) = 5.60$, $p < .001$, 95% CI [0.87, 1.80]). Again, there was no overall effect of experimenter Effort ($\beta = 0.36$ log seconds, $t(100) = 1.54$, $p = .13$, 95% CI [-0.10, 0.81]). There was no interaction between Effort and Outcome ($\beta = 0.32$ log seconds, $t(100) = 0.97$, $p = .33$, 95% CI [-0.30, 1.01], see Figure 2.2 and Table 2.1 and 2.2 for means and medians across conditions).

As in Experiment 1, we ran planned comparisons on the contrasts of interest looking at the effect of Effort separately in the Success and Failure conditions, and looking at the effect of Outcome separately in Effort and No Effort conditions, following up on any significant effects with comparisons to the Baseline condition. As predicted, children here used the verbal testimony rather than the experimenter's actions to calibrate their expectations of task difficulty; there was no effect of how hard the experimenter tried in the Success conditions of Experiment 2 (in contrast to the effect of Effort in the Success conditions of Experiment 1). As in Experiment 1, there was also no effect of Effort in the Failure conditions (Success: $W = 352, p = .80, r = -.03$; Failure: $W = 402, p = .24, r = -.16$)

However, as predicted, there was an effect of Outcome in both the Effort and No Effort conditions such that children tried harder after observing Success than Failure (Effort: $W = 132, p < .001, r = -.52$; No Effort: $W = 79, p < .001, r = -.66$). In the Effort conditions, children tried harder given Success than Baseline ($W = 210.5, p = .02, r = -.32$), while children's persistence did not differ between Failure and Baseline ($W = 408.5, p = .20, r = -.18$). In the No Effort conditions, children persisted more given Success than at Baseline ($W = 202.5, p = .01, r = -.34$) and persisted less given Failure than at Baseline ($W = 483, p = .008, r = -.37$).

The results of Experiment 2 suggest that children use adult testimony to calibrate their persistence: they try harder when they expect a task to be difficult even if they see an adult succeed effortlessly. Moreover, telling children a task will be hard *and* showing them that it is possible (i.e., because the adult succeeds) leads them to try harder than just telling them it will be difficult (as in the Baseline condition). However, neither the adult's testimony nor the adult's example of persistence increases children's persistence above baseline when the adult fails – and if the adult fails without trying, children's persistence drops below baseline.

2.4 Experiment 3: Pep talk

Adults sometimes adopt a very different strategy when they want their children to persist; rather than telling children a task will be difficult, they give the child a “pep talk” – encouraging the child, telling the child the task is achievable, and expressing confidence in the child’s ability to succeed. Some research suggests that this form of verbal encouragement is effective at increasing participants’ effort in physical tasks (Bickers, 1993; McNair, Depledge, Brett Kelly, & Stanley, 1996). Less is known about the efficacy of broad encouragement in academic contexts, but some studies suggest that encouraging children helps them stay on task and increases their performance (Brown & Howard, 2014; Guéguen, Martin, & Andrea, 2015). In Experiment 3 we look at how children integrate pep talks with observations of adult effort and outcomes by replicating the design in Experiment 1, but first encouraging children.

2.4.1 Methods

2.4.1.1 *Participants and Materials*

One hundred and thirty-nine 4-5 year-old children were recruited for the study, but only 130 were included in the data analysis (mean: 59.35 months; range: 48 - 71 months) due to parental interference (n = 5) and experimental error (n = 4). Children were randomly assigned to one of five conditions: No Effort Success, Effort Success, No Effort Failure, Effort Failure, or Baseline (n = 26/condition; ages were matched across conditions, $\beta = 0.25$, 95% CI [-0.58, 1.08]). All materials were the same as in Experiment 1.

2.4.1.2 Procedure

The procedure was the same as in Experiment 1 except as follows. Before handing children their toy, the experimenter said, “Ok, now it’s time for you to play with your toy. I think you will do a great job playing with this toy! I have a lot of confidence in you! You got this!” The experimenter again reminded children that they could indicate that they were all done playing by ringing the bell and again said “You got this” before actually handing the toy to the child.

2.4.2 Results and Discussion

Coding and analyses were identical to those in Experiment 1. Results were coded from videotape by two coders blind to condition (28% of videos were doubled scored with inter-rater reliability $r = .99$, $p < .001$). We performed a multiple regression where seconds playing with the toy was input as the dependent variable and Effort, Outcome, and their interaction as the independent variables (model $r^2 = .27$). As in previous Experiments, there was a positive effect of Outcome, with children playing with the toy for a longer amount of time in the Success conditions vs. the Failure conditions ($\beta = 0.94$ log seconds, $t(100) = 3.55$, $p < .001$, 95% CI [0.39, 1.54]). There was a no main effect of experimenter Effort ($\beta = 0.37$ log seconds, $t(100) = 1.38$, $p = .17$, 95% CI [-0.12, 0.85]) and no interaction between Effort and Outcome ($\beta = 0.22$ log seconds, $t(100) = 0.58$, $p = .57$, 95% CI [-0.53, 1.05], see Figure 2.2 and Table 2.1 and 2.2 for means and medians across conditions).

As before, we ran planned comparisons on the contrasts of interest looking at the effect of effort separately in the Success and Failure conditions and looking at the effect of Outcome

separately in Effort and No Effort conditions, following up on any significant effects with comparisons to the Baseline condition. In Success conditions, there was an effect of Effort, with children trying harder in the Effort vs. No Effort condition ($W = 459.5, p = .02, r = -.31$). Children in the Effort condition persisted more than children at Baseline ($W = 208, p = .02, r = -.33$); there was no difference in children's persistence in No Effort condition and Baseline ($W = 314.5, p = .67, r = -.06$). There was no effect of Effort in the Failure conditions ($W = 421.5, p = .12, r = -.21$).

There was a significant effect of Outcome in both the Effort and No Effort conditions such that children tried harder given Success than Failure (Effort: $W = 125, p < .001, r = -.54$; No Effort: $W = 151, p < .001, r = -.47$). In the Effort conditions, as noted, children tried harder given Success than Baseline ($W = 208, p = .02, r = -.33$); but persisted less given Failure than Baseline ($W = 448, p = .05, r = -.28$). In the No Effort conditions, children's persistence did not differ between Success and Baseline ($W = 314.5, p = .67, r = -.06$) but given Failure, children persisted less than they did at Baseline ($W = 413, p = .001, r = -.45$).

The results of Experiment 3 mirror the results of Experiment 1: children try harder after seeing an adult try hard and succeed vs. effortlessly succeed, and also try harder after seeing success vs. failure, regardless of adult effort. Unlike Experiment 2, a pep talk did not obviate the difference between the Effort and No Effort Success conditions. That is, warning children that the task might be difficult seemed to allow them to ignore the adults' relatively minimal effort in the No Effort Success condition, so that they persisted despite the adults' failure to model persistence. By contrast, encouraging children did not overcome the impact of the adults' effortless success, and children were less likely to persist.

Note that the testimony in Experiment 3 was misleading. The children were told, “You got this” when in fact, the task was impossible for them. In this respect, the testimony in Experiment 3 differed greatly from the (more) truthful testimony in Experiment 2, in which children were warned that the task would be hard (indeed, the task was impossible). Arguably, this mirrors real world behavior; adults may well offer encouragement to children because they believe encouragement is helpful, regardless of whether or not the adult is 100% sure that the child can accomplish the task. The current results suggest that adults may be correct in believing that encouragement (regardless of whether it accurately reflects children’s abilities to achieve the task) has a positive impact on children’s persistence. Children were numerically more likely to perform at ceiling in the Effort Success condition of Experiment 3 than in either of the other two experiments: in Experiment 3, 10/26 children (38%) persisted for the whole four minutes (the maximum time allowed); by contrast only 2/26 (8%) performed at ceiling in Experiment 1 and only 6/26 (23%) did so in Experiment 2 (see Figure 2.3). The results across Experiments 2 and 3 suggest both that children integrate adult testimony with observations of their actions and their outcomes and that different kinds of testimony may impact children’s behavior in distinct ways.

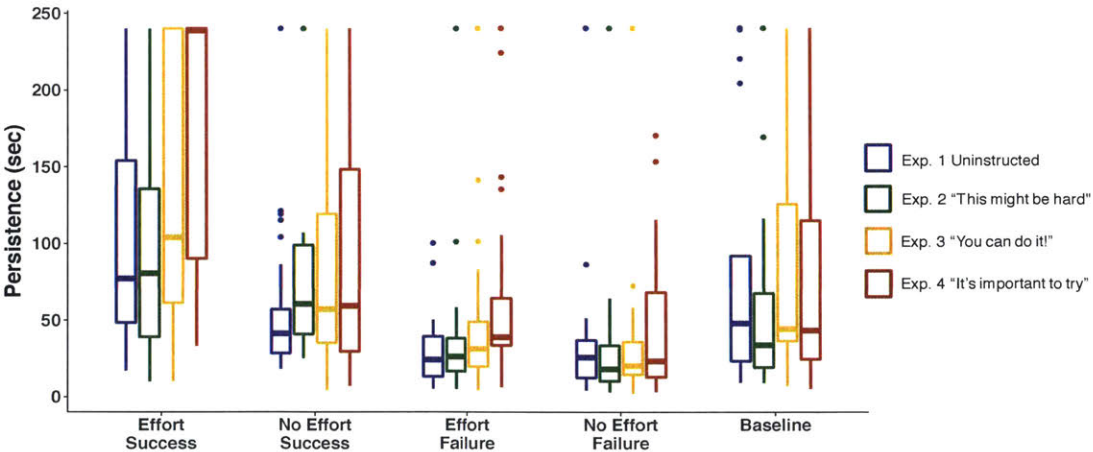


Figure 2.3. Results from Experiment 1, 2, and 3 on the same axis. See Figure 2.2 text for explanation of plot style.

Table 2.1. Medians across experiments by condition

	Effort Success	No Effort Success	Effort Failure	No Effort Failure	Baseline
Exp. 1: Uninstructed	77.0	41.0	24.0	25.5	47.5
Exp. 2: Honest Expectations	80.0	60.5	26.0	24.0	33.5
Exp. 3: Pep Talk	104.0	57.0	31.0	20.0	44.0
Exp. 4: Statement of Values	238.5	59.0	38.5	23.0	43.0

Table 2. Means across experiments by condition

	Effort Success	No Effort Success	Effort Failure	No Effort Failure	Baseline
Exp. 1: Uninstructed	107.2	56.9	30.0	34.9	85.7
Exp. 2: Honest Expectations	96.1	86.6	37.6	30.4	58.9
Exp. 3: Pep Talk	137.8	85.7	46.5	33.6	85.0
Exp. 4: Statement of Values	171.0	94.0	61.5	45.0	81.1

2.5 Experiment 4: Statement of Values

Thus far we have looked at how children respond to observations of adult effort and outcomes (Experiment 1), the impact of this evidence when children are truthfully told that a task will be hard (Experiment 2), and the impact of this evidence when children are falsely told that the task is within their reach (Experiment 3). In Experiment 4 we turn to a final common message children hear when adults want them to work hard: that working hard is valuable and

important. That is, here we look at how children respond when adults simply proselytize the value of effort.

In recent years, character traits (so called non-cognitive abilities), like grit, have garnered widespread attention due to their relationship to academic success and relative amenability to intervention over more seemingly stable, yet important traits, like IQ (Cunha & Heckman, 2008; Duckworth & Seligman, 2005; Eskreis-Winkler et al., 2014; Heckman & Kautz, 2013; Tough, 2012). Some schools have gone so far as to implement “Character Growth Cards” and organizations like the “Character Lab” have been formed to help schools teach and assess non-cognitive skills. Yet as practice and policy move forward, little work has examined the effect of adults’ explicit messaging about the value of effort on children’s effortful behavior or how children incorporate this information with direct evidence of the utility of effort on outcomes. In Experiment 4 we replicate the design in Experiment 1 but first tell children that, “It’s important to try your best and not give up”.

2.5.1 Methods

2.5.1.1 *Participants and Materials*

One-hundred and seventy 4-5 year-old children were recruited for the study, but only 130 were included in the data analysis (mean: 57.6 months; range: 48 - 71 months) due to parental interference (n = 9), not reaching criteria with the ‘all done playing’ bell (n = 3), fussing out (n=2), experimental error (n = 6), or getting the manipulation check (described below) wrong (n=20). Children were randomly assigned to one of five conditions: No Effort Success, Effort Success, No Effort Failure, Effort Failure, or Baseline (n = 26/condition; ages were matched

across conditions, $\beta = 0.49$, 95% CI [-0.28, 1.26]). All materials were the same as in Experiment 1.

2.5.1.2 Procedure

The procedure was the same as in Experiment 1 except as follows. After introducing the “all done playing” bell, the experimenter asked the child if they had ever done something really hard before. Then the experimenter said, “Lots of things are really hard, aren’t they? Well we are going to play with some toys today and, sometimes, new toys are tricky. But you know what the best thing to do is when something is tricky? To try your best and not give up. Do you agree? So what do you think the best thing to do is when something is tricky? (Let child answer) Yeah, it’s just really important to try our best and not give up.” The experimenter then proceeded to play with their box (in all conditions but Baseline), reminding children that they thought it was “super important when something gets tricky to try your hardest and not give up”. Before giving children their toy to play with, they again reminded them of the importance of trying one’s hardest.

In contrast to Experiments 2 and 3, we included a manipulation check in Experiment 4 to increase our confidence that children encoded the verbal testimony. We used the manipulation check as exclusion criteria, excluding children from analysis if they failed to remember the moral message. Children were asked if the experimenter said that it was really important to “keep your room tidy and clean” or to “try your best and not give up” (order counter balanced). If children didn’t answer, they were again prompted with the open-ended question “What did we say was the best thing to do when something is tricky?”

2.5.2 Results and Discussion

Coding and analyses were identical to those in Experiment 1. Results were coded from videotape by two coders blind to condition (23% of videos were doubled scored with inter-rater reliability $r = .99$, $p < .001$). We performed a multiple regression where seconds playing with the toy was input as the dependent variable and Effort, Outcome, and their interaction as the independent variables (model $r^2 = .30$). As in previous Experiments, there was a positive effect of outcome, with children playing with the toy for a longer amount of time in the Success conditions vs. the Failure conditions ($\beta = 0.77$ log seconds, $t(100) = 2.87$, $p = .005$, 95% CI [0.19, 1.40]). There was a non-significant trend for a main effect of experimenter Effort ($\beta = 0.42$ log seconds, $t(100) = 1.59$, $p = .12$, 95% CI [-0.11, 0.95]); there was no interaction between Effort and Outcome ($\beta = 0.50$ log seconds, $t(100) = 1.31$, $p = .20$, 95% CI [-0.24, 1.21], see Figure 2.2 and Table 2.1 and 2.2 for means and medians across conditions).

As before, we ran planned comparisons on the contrasts of interest looking at the effect of effort separately in the Success and Failure conditions and looking at the effect of Outcome separately in Effort and No Effort conditions, following up on any significant effects with comparisons to the Baseline condition. In Success conditions, there was an effect of Effort, with children trying harder in the Effort vs. No Effort condition ($W = 516$, $p = .001$, $r = -.46$). Children in the Effort condition persisted more than children at Baseline ($W = 16.5$, $p < .001$, $r = -.54$); there was no difference in children's persistence in No Effort condition and Baseline ($W = 306.5$, $p = .57$, $r = -.08$). In the Failure conditions, there was a non-significant trend for children in the Effort condition to try more than children in the No Effort condition ($W = 424.5$, $p = .12$, $r = -.22$).

There was a significant effect of Outcome in both the Effort and No Effort conditions such that children tried harder given Success than Failure (Effort: $W = 89, p < .001, r = -.64$; No Effort: $W = 209.5, p = .02, r = -.32$). In the Effort conditions, as noted, children tried harder given Success than Baseline ($W = 16.5, p < .001, r = -.54$); but there was no difference between Failure and Baseline ($W = 105, p = .66, r = -.06$). In the No Effort conditions, children's persistence did not differ from Baseline given either outcome (Success: $W = 306.5, p = .57, r = -.08$; Failure: $W = 442, p = .06, r = -.10$).

The results of Experiment 4 largely replicate the pattern found in Experiments 1 and Experiment 3: children try harder when they see adults try hard and succeed then when they see effortless success, and they also try harder when they see success rather than failure, regardless of adult effort. However, the combination of adults saying they value effort while modeling effortful success was particularly powerful: 13/26 children (50%) performed at ceiling in this condition; numerically more children than in any other condition of any other experiment (see Figure 2.3).

2.6 General Discussion

Across four experiments, we looked at how information about adults' actions, outcomes, and testimony affected preschoolers' persistence on novel tasks. Our goals in this study were three-fold. First, we wanted to assess the extent to which children's persistence was malleable in the face of relatively small interventions. Second, we wanted to look at situations children might experience in the real world when they see parents try (more or less hard) at a task, succeed (or not), and give motivational messages to children. Third, we wanted to see if any specific combination of factors might be especially effective at encouraging children's persistence.

Note that in principle, preschoolers might have been relatively immune to the evidence they observed. Their persistence on the tasks might have been governed by their intrinsic motivation to complete the task or individual differences in temperament or mood. However, that was not the case. Children's response to the task was strikingly malleable: the range of median persistence varied ten-fold across conditions and experiments, from 23 seconds to almost four minutes. Moreover, we found this variation with only very simple interventions on adults' language, effort and outcomes, mirroring the kinds of contexts children actually encounter. Underlying the variation, there was also remarkable consistency across all experiments: the dominant factor affecting children's persistence was whether the adult succeeded or failed at the task. Children tried harder in the Success conditions than the Failure conditions, and children's performance in the Failure conditions was at or below baseline. Moreover, in all four experiments, there was no impact of adult effort when the adult failed to achieve the task. Rather, children's persistence remained low whether the adult tried hard or not. This suggests that children deploy their effort rationally; they do not spend a lot of time trying to achieve tasks when the evidence suggests that it is unlikely that they will succeed. However, children were sensitive to how hard the adult tried when the adult succeed at the task. Across three of the four experiments, when the adult succeeded, children tried hard when the adult tried hard and were less persistent when the adult succeeded easily. These commonalities held across the studies despite the differences in what the adult said to the children. In this sense, we might conclude that actions speak louder than words, and that outcomes speak louder than both.

Nonetheless, children also listened to what adults said. Warning children that the task might be hard buffered children against seeing the adult succeed effortlessly. Only in that context were children as persistent in the Low Effort Success condition as the High Effort Success

condition. Additionally, when the adult tried hard and succeeded, the words she said to the child mattered: when adults encouraged children, or asserted the value of effort, a third to half the children (38% in the pep talk condition and 50% in the exhortation condition) persisted at ceiling. Critically, these conditions involved the adult practicing what she preached: she demonstrated success and hard work while expressing faith in the child's ability to succeed or endorsing the value of hard work. In this sense, words have an additive value, enhancing children's inference from actions and outcomes when the message is congruent with the behavior children observe.

The current findings are in line with previous work showing that children can learn the value of effort from adult models (Brown & Inouye, 1978; Leonard et al., 2017; Zimmerman & Blotner, 1979). However, this work goes beyond previous studies both by examining behavior in preschool-age children, an age range previously not explored in this literature, and by looking at the influence of diverse kinds of testimony that adults use in talking about effort with children.

Some previous work has suggested that preschool-age children may be overly optimistic about their abilities (e.g., Lockhart, Chang, & Story, 2002; Schneider, 1998), predicting for instance, that they could throw 7/10 balls into a basket (when in reality got ~4/10 balls in) despite evidence of their own and their peers' past failures. In contrast to that work, we find that children are sensitive to other people's success and failure and use this data to update the probability of their own success. One explanation for this discrepancy may be that previous studies showing over-optimism have tended to look at children's explicit judgments whereas here we use a direct behavioral assay of how willing children are to continue persisting at a task. Preschoolers understand that adults are more knowledgeable than they are (e.g., Lutz & Keil, 2002), so it makes sense that if they see an adult fail at task, they may well conclude that they

should not bother trying. In this sense, we might note that all of the children spent at least some time trying to achieve the goal – children attempted the task and worked at it for at least a short amount of time even when they had just seen an adult try hard and fail. Thus, there is some evidence for children’s optimism even here; nonetheless, children’s willingness to try is modulated by what the adult does, achieves, and says.

In the current study, we found that telling the children the task was hard encouraged children to persist if and only if they had seen the adult succeed at the task. This finding is striking because one might have predicted that telling children something will be hard could lead them to give up. After all, adults perform worse on anagrams if they are labeled “hard” versus “easy” (Scasserra, 2008) and 5th and 6th graders are less likely to choose tasks that are labeled “hard” than “easy” (Hom & Maxwell, 1983). However, here we find that children step up to the challenge when a task is labeled as hard if they see success is possible. One possibility is that observing the adult outcome helped children estimate the difficulty of the task. If adults fail, this signals that the task may be impossibly hard for them, but if they succeed, it signals that the task is possible and may just require some additional effort. Thus, adult outcomes here may indicate that the task is within children’s zone of proximal development (Vygotsky, 1978). This may be especially the case when, as in the current study, the adult demonstrations occurred within a pedagogical context where the adult ostensibly communicated her goals to the child (Csibra & Gergely, 2009; Gergely et al., 2002). In such contexts, children may extend a generalizable inference that the task is intended to be within their reach.

Across studies, children’s persistence in the success and baseline conditions had high variance. This may arise from a number of factors, including stable individual differences in susceptibility to modeling, mindset about the relationship between effort and outcome,

differences in the child's estimate of their own self-efficacy with respect to the task, and socio-economic and cultural influences – as well as more transient factors such as the child's mood, fatigue, and opportunity costs with respect to other activities they could engage in (Belsky, Bakermans-Kranenburg, & van IJzendoorn, 2007; Dweck, 2006; Ellis, Boyce, Belsky, Bakermans-Kranenburg, & van Ijzendoorn, 2011; Evans, 2016; Evans, Gonnella, Marcynyszyn, Gentile, & Salpekar, 2005). We showed effects of adult models, outcomes, and testimony when randomizing across these factors, but future studies might look at how these factors relate to children's individual differences in learning about effort from adult models.

In particular, cultural factors may play a role in children's learning from adult models of effort. In collectivist societies, children exhibit a higher level of imitative learning than children in individualist societies, like the United States (Clegg & Legare, 2016). For example, in India, a collectivist society, adult modeling of altruism has a greater influence on children's giving behavior than in the US (Blake, Corbit, Callaghan, & Warneken, 2016). Adult modeling may also have more or less of an impact if it is aligned with cultural norms. Indeed, children imitate with higher fidelity if the demonstrator says that a task is conventional versus instrumental (Legare, Wen, Herrmann, & Whitehouse, 2015). Finally, children who grow up in societies where they are more involved in adult work or observational learning may develop different theories of effort from adult models than children growing up in industrialized western societies. How these cultural factors impact children's learning about effort is a rich area for future research.

Here we limited children's perceived complexity of the task by using a fairly opaque toy that was not obviously too hard or too easy. However, differences in the surface features of the task indicating that it might be more or less difficult should also affect how hard children try and

previous research suggests that children are sensitive to these factors (e.g., Gweon, Asaba, & Bennett-Pierre, 2017). We also assumed that children would treat adult models as more competent than themselves (Lutz & Keil, 2002); however, we did not directly assess children's perception of their own skill relative to the task or the adult model. Research suggests that adults will quit if they see a model of similar competence fail on a task but will persist if they observe failure by a less competent model (I. Brown & Inouye, 1978). Future research might manipulate the relative competence of the adult model to look at the degree to which children are sensitive to the difference in skill between them and the adult model when learning about effort calibration.

Here we show that adults causally impact children's persistence with their actions, outcomes and words. However, future work is needed to explore how adult models affect children's persistence across contexts and in relation to their explicit theories of effort. Considering that perseverance has a very real-world impact on school achievement (Duckworth & Seligman, 2005; Eskreis-Winkler et al., 2014), future work should explore whether long term exposure to adult statements of encouragement and the value of effort, in conjunction with modeling effortful success, increases children's persistence over time. However, at least in simple contexts, the current work suggests that if you want children to persist, you should practice what you preach.

Chapter 3

Infants make more attempts to achieve a goal when they see adults persist

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Abstract

Persistence, above and beyond IQ, is associated with long-term academic outcomes. To look at the effect of adult models on infants' persistence, 15-month-olds were assigned to an Effort condition in which they saw an adult try repeatedly, using various methods, to achieve each of two different goals; a No Effort condition in which the adult achieved the goals effortlessly, or a Baseline condition. Infants were then given a difficult, novel task. Across an initial study and two pre-registered experiments (N = 262), infants in the Effort condition made more attempts to achieve the goal than infants in the other conditions. Pedagogical cues modulated the effect. The results suggest that adult models causally affect infants' persistence and that infants can generalize the value of persistence to novel tasks.

3.1 Introduction

Many cultures emphasize the value of effort and perseverance. This emphasis is substantiated by scientific research; individual differences in conscientiousness, self-control, and

“grit” correlate with academic outcomes independent of IQ (Eskreis-Winkler et al., 2014; Duckworth & Seligman, 2005; Poropat, 2009). Even the way children think about the relationship between hard work and achievement affects school outcomes: Experimental interventions suggest that children who believe effort determines achievement outperform those who believe ability is a fixed trait (Blackwell, Trzesniewski, & Dweck, 2007). Although most research on persistence has focused on school-age children (e.g., Eccles, 2002; Yeager & Dweck, 2012), studies suggest that persistence in infancy and early childhood statistically predicts longer-term cognitive outcomes (Messer et al., 1986; Yarrow et al., 1982; Yarrow et al., 1983), arguably mediated by a suite of temperamental and cognitive factors involved in executive function and “effortful control” (see Kochanska, Murray, & Harlan, 2000 and Rothbart, 2007 for reviews). In addition to such intrinsic factors, observational studies suggest that early task persistence may be affected by adult behaviors such as developmentally appropriate support for children’s autonomy, caregiver responsiveness, and praise for children’s effort rather than ability (Frodi, Bridges, & Grolnick, 1985; Gunerson et al., 2013; Kelley, Brownell, & Campbell, 2000).

However, previous studies leave open the question of whether there is a causal relationship between adult behavior and infants’ persistence. Additionally, they leave open the question of whether infants’ persistence might be affected not just by adults’ responses to infants, but by adults’ responses to challenges. Here, we asked whether infants might be sensitive to evidence that hard work pays off. Does seeing an adult exert effort to succeed encourage infants to persist longer at their own challenging tasks?

Both empirical and theoretical work suggests that young human learners can draw rich, abstract generalizations from sparse data (see Tenenbaum, Kemp, Griffith, & Goodman, 2011 for discussion). A few examples suffice for infants to infer the meanings of novel words (Xu &

Tenenbaum, 2007), causal relationships (Gweon & Schulz, 2011; Stahl & Feigenson, 2015; Walker & Gopnik, 2014) and social roles (Hamlin, 2013; Thomsen et al., 2011). Especially in pedagogical contexts—where adults make eye contact, say the child’s name, use child-directed speech, and perform intentional actions—infants draw broad, generalizable inferences from adult models (Csibra & Gergely, 2009; Gergely, Egedy, & Kirly, 2007). However, in such studies, infant behavior is simply a dependent measure used to assess infants’ learning of novel concepts, and there are few behavioral costs associated with learning new information. Here by contrast, we asked whether infants can draw an abstract inference about how to behave, and in particular, whether they can learn the value of engaging in costly, effortful actions.

We tested the hypothesis that infants who saw even a couple of examples of an adult working hard to achieve her goals would persist longer on a novel task than those who saw an adult succeed effortlessly. For the adult model, we chose goals that might be comprehensible to infants: opening a container and detaching a keychain from a carabiner. Intuitively, “working hard” at these tasks may involve a number of different behaviors (e.g., repeating actions, trying different actions, speculating on the appropriate actions, etc.). This limited our ability to specify which aspects of the modeled behavior might be important to the infants but allowed us to assess infants’ response to behaviors roughly comparable to those they might see outside the laboratory. By contrast, the infant task—activating a toy—was chosen for ease and reliability of coding; here, task persistence was operationalized simply as the number of button presses. The design thus provided a strong test of infants’ ability to infer the value of effort: Infants had to generalize from the diversity of observed adult behaviors to the effort appropriate for their own goal. In line with other work on infants and adult models of rational action (e.g., Gergely, Bekkering, Kirly, 2007), we tested 13- to 18-month-olds (mean age 15.37 months). Infants were randomly assigned

to an Effort, No Effort, or Baseline condition ($n = 34$ per condition). To ensure the robustness of the results, we subsequently ran a preregistered replication of the Effort/No Effort contrast (available on the Open Science Framework at <https://osf.io/j4935/>; $n = 40$ per condition).

3.2 Experiment 1

3.2.1 Materials and Methods

3.2.1.1 *Participants*

Infants were recruited at an urban children's museum and tested individually in a quiet testing room off the museum floor. A power analysis assuming a large effect size ($d = 0.8$, power = 0.9) indicated that 34 infants per condition would allow a high probability of finding any differences between conditions in planned t-test comparisons. A total of 24 infants were excluded from the experiment (11 in Effort condition, 7 in No Effort condition and 6 in Baseline). Infants were excluded for the following reasons: never pressing the button on the toy ($n = 8$; 4 in Effort Condition, 4 in No Effort condition), experimental error due to stimuli breaking or not getting child's date of birth ($n = 3$; 1 in each condition type), and parental interference ($n = 13$; 6 in Effort condition, 2 in No Effort condition and 5 in Baseline). Parental interference consisted of: 1) demonstrating how the toy worked by pressing the button themselves ($n = 11$; 5 in Effort condition, 2 in No Effort condition, and 4 in Baseline); 2) handing the child a toy other than the test toy ($n = 1$ in Effort condition) and 3) not giving back the toy to the child once they tossed it off their table ($n=1$ in Baseline). The remaining 102 infants (mean: 15.36 months; range: 13-18 months; 50 Female, 52 Male) were randomly assigned to the Effort, No Effort, and Baseline conditions ($n = 34$ / condition; ages were matched between conditions, $\beta = -0.15$, 95% CI [-0.51, 0.20]). All research was approved by the MIT Institutional Review Board and conducted with the informed consent of parents.

3.2.1.2 *Materials*

Two toys were used by the adult model. One toy was a tomato container with a rubber frog inside. The tomato container looked as though it could be opened by removing a plastic lid on the bottom of the container, but actually opened by peeling off a sticker at the top of the container. The other toy was a carbineer with a cow key chain attached. The key chain lit up and made mooing sounds when a button was pressed and could be removed by twisting and then squeezing the carabineer. The toy used for the infant test task was a square music box (6.35³ cm) covered in felt with a large red button with a musical note (3.81 cm) on the top. The button was easy to press but inert; a button concealed under the felt at the bottom of the toy actually activated the music. The bottom of the toy needed to be pressed firmly on a hard surface to trigger the button. The trigger was intended to be too difficult for the infants to activate (although 7% of infants succeeded, excluding these children did not change our results). Additionally, three warm-up toys (a rattle, a stuffed elephant, and a toy that lit up and vibrated) were used to familiarize the infant to the high chair and testing room.

3.2.1.3 *Procedure*

During the experiment, infants sat in a high chair or booster seat next to their parent. The experimenter made eye contact with the infant, greeted the infant by name, and used child-directed speech throughout. In the Effort condition, the experimenter picked up a container with a toy inside, announced her intention (“Look, there’s something inside of there! I want to get it out!”), then worked to open the container, narrating her attempts as she proceeded (“Hmm...I wonder how I can get my toy out of here? Does this work? No, how about this...”). She

successfully opened the container only at the end of a 30-s interval. The experimenter then put aside the container and demonstrated a carabiner with a toy keychain attached. She announced her intention (“How do I get this off?”) and again worked at the task, narrating her efforts and only succeeding at the end of the 30-s interval. The No Effort condition was identical except that the experimenter successfully accomplished each goal within 10 s and repeated the task twice more, for a total of three demonstrations over each 30-s interval. In the Baseline condition, the adult did not model any behavior and the infant proceeded directly to the test trial (Fig. 1).

In the test trial, the experimenter introduced the infant to a music box with a button. The button was easy for infants to press, but inert. The experimenter said, “Now it’s your turn to play with a toy. See this toy! This toy makes music!” The experimenter placed the toy out of the infant’s sight and activated the music toy using a hidden button designed to be difficult for infants to find or activate. The toy played a musical tune for approximately 5 seconds. The experimenter then handed the toy to the infant and left the room. The test trial was terminated after 2 min or after the baby handed the toy to her parent and/or threw the toy down a total of three times (called a “handoff” throughout). All trials were videotaped. At the end of the experiment, the experimenter helped the infant successfully activate the music toy.

3.2.1.4 *Coding and analyses*

Button presses were operationalized as a hand pushing down the button. Button presses were coded from videotape by two coders blind to hypotheses and condition (inter-rater reliability $r = .99, p < .001$). Data from a single coder was used for analyses but all results held with the second coder’s data. Coders agreed with the experimenter’s judgment on the termination of the experiment 100% of the time. Additionally, a coder blind to condition and hypotheses

coded the tapes for potential confounds. No difference was found across the conditions for whether the parent talked to the child ($X^2(2, N=102) = 1.03, p = .60$), parents' proximity to the infant (as distance in inches, $H(2) = 4.32, p = .12$), and parents' encouragement to the infant ($X^2(2, N = 102) = 5.56, p = .06$). Additionally, because the experimenter might have conveyed more enthusiasm in handing the toy to the child in the Effort than the No Effort condition, a second coder rated the experimenter's enthusiasm at the start of the test trial on a Likert scale, blind to conditions ($W = 525, p = .50$). For linear models, the dependent variables were transformed to the 0.5 power so that the distribution would adhere better to a normal distribution. The 95% confidence intervals reported throughout were obtained from a bootstrap with 10,000 samples.

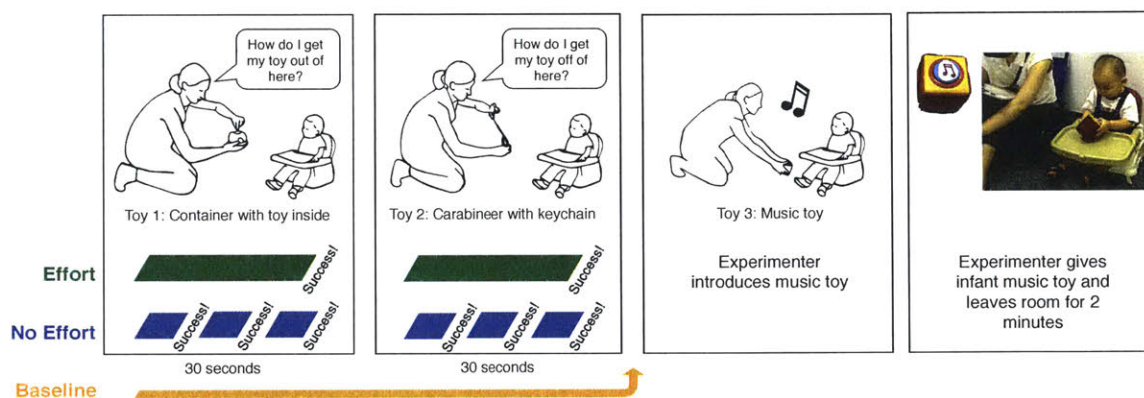


Fig. 3.1. Schematic of study design. Infants were assigned to one of three conditions: Effort, No Effort or Baseline. In the Effort condition, the experimenter struggled for 30 seconds before achieving each of two goals. In the No Effort condition, the experimenter achieved her goals effortlessly three times over 30 seconds. In the Baseline condition, there was no experimenter demonstration. The experimenter then introduced the infant to a novel toy, activated the toy out of the infant's sight so that it played a 5 second tune, gave the infant the toy, and left the room for two minutes. The dependent variables were the number of times infants pressed the large (inert) button on the music toy in total and before the first handoff.

3.2.2 Results

We looked at the total number of times the infants pressed the button before the termination of the experiment and, as a potentially more nuanced measure, the number of times the infants pressed the button before the first handoff. (See Fig. 3.2 and Tables 3.1 and 3.2 for results and analyses.) Both measures differed by condition (total button presses: $F(2, 99) = 5.10, P = 0.008, \eta^2 = 0.09$; presses before first handoff: $F(2, 99) = 4.88, P = 0.01, \eta^2 = 0.09$). Planned follow-up analyses revealed that, as predicted, children in the Effort condition pressed the button more times than children in the No Effort condition and children at Baseline; there was no significant difference in total button presses between the No Effort condition and the Baseline condition. The same pattern of results held when looking only at the number of button presses before the first handoff. All results were obtained through linear models but remained the same when tested with nonparametric Wilcoxon rank-sum test (total button presses: Effort vs. Baseline, $W = 793, P = 0.008, r = -0.32$; Effort vs. No Effort, $W = 763, P = 0.02, r = -0.27$; No Effort vs. Baseline, $W = 593, P = 0.86, r = -0.02$; presses before first handoff: Effort vs. Baseline, $W = 367.5, P = 0.01, r = -0.31$; Effort vs. No Effort, $W = 390.5, P = 0.02, r = -0.28$; No Effort vs. Baseline, $W = 582.5, P = 0.96, r = -0.01$).

Along with ANOVAs, non-parametric Kruskal-Wallis tests revealed that both the total number of times infants pressed the button and the number of times they pressed the button before first handoff differed by condition (total button presses: $H(2) = 8.13, p = .02$; presses before first handoff: $H(2) = 8.02, p = .02$).

Post hoc analyses suggest that these results were specific to infants' persistence in trying to activate the toy; there were no differences in overall playtime between conditions (mean play time in seconds, Effort: 88.26, 95% CI [78.06, 98.41], No Effort: 85.00, 95%CI [73.97, 96.21];

Baseline: 71.71, 95%CI [60.88, 82.32]; $F(2,99) = 2.47, p = .09, \eta^2 = .05$) or tendency to hand off or discard the toy between conditions (mean number of hand-offs, Effort: 2.09, 95% CI [1.71, 2.53], No Effort: 2.09, 95%CI [1.68, 2.53]; Baseline: 2.56, 95%CI [2.27, 2.91]; $X^2(6, N=102) = 4.55, p = .60$).

Further analyses revealed a correlation between age in months and total number of button presses ($r_s(100) = 0.24, p = .02$), but not button presses before handoff ($r_s(100) = 0.12, p = .22$). No age by condition interactions were found for either total button presses or button presses before first handoff (both $p > .6$).

We opted to limit the exclusion criteria to those specified above, however, the results were robust to the inclusion criteria; all results held if we additionally excluded children 1) who successfully activated the toy ($n = 7, 4$ in Effort Condition, 3 in No Effort condition) 2) whose parents verbally encouraged them to press the button ($n = 19, 9$ in Effort Condition, 8 in No Effort condition and 2 in Baseline), 3) whose parents physically encouraged their child to press the button by pointing to the toy or pushing the toy toward the child ($n = 9, 4$ in Effort Condition, 3 in No Effort condition, and 2 in Baseline) and 4) whose parents asked to terminate the experiment early because their child was fussy ($n = 2, 1$ in Effort Condition, 1 in No Effort condition).

Further, results were robust to outliers (defined as more than 1.5 interquartile range above the third quartile). When the 1 Effort and 2 Baseline outliers for total button presses were excluded, the ANOVA and Kruskal-Wallis test ($F(2, 96) = 6.33, p = .003, \eta^2 = .12; H(2) = 9.26, p = 0.01$) and post-hoc comparisons that were significant remained significant (Effort vs Baseline: $\beta = 1.37, t(63) = 3.54, p = .0008, 95\% \text{ CI } [0.63, 2.13]; W = 757.5, p = .003, r = -.37$; Effort vs No Effort: $\beta = 1.11, t(65) = 2.50, p = .02, 95\% \text{ CI } [0.24, 2.00]; W = 729, p = .04, r = -$

.26). This was also true when excluding the 2 Effort, 2 No Effort, and 1 Baseline outliers for button presses before first hand off ($F(2, 94) = 5.04, p = .008, \eta^2 = .10; H(2) = 8.22, p = 0.02$; Effort vs Baseline: $\beta = 1.00, t(63) = 2.70, p = .009, 95\% \text{ CI } [0.27, 1.74]; W = 336.5, p = .01, r = -.31$; Effort vs No Effort: $\beta = 1.05, t(62) = 2.55, p = .01, 95\% \text{ CI } [0.24, 1.85]; W = 330.5, p = .01, r = -.30$).

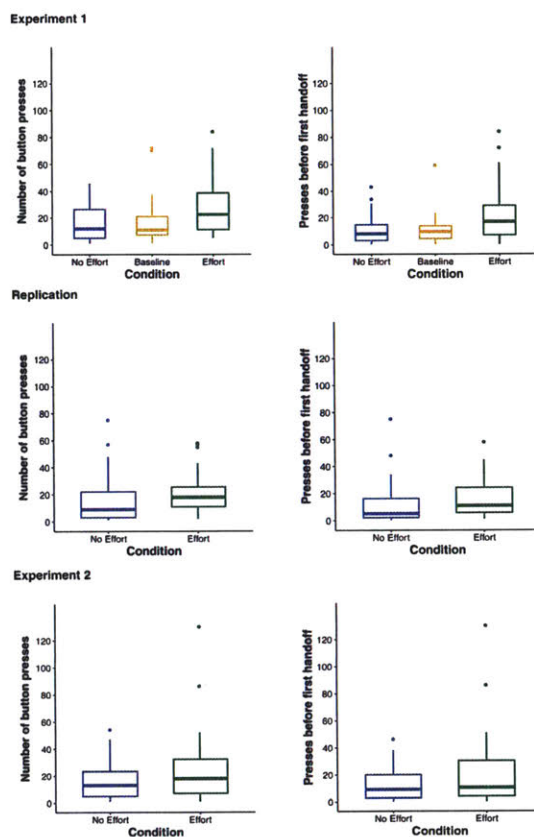


Fig. 3.2. Results from Experiment 1, the Replication, and Experiment 2. The top and the bottom of the box correspond to the first and third quartiles (the 25th and 75th percentiles). The upper whisker (vertical black line) extends from the third quartile to the largest value no further than 1.5 interquartile ranges from the third quartile; the lower whisker extends from the 25th percentile down to the smallest value at most 1.5 interquartile ranges from the first quartile (i.e., the largest and smallest values that are not outliers). The dark dots are values more than 1.5 times the interquartile range above the third quartile (outliers). See text for statistical analyses.

Table 3.1. Linear models for each condition contrast in Experiment 1, the Replication, and Experiment 2. The 95% confidence intervals are from a bootstrap of the beta coefficients with 10,000 samples for the total button presses and the number of button presses before the first handoff in each condition. For all models, the data were transformed to the 0.5 power to better adhere to a normal distribution.

	Experiment 1	<i>R</i> ²	<i>B</i>	<i>t</i>	<i>df</i>	<i>p</i>	95% CI
Effort vs. Baseline	Total button presses	.10	1.21	2.73	66	.008	0.35, 2.08
	Presses before first handoff	.10	1.16	2.66	66	.01	0.31, 1.99
Effort vs. No Effort	Total button presses	.10	1.24	2.71	66	.008	0.36, 2.11
	Presses before first handoff	.09	1.14	2.48	66	.02	0.24, 2.03
No Effort vs. Baseline	Total button presses	.00	0.03	0.08	66	.94	-0.81, 0.85
	Button presses before handoff	.00	-0.02	-0.04	66	.97	-0.76, 0.71
Replication							
Effort vs. No Effort	Total button presses	.05	0.82	2.08	78	.04	0.84, 2.44
	Button presses before handoff	.04	0.79	1.91	78	.06	0.75, 2.44
Experiment 2							
Effort vs. No Effort	Total button presses	.05	0.93	2.11	78	.04	0.07, 1.79
	Button presses before handoff	.02	0.66	1.40	78	.17	-0.28, 1.56

Table 3.2. Medians and 95% confidence intervals from a bootstrap with 10,000 samples for the two main outcome measures for each condition in Experiment 1, the Replication and Experiment 2.

		Total button presses		Presses before first handoff	
		Median	95% CI	Median	95% CI
Exp. 1	No Effort	12	-2, 17.0	8	3, 12
	Baseline	11	4, 13	9.5	8, 13
	Effort	22.5	15, 29	17	11, 24
Rep.	No Effort	9	0, 13	5	0, 7
	Effort	18	12.5, 23	11	5, 14
Exp. 2	No Effort	13	8, 19.5	9	2, 13
	Effort	18	5, 25.5	10.5	1.5, 15

Table 3.3. Wilcoxon rank-sum tests for the two main outcome measures of interest by each condition in experiment 1, the replication, and experiment 2.

Experiment 1		<i>W</i>	<i>p</i>	<i>r</i>
Effort vs. Baseline	Total button presses	793	.008	-.32
	Presses before first handoff	367.5	.01	-.31
Effort vs. No Effort	Total button presses	763	.02	-.27
	Presses before first handoff	390.5	.02	-.28
No Effort vs. Baseline	Total button presses	593	.86	-.02
	Presses before first handoff	582.5	.96	-.01
Replication				
Effort vs. No Effort	Total button presses	556.5	.02	-.26
	Presses before first handoff	573.5	.03	-.24
Experiment 2				
Effort vs. No Effort	Total button presses	599	.05	-.22
	Presses before first handoff	684	.27	-.12

3.3 Replication

3.3.1 Materials and Methods

3.3.1.1 *Participants*

Infants were recruited in the same fashion as in experiment 1. A power analysis using the effect sizes for the dependent measures in the Effort and No Effort conditions in experiment 1 ($d = .63$, power = .8) indicated that we needed 40 infants per condition in the replication. A total of 30 infants were excluded from the experiment (14 in Effort condition and 16 in No Effort condition). Infants were excluded for the following reasons: never pressing the button on the toy ($n = 7$; 6 in Effort Condition, 1 in No Effort condition), experimental error due to stimuli

breaking, incorrectly demonstrating condition, or ending experiment early (n = 4; 1 in Effort Condition, 3 in No Effort condition), and parental interference (n = 16; 4 in Effort condition, 12 in No Effort condition). Again, parental interference consisted of: 1) demonstrating how the toy worked by pressing the button themselves (n = 13; 4 in Effort condition, 9 in No Effort condition); 2) handing the child a toy other than the test toy (n = 1 in No Effort condition) and 3) not giving back the toy to the child once they tossed it off their table (n = 2 in No Effort condition). Additionally, we excluded infants for being fussy (operationalized as parents ending the experiment early due to perceived child fussiness) in the replication (n = 3, all in Effort condition). Although we did not exclude (two) fussy infants in experiment 1, we had pre-registered the exclusion criteria to exclude fussy infants in the replication (and all results of experiment 1 hold when excluding the two fussy infants).

The remaining 80 infants (mean: 15.21 months; range: 13-18 months; 44 Female, 36 Male) were randomly assigned to the Effort, and No Effort conditions (n = 40/ condition; ages were matched between conditions, $\beta = -0.43$, 95% CI [-1.14, 0.30]).

3.3.1.2 *Materials*

All Materials were the same as in the experiment 1 except that some additional felt was added to cover the concealed switch at the bottom of the toy to make it harder for infants to activate.

3.3.1.3 *Procedure*

The procedure was the same as in experiment 1.

3.3.1.4 Coding and analyses

All data were coded from videotape by the first author and a coder blind to hypotheses and condition; data from the coder blind to hypotheses and condition were used throughout but all results remained the same with the first author's coding (button pressing inter-rater reliability $r = .99, p < .001$). A third coder blind to hypotheses and conditions rescored 30% of the button pressing data (inter-rater reliability with the other blind coder was $r = .99, p < .001$ for both coders). Coders agreed with the experimenter's judgment on the termination of the experiment 100% of the time. The coder blind to hypotheses and conditions also coded the tapes for potential confounds. No difference was found across the conditions for whether the parent talked to the child ($\chi^2(1, N = 80) = 0.0, p = 1.0$), parents' proximity to the infant (as distance in inches, $W = 768, p = .76$), parents' encouragement to the infant ($\chi^2(1, N = 80) = 0.33, p = .57$), and tone of voice of the experimenter when they handed the toy to the infant (on a Likert scale from 1, not encouraging, to 7, very encouraging: $W = 788, p = .87$). As in experiment 1, the dependent variables were transformed to the 0.5 power to better adhere to a normal distribution for linear models.

3.3.2 Results

In the preregistered replication of the contrast between the Effort and No Effort conditions, again, infants in the Effort condition pushed the button both more times overall and more times before the first handoff than did infants in the No Effort condition (total button presses: $W = 556.5, P = 0.02, r = -0.26$; presses before first handoff: $W = 573.5, P = 0.03, r = -0.24$). Analyses again revealed that the results were specific to infant persistence in activating the toy; there were no differences in overall playtime by condition (mean play time in seconds,

Effort: 88.25, 95% CI [78.42, 98.47], No Effort: 76.15, 95%CI [66.03, 85.90]; $t(78) = -1.66, p = .10, d = -.37$) or in tendency to discard or hand off the toy between conditions (mean number of hand-offs, Effort: 2.13, 95% CI [1.75, 2.55], No Effort: 2.48, 95%CI [2.18, 2.83], $\chi^2(3, N=80) = 3.96, p = .27$). Removing outliers (values 1.5 times the interquartile range above the third quartile) had no effect on the results in either experiment 1 or the replication. These results suggest that two examples suffice for infants to generalize the value of effort to a new task.

To further understand the patterns in our results, we ran simulations to calculate the power of our results using our own data. We ran 10,000 linear models and Wilcoxon rank-sum tests with 40 bootstrapped samples from the effort and no effort group respectively. We then coded each significant model as 1 and each insignificant model as 0. Dividing the number of significant models by the total number of simulations gives us an estimate of our studies' power. For the total number of presses, we got a power of .55 for the linear models and a power of .66 for the Wilcoxon rank-sum test. For the presses before first handoff, we got a power of .48 for the linear models and .59 for the Wilcoxon rank-sum test. This confirms that we had sufficient power to detect an effect and suggests that the Wilcoxon rank-sum test is a more powerful model for this data over the linear models (presumably because of the non-normality of our data).

In contrast to the experiment 1, Spearman correlations reveal no relationship between age in months and total number of button presses ($r_s(78) = 0.08, p = .47$). This relationship was also not found between age and button presses before handoff ($r_s(78) = 0.06, p = .59$). No age by condition interactions were found for either total button presses or button presses before first handoff (both $p > .3$).

Additionally, all results held when excluding children with possible confounds of 1) parents verbally encouraging their children to press the button ($n = 15, 9$ in Effort Condition, 6 in

No Effort condition) and 2) parents physically encouraging their child to press the button by pointing to the toy or pushing the toy toward the child ($n = 19$, 8 in Effort Condition, 11 in No Effort condition). Note that no children successfully activated the toy in the replication because after experiment 1, we added more felt to the bottom of the toy to make it more difficult for the infants to activate.

Although we did not pre-register removing outliers from our analyses, we explored the robustness of our results when taking them out at the suggestion of a reviewer. When removing the 3 Effort and 2 No Effort total button presses outliers, the significant difference in total button presses by condition remained significant ($\beta = 0.80$, $t(73) = 2.33$, $p = .02$, 95% CI [0.13, 1.49]; $W = 478$, $p = .02$, $r = -.27$). Similarly, when removing the 1 Effort and 2 No Effort button presses before first handoff outliers, the button presses before first handoff in the Effort condition was significantly more than the No Effort condition ($\beta = 0.95$, $t(75) = 2.56$, $p = .01$, 95% CI [0.22, 1.71]; $W = 494.5$, $p = .01$, $r = -.29$).

3.4 Experiment 2

As noted, infants are especially likely to draw rich, abstract inferences in pedagogical contexts (Csibra & Gergely, 2009; Gergely, Egyed, & Kirlyay, 2007). However, times when adults are struggling to achieve their goals may be times when they are especially unlikely to engage infants pedagogically. To look at whether pedagogical cues are critical to infants' inferences or whether infants can infer the value of effort merely from observing an adult struggling to achieve goals, we eliminated ostensive cues in Experiment 2 (preregistered at <https://osf.io/rwxpq/>): The experimenter did not make eye contact, use infant-directed speech, or use the infant's name during the Effort and No Effort demonstrations.

3.4.1 Materials and Methods

3.4.1.1 *Participants*

Infants were recruited in the same fashion as in experiment 1 and the replication. A total of 17 infants were excluded from the experiment (9 in Effort condition and 8 in No Effort condition). Infants were excluded for the following reasons: never pressing the button on the toy (n = 4; 2 in Effort Condition, 2 in No Effort condition), experimental error due to stimuli breaking and not getting child's date of birth (n = 3; 2 in Effort Condition, 1 in No Effort condition), and parental interference (n = 6; 2 in Effort condition, 4 in No Effort condition). In this experiment, the only form of parental interference was demonstrating how the toy worked by pressing the button themselves (n = 6; 2 in Effort condition, 4 in No Effort condition). As in the replication, we also excluded infants for being fussy (operationalized as parents ending the experiment early due to perceived child fussiness; n = 4; 3 in Effort condition, 1 in No Effort condition).

The remaining 80 infants (mean: 15.55 months; range: 13-18 months; 41 Female, 39 Male) were randomly assigned to the Effort, and No Effort conditions (n = 40 in Effort, 40 in No Effort; ages were matched between conditions, $\beta = -0.35$, 95% CI [-1.11, 0.41]).

3.4.1.2 *Materials*

All Materials were the same as in the replication.

3.4.1.3 *Procedure*

The procedure was the same as in the replication except the experimenter did not make eye contact, say the infants' name or use infant-directed speech during the Effort and No Effort demonstrations.

3.4.1.4 *Coding and analyses*

All data were coded from videotape by the first author and a coder blind to hypotheses and condition (button press inter-rater reliability $r = .99, p < .001$); data from the coder blind to hypotheses and condition were used throughout but all results remained the same with the first author's coding. Coders agreed with the experimenter's judgment on the termination of the experiment 100% of the time. The coder blind to hypotheses and conditions also coded the tapes for potential confounds. No difference was found across the conditions for whether the parent talked to the child ($\chi^2(1, N = 80) = 0.21, p = .65$), parents' proximity to the infant (as distance in inches, $W = 886.5, p = .39$), parents' encouragement to the infant ($\chi^2(1, N = 80) = 1.47, p = .23$), and tone of voice of the experimenter when they handed the toy to the infant (on a Likert scale from 1, not encouraging, to 7, very encouraging: $W = 713, p = .28$). As in both previous experiments, the dependent variables were transformed to the 0.5 power to better adhere to a normal distribution for linear models.

To make sure infants' attention to the experimenter demonstration did not differ by pedagogical context, a blind coder coded the number of seconds infants were looking at the experimenter during the two demonstrations in the first 32 participants with data where infants eyes were visible from the replication and experiment 2. Infant attention did not differ across the replication and experiment 2 (Mean (SD): replication = 64.6 (6.3) seconds, experiment 2 = 63.9 (4.4); $t(62) = -0.56, p = .58$).

3.4.2 Results

Consistent with previous research (Butler & Markman, 2012; Butler et al., 2015), the results suggest that pedagogical cues modulate learning. The primary result was replicated: Infants in the Effort condition pressed the button more times overall than did infants in the No Effort condition (Table 3.3). However, the effect was weak: In contrast to the previous studies, (i) the main result was not robust to removing outliers ($\beta = 0.72$, $t(75) = 1.86$, $P = 0.07$; 95% confidence interval (CI), -0.04 , 1.47 ; $W = 561$, $P = 0.07$, $r = -0.21$), (ii) bootstrapped 95% CIs on medians in the Effort and No Effort conditions largely overlapped, and (iii) there was no effect of condition on the number of button presses before first handoff. Additionally, although the tendency to hand off the toy did not differ between conditions (mean number of hand-offs, Effort: 1.93, 95% CI [1.55, 2.30], No Effort: 2.20, 95%CI [1.83, 2.60], $\chi^2(3, N=80) = 5.17$, $p = .16$), there was a difference in overall playtime between conditions, with children in the Effort condition playing for longer than children in the No Effort condition (mean play time in seconds, Effort: 100.65, 95% CI [93.20, 108.40], No Effort: 81.83, 95%CI [71.48, 92.45]; $t(78) = -2.80$, $p = .007$, $d = -.63$). These results suggest that the absence of ostensive cues made the effect both weaker and less specific. Note also that in order to match the modeled behavior in the pedagogical conditions of experiment 1, the experimenter talked and gestured (to herself) in the non-pedagogical conditions in experiment 2. Entirely eliminating all communicative information might have further attenuated the effect.

Just as in experiment 1, Spearman correlations revealed a relationship between age in months and total number of button presses ($r_s(78) = .24$, $p = .03$). This relationship was not found between age and button presses before handoff ($r_s(78) = .15$, $p = .19$). No age by

condition interactions were found for either total button presses or button presses before first handoff (both $p > .2$).

When excluding children with possible confound of parents verbally encouraging their children to press the button ($n = 13$, 9 in Effort Condition, 4 in No Effort condition), there was no effect of condition on total number of button presses ($W = 686.5$, $p = .11$, $r = -.20$). Further, when excluding children with the possible confound of parents physically encouraging their child to press the button by pointing to the toy or pushing the toy toward the child ($n = 25$, 12 in Effort Condition, 13 in No Effort condition), the total number of button press difference by condition was only a trend ($W = 485$, $p = .07$, $r = -.24$).

We looked at whether the results were robust to removing outliers (although as noted, we planned to analyze all the data that met inclusion criteria and this was not a pre-registered analysis). There were 2 outliers in the Effort condition and 1 in the No Effort condition (with outliers defined as infants whose button pressing was in the 1.5 quartile interval above the third quartile). Without these outliers, the results became a non-significant trend ($\beta = .72$, $t(75) = 1.86$, $p = .07$, 95% CI [-0.04, 1.47]; $W = 561$, $p = .07$, $r = -.21$) and the effect of outliers on Experiment 2 can also be seen in the substantial overlap in the 95% confidence intervals for the median (a degree of overlap not present in experiment 1 or the replication; see Table 3.2.)

3.5 Discussion

Overall, however, these studies suggest that seeing just two examples of an adult working hard to achieve her goals can lead infants to work harder at a novel task relative to infants who see an adult succeed effortlessly. Critically, the adult examples affected infants' persistence even though the adult had different goals and performed different actions than the infants. These

results are in line with a growing body of work suggesting that infants and toddlers are sensitive to the effort that agents use in performing goal-directed actions (Jara-Ettinger, Tenenbaum, & Schulz, 2015; Liu & Spelke, 2017); they go beyond such work in suggesting that infants can also learn to try harder themselves.

Of course, repeatedly attempting to achieve a goal is only a good idea when it is reasonable to assume that persistence will pay off. A number of features of this design made that assumption plausible here: The toy was designed to look like a developmentally appropriate infant toy; infants had heard the toy activate; they were given the toy by a friendly, presumably helpful adult; and, as noted, they had previously seen the adult successfully achieve her own goals. Absent any of these factors, adult persistence might be less likely to increase infants' persistence; however, precisely such factors might help infants to distinguish between (valuable) persistence and (pointless) perseveration. Future work might look at how demonstrations of the effort involved in goal achievement affect infants' persistence, not just immediately and within a single setting, but across contexts, over time, and with respect to children's explicit attitudes toward challenges (e.g., Yeager & Dweck, 2015).

The precise nature and scope of infants' inferences remains a question for future research. Infants might have learned something about the value of effort generally, or they might have made relatively specific assumptions about the value of effort in this context. For instance, infants in the Effort condition might have inferred that the toy was difficult to operate and thus required persistence, whereas infants in the No Effort condition may have inferred that the toy should work easily; when it did not, they may have assumed the toy was broken rather than that more effort was required (see, e.g., Gweon & Schulz, 2011). Additionally, we looked only at cases where the adult model succeeded at the task. (Pilot work suggested that it was difficult to

sustain infants' attention to both demonstrations when the adult failed.) If an adult fails to achieve a goal after trying only slightly, infants might infer that the goal may be achievable with more effort. If so, the current results might reverse: Infants might persist more when they see an adult fail after trying a little than a lot. Alternatively, if an adult fails to achieve a goal, infants might conclude that the task is beyond their abilities, regardless of adult effort. Future work might investigate these predictions.

The tasks used in this study were designed to be readily comprehensible to infants. Whether infants would be sensitive to adult persistence in contexts where the adult's goals and goal-directed actions were more opaque to the child remains an empirical question. The infant task also appeared deceptively simple: The only salient feature of the box was a large, easy-to-press button. This design was useful in constraining infants' actions and operationalizing persistence; however, it leaves open the question of how infants' persistence might be affected in less constrained contexts.

The generalizability of the results may be limited, insofar as the infants in the current study were recruited from a relatively privileged sample of parents at an urban children's museum. Some work suggests that inferences relevant to the current work may hold broadly (e.g., assumptions about pedagogical sampling hold even in traditional Mayan communities where formal instruction is rare (Schneidman, Gweon, Schulz, & Woodward, 2016)). However, different prior beliefs about the competence and trustworthiness of adults (see, e.g., Koenig & Harris, 2005) or the reliability of expected rewards (e.g., Kidd, Palmeri & Aslin, 2013) may support different inferences about both the utility of learning from adult models and the utility of persistence itself. Future research might investigate the degree to which observations of adult

effort increase infants' persistence in a broader range of cultural and socioeconomic environments.

Cultural factors may also affect the extent to which children have opportunities to see adults working hard to achieve their goals. In some communities, children learn predominantly by observing and participating in the challenging tasks of adult life (Gaskins, 1999). By contrast, in modern, industrialized cultures, children learn primarily by being instructed in knowledge and skills that adults have already mastered; in such contexts, children may assume that most things come easily to adults. In investigating infants' ability to learn persistence from adult models, we do not mean to suggest that observing adult models is the only or best way for children to learn the value of persistence; its value may also be communicated by explicit messages about the importance of hard work or simply observing that adults fulfill their responsibilities.

Nonetheless, the current study suggests the potential value in letting children "see you sweat": Showing children that hard work works might encourage them to work hard too.

Chapter 4

Differential effects of socioeconomic status on working and procedural memory systems

This chapter is based on Leonard, J.A., Mackey, A.P., Finn, A.S., & Gabrieli, J.D.E. (2015).

Differential effects of socioeconomic status on declarative and procedural memory. *Frontiers in Human Neuroscience*, 9:554. doi:10.3389/fnhum.2015.00554

Abstract

While prior research has shown a strong relationship between socioeconomic status (SES) and working memory performance, the relation between SES and procedural (implicit) memory remains unknown. Convergent research in both animals and humans has revealed a fundamental dissociation, both behaviorally and neurally, between a working memory system that depends on medial temporal-lobe structures and the dorsal lateral prefrontal cortex (DLPFC) vs. a procedural memory system that depends on the basal ganglia. Here, we measured performance in adolescents from lower- and higher-SES backgrounds on tests of working memory capacity (complex working memory span) and procedural memory (probabilistic classification) and their hippocampal, DLPFC, and caudate volumes. Lower-SES adolescents had worse working memory performance and smaller hippocampal and DLPFC volumes than their higher-SES peers, but there was no significant difference between the lower- and higher-SES groups on the procedural memory task or in caudate volumes. These findings suggest that SES may have a

selective influence on hippocampal-prefrontal-dependent working memory and little influence on striatal-dependent procedural memory.

4.1 Introduction

There has been growing interest in the fields of neuroscience and psychology to understand how socioeconomic status (SES) influences neural and cognitive development in children and adolescents (Hackman and Farah, 2009; Mackey et al., 2015; Noble et al., 2015). SES is a measure of one's overall status in society and can be operationalized by parental income, occupation, education, or a composite of these measures. Most studies examining SES associations with cognitive development have focused on explicit memory tests and found that children from lower-SES backgrounds perform worse on measures of working and declarative memory than their higher-SES peers (Herrmann and Guadagno, 1997; Farah et al., 2006; Noble et al., 2007; Evans and Schamberg, 2009; Sarsour et al., 2011; Hackman et al., 2015). However, it is unknown as to whether SES is associated with differences in procedural (implicit) memory. Convergent research with humans and animals has revealed a fundamental dissociation, both in behavior and in the underlying neural circuitry, between explicit or declarative memory and implicit procedural memory (Squire, 1992; Gabrieli, 1998), raising the possibility that SES may not affect these two memory systems equally. Here we asked whether SES also influences behavioral and neural correlates of procedural memory.

Declarative memory and procedural memory rely on separable neural substrates (Cohen and Squire, 1980; Graf and Schacter, 1985; Knowlton et al., 1996). Long-term declarative memory, measured by performance on explicit tests of recall and recognition, depends upon structures in the medial temporal lobe (MTL) and dorsal lateral prefrontal cortex (DLPFC).

Bilateral MTL injury results in global amnesia (Scoville and Milner, 1957; Squire and Zola-Morgan, 1991) and prefrontal lesions impair declarative memory for contextual details (Schacter et al., 1984; Janowsky et al., 1989; Milner et al., 1991). In contrast, simple short-term memory maintenance, operationalized as tests of immediate recall for digits and spatial locations, remains intact after MTL lesions (Scoville and Milner, 1957; Baddeley and Warrington, 1970; Cave and Squire, 1992; Buffalo et al., 1998) and appears to depend upon modality-specific posterior neocortices (Kimura, 1963; Warrington et al., 1971).

Complex working memory capacity, the amount of goal-relevant information that can be simultaneously stored and manipulated, is measured via declarative or explicit tests, and appears to depend upon both MTL and DLPFC brain regions. Complex working memory is impaired in patients with MTL lesions (Hannula et al., 2006; Nichols et al., 2006; Olson et al., 2006a,b; Hartley et al., 2007; Ezzyat and Olson, 2008; Olsen et al., 2012) and also in patients with DLPFC lesions (Barbey et al., 2013). Thus, complex working memory, like declarative memory, appears to depend upon the integrity of a memory system that involves both MTL and DLPFC regions.

Procedural memory, measured implicitly by skill learning over time, does not depend upon the MTL structures supporting declarative and complex working memory, but rather depends upon the integrity of the basal ganglia. Amnesic patients with MTL or similar lesions and severe impairments in declarative memory exhibit intact procedural memory on motoric, perceptual, and cognitive tasks (Milner, 1962; Corkin, 1968; Cohen and Squire, 1980; Gabrieli et al., 1993; Knowlton et al., 1994, 1996). Patients with striatal injuries, however, exhibit impaired learning on such tasks (Heindel et al., 1989; Knowlton et al., 1996; Shohamy et al., 2004).

The neurobiological distinction between MTL-dependent declarative memory and striatum-dependent procedural memory has been evident in the probabilistic classification task, in which participants learn how to classify stimuli into categories (e.g., sunny or rainy weather) based on trial-by-trial feedback. Amnesic patients with MTL lesions and severe declarative memory impairments have exhibited intact learning on this task (Knowlton et al., 1996). In contrast, despite superior declarative memory relative to the amnesic patients, patients with striatal dysfunction due to Parkinson's disease have exhibited severely impaired probabilistic learning (Knowlton et al., 1996; Shohamy et al., 2004). Functional neuroimaging studies with healthy individuals support the conclusion that probabilistic learning is associated with the striatum, specifically the caudate (Poldrack et al., 1999, 2001; Seger and Cincotta, 2005).

Lower-SES has been associated with smaller hippocampal volume (Hanson et al., 2011; Noble et al., 2012, 2015), but the specific mechanisms that mediate this association are uncertain. Lower-SES is a multifaceted construct that includes increased exposure to stress, poor nutrition, and lack of cognitive stimulation (Hackman et al., 2010). All of these factors have been individually linked to the hippocampal integrity in animal experiments. Stress (Sapolsky, 1996) and malnutrition of protein-energy, iron, and zinc harm the developing hippocampus (Georgieff, 2007), while environmental enrichment increases dendritic branching and synaptic density in the hippocampus (Kempermann et al., 1997). Thus, multiple facets of lower-SES may harm development of the hippocampus in humans. On the other hand, there is little evidence about the influence of these factors on the development of striatal structures.

Given that complex working memory and procedural memory rely on separable neural substrates, SES may not affect both systems equally. In the current study, we tested this hypothesis by examining the performance of adolescents from lower- and higher-SES

environments (operationalized by family income) on tests of working memory (complex working memory span) and procedural memory (probabilistic classification task). We also measured the volumes of the hippocampus and DLPFC critical for complex working memory, and the caudate, critical for procedural memory.

4.2 Methods

4.2.1 Participants

As part of a larger study looking at SES, brain development, and educational outcomes (see Mackey et al., 2015; Finn et al., under revision), adolescents were recruited from a variety of home and schooling environments directly through schools, or through summer camps, outreach programs, and advertisements in local papers and on websites. In total, neuroimaging data are presented here for 58 participants (mean age: 14.42, range 13.08–15.18; 27 males; the same 58 from Mackey et al., 2015, and a subset from Finn et al., 2016). Three participants were excluded for the following reasons: one participant had no information on family income, one participant had abnormal brain structure, and one participant had excessive motion artifacts (see “Structural analysis”). This study was approved by the Committee for the Use of Humans as Experimental Subjects at the Massachusetts Institute of Technology. All participants provided written assent, and their parents provided written consent.

Participants were divided into lower-SES and higher-SES groups based on whether or not they had received free or reduced price lunch within 3 years before participation in the study. Participants who were eligible for free or reduced price lunch had a family income below 185% of the poverty line, which, at the time of the study, was approximately \$42,000 per year for a family of two adults and two children. Twenty-three adolescents were in the lower-SES group

(seven males, 22% African American, 4% Asian, 54% White, 4% Native Hawaiian or Pacific Islander, 26% multiple races, 35% did not report race; 35% not Hispanic, 65% Hispanic) and 35 adolescents were in the higher-SES group (20 males, 6% African American, 14% Asian, 54% White, 3% Native Hawaiian or Pacific Islander, 17% multiple races, 6% did not report race; 91% not Hispanic, 3% Hispanic, 6% did not report ethnicity). The groups did not differ in their distribution of age [lower-SES: $M = 14.35$, $SD = 0.47$; higher-SES: $M = 14.47$, $SD = 0.38$; $t_{(56)} = 1.05$, $p = 0.30$], but did differ in their distribution of boys and girls [$\chi^2(1, N = 58) = 3.98$, $p = 0.05$], so we controlled for sex in all analyses.

4.2.2 Procedure

4.2.2.1 Behavioral Data Acquisition

Participants were tested individually at the Massachusetts Institute of Technology. Participants underwent scanning and behavioral testing during the same visit. The behavioral tests were conducted outside of the scanner. Not all participants were able to complete both memory tasks due to fatigue or reaching the time limit of their visit. Of the 23 lower-SES participants, 19 completed the procedural memory task and 23 completed the working memory task. Of the 35 higher-SES participants, 28 completed the procedural memory task, and 34 completed the working memory task.

4.2.2.2 Income Status

With family consent, free/reduced price lunch statistics were obtained from a database maintained by the Massachusetts Department of Elementary and Secondary Education. None of

the participants in the current study were enrolled in special education or had limited English proficiency during the 3 years for which data were available.

4.2.2.3 Procedural Memory Task

A probabilistic classification task (similar to that described in Knowlton et al., 1994) was administered using Psychopy software (Peirce, 2007). Participants were presented with 1–3 of four differently patterned cards on a computer screen and asked to predict whether the cards indicated rain or shine. Card position did not vary across trials. The weather outcome (rain or shine) was calculated according to the conditional probabilities of each card and the combination of cards. For example, a particular combination of three cards was associated with rain 80% of the time. In total, there were 14 card combinations. There were 100 trials, with sunny and rainy outcomes occurring equally overall. Participants had unlimited time to choose an outcome. After the participant chose an outcome, they were given feedback (smiling face for correct responses, sad face for incorrect responses).

A participant was considered to have made an optimal (correct) response if they selected the outcome most often associated with the cue pattern, regardless of the actual probabilistically determined response on the given trial. For example, if a participant selected rain for a card that predicted rain 75% of the time, they would be counted as making an optimal response even if on that particular trial the card predicted sun.

4.2.2.4 Working Memory Task

A count span task (Conway et al., 2005; Cowan et al., 2005) was administered using PsychoPy software (Peirce, 2007). In this task, similar to that described in Finn et al.

(2014) participants were presented with consecutive arrays of blue circles, blue triangles, and red circles. They were told to count only the blue circles in each array (ranging from 1 to 9 circles in each array) and to hold that number in mind. They could press the space bar to proceed with the next array, or it would forward to the next display after 5 s. Loads ranged from 1 to 6 and were presented in random order, for a total of three instances of each load. After the presentation of arrays, participants were prompted to enter the number of blue circles in the order they were presented. Participants were given full credit for a given load if they got two out of three instances correct and half credit for each load they got one out of three instances correct (Daneman and Carpenter, 1980).

4.2.2.5 Neuroimaging Data Acquisition

As described in Mackey et al. (2015), structural MRI data were acquired at the Athinoula A. Martinos Imaging Center at the McGovern Institute for Brain Research at the Massachusetts Institute of Technology. Data were acquired using a 32-Channel Tim Trio 3 Tesla, high-speed magnetic resonance imaging (MRI) scanner equipped for echo planar imaging (EPI; Siemens, Erlangen, Germany). An automated scout image was acquired and shimming procedures were performed to optimize field homogeneity. A multi-echo high-resolution structural image was acquired using a protocol designed for children to better account for motion artifacts (repetition time = 2530 ms; echo times = 1.64, 3.44, 5.24, 7.04 ms; flip angle = 7°; resolution = 1 mm isotropic; Tisdall et al., 2012).

4.2.2.6 Structural Analysis

As described in Mackey et al. (2015), data were visually inspected for image quality by two coders blind to income group. Using a visual guide of artifacts associated with motion, coders rated the images on a scale of one (perfect) to four (unusable). If coder ratings differed by more than a point, a third blind coder made a final decision. One participant was excluded for poor image quality. Ratings did not differ between the lower- and higher-SES groups [lower-SES: $M = 2.04$, $SD = 0.45$; higher-SES: $M = 2.04$, $SD = 0.43$; $t_{(56)} = -0.05$, $p = 0.96$].

The hippocampus was segmented by software from Iglesias et al. (2015) that uses Bayesian inference to apply a manually labeled hippocampal atlas to MRI images. The first author, blind to participant income group, manually checked all hippocampal segmentations. At the time of analysis, this software was only available for segmentation of the hippocampus, so the first author, blind to participant income, manually edited each caudate volume from FreeSurfer 5.3's automated subcortical segmentation. Although FreeSurfer 5.3 does not have highly accurate subcortical parcellations, its cortical parcellations are well-validated (Klein et al., 2010). Therefore, DLPFC volumes were taken from FreeSurfer 5.3 parcellations (Fischl et al., 2002, 2004). Structural analyses controlled for sex because brain anatomy has been shown to differ by sex (e.g., Lenroot et al., 2007).

4.3 Results

4.3.1 Memory Performance

Both the procedural memory learning score (the difference between the proportion of trials on which the optimal response was chosen on the last 25 trials vs. the first 25 trials) and the count span score were Z -scored so that they could be compared statistically. A repeated

measures analysis of variance (ANOVA) revealed a significant SES group by task interaction ($F(1, 97) = 5.00, p = 0.03, \eta^2 = 0.05$), a main effect of SES ($F(1, 97) = 5.35, p = 0.02, \eta^2 = 0.05$), but no main effect of task ($F(1, 97) = 0.003, p = 0.96, \eta^2 = 0$). Planned *post-hoc* linear model group comparisons showed that the lower-SES group and higher-SES group did not significantly differ on their procedural memory learning score (lower-SES: $M = 0.08, SD = 0.22$; higher-SES: $M = 0.06, SD = 0.19$; $b = 0.02, t(44) = 0.31, p = 0.76, r^2 = -0.04, 95\% \text{ CI } [-0.11, 0.14]$; Figure 4.1A). Further, a repeated measures ANOVA on optimal performance over the four epochs (25 trials per epoch) showed a significant main effect of epoch, demonstrating learning during the probabilistic classification task ($F(3, 135) = 3.42, p = 0.02, \eta^2 = 0.07$), but no significant main effects of SES group ($F(1, 44) = 0.36, p = 0.55, \eta^2 = 0.008$), and no epoch by SES interaction ($F(3, 135) = 0.18, p = 0.91, \eta^2 = 0.003$).

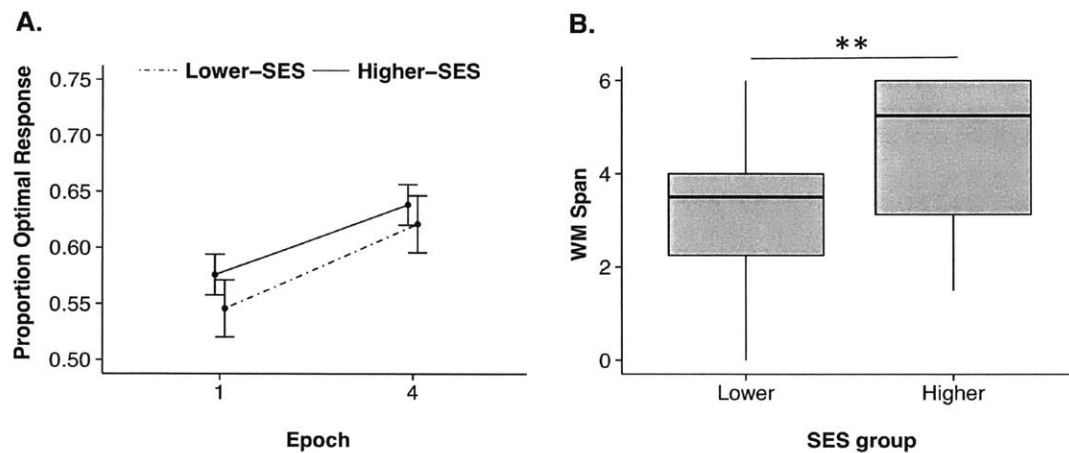


Figure 4.1. Probabilistic classification and working memory performances for lower-SES and higher-SES groups. (A) Learning on the probabilistic classification task shown through improved accuracy from the first 25 trials, epoch 1, to the last 25 trials, epoch 4. Error bars corrected for within subjects design. (B) Working memory (WM) span by SES group; ** $p < 0.01$.

Data from the count span task were not normally distributed (Shapiro–Wilk test $p < 0.05$), so we performed a Kruskal–Wallis H-test. Planned *post-hoc* analyses showed that working memory capacity was significantly smaller in the lower-SES than the higher-SES group (lower-SES: Median = 3.50; higher-SES: Median = 5.25; $\chi^2(1) = 8.72, p = 0.003$; Figure 4.1B).

4.3.2 Neuroanatomical Volumes

Volume data were Z-scored to account for large differences in volume across the hippocampus, caudate, and DLPFC, so that they could be statistically compared. A repeated measures ANOVA on volume showed a main effect of SES ($F(1, 335) = 50.09, p < 0.001, \eta^2 = 0.42$), region ($F(1, 335) = 3.77, p = 0.02, \eta^2 = 0.06$), and an SES by region interaction ($F(1, 335) = 7.14, p < 0.001, \eta^2 = 0.12$). Planned *post-hoc* t-tests were conducted on each region by SES group. Neither right nor left caudate volumes differed significantly between the SES groups (Right: $b = 42.47, t(55) = 0.30, p = 0.77, r^2 = 0.01, 95\% \text{ CI } [-242.61, 327.55]$; Left: $b = 83.92, t(55) = 0.57, p = 0.57, r^2 = 0.03, 95\% \text{ CI } [-212.82, 380.67]$). Both left and right hippocampus volumes were significantly smaller in the lower-SES group than the higher-SES group (Right: $b = 242.80, t(55) = 2.57, p = 0.01, r^2 = 0.19, 95\% \text{ CI } [53.25, 432.35]$; Left: $b = 216.31, t(55) = 2.64, p = 0.01, r^2 = 0.23, 95\% \text{ CI } [52.16, 380.45]$). Further, both left and right DLPFC volumes were significantly smaller in the lower-SES group than the higher-SES group (Right: $b = 2359.54, t(55) = 3.80, p < 0.001, r^2 = 0.48, 95\% \text{ CI } [1116.12, 3602.96]$; Left: $b = 1379.20, t(55) = 2.15, p = 0.04, r^2 = 0.33, 95\% \text{ CI } [94.81, 2663.55]$; Figure 4.2). This same pattern held within the subset of participants who completed both the declarative and procedural tasks (Right caudate: $b = 28.54, t(44) = 0.19, p = 0.84, r^2 = 0.03, 95\% \text{ CI } [-270.57, 327.65]$; Left caudate: $b = 79.69, t(44) = 0.52, p = 0.61, r^2 = 0.06, 95\% \text{ CI } [-231.18, 390.55]$; Right

hippocampus: $b = 224.87$, $t(44) = 2.13$, $p = 0.04$, $r^2 = 0.18$, 95% CI [12.05, 437.69]; Left hippocampus: $b = 234.64$, $t(44) = 2.56$, $p = 0.01$, $r^2 = 0.25$, 95% CI [50.19, 419.08]; Right DLPFC: $b = 2121.65$, $t(44) = 3.63$, $p < 0.001$, $r^2 = 0.59$, 95% CI [943.74, 3299.56]; Left DLPFC: $b = 1216.30$, $t(44) = 2.24$, $p = 0.03$, $r^2 = 0.53$, 95% CI [112.63, 2310.00]).

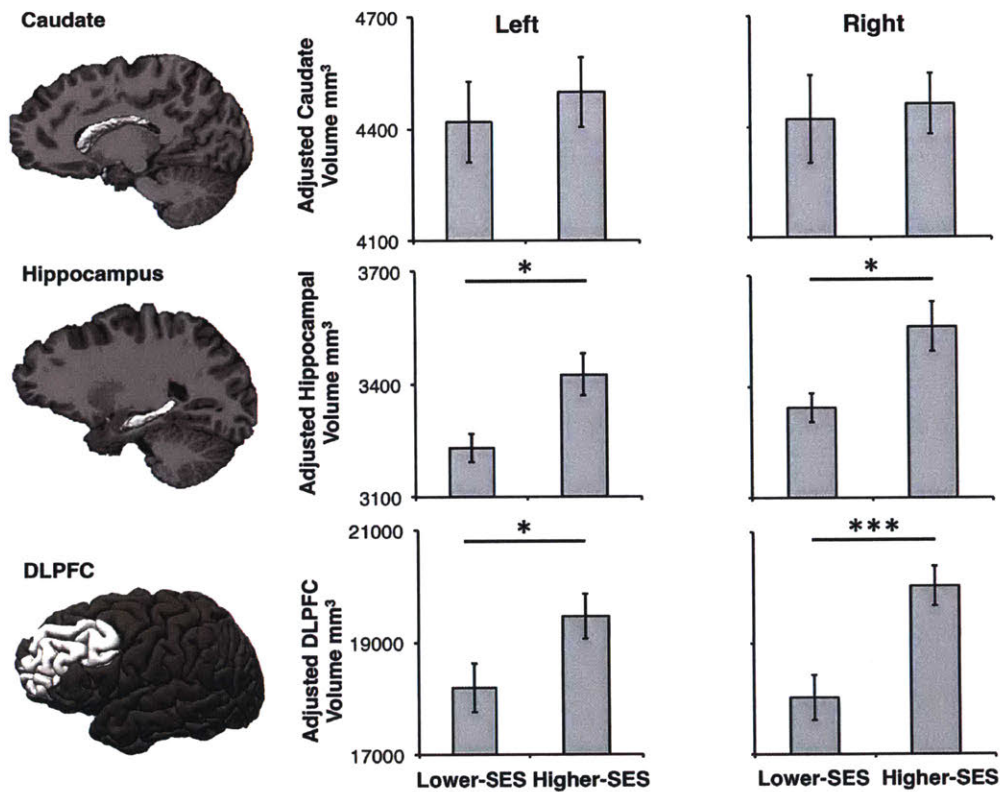


Figure 4.2. Caudate, hippocampus, and DLPFC volumes in lower-SES and higher-SES groups. All volumes are adjusted for sex. Error bars represent standard error; * $p < 0.05$; *** $p < 0.001$

Exploratory analyses examined the relations between each ROI volume and behavioral performance on the procedural and working memory task within each SES-group. Within the higher-SES group, greater right hippocampal volume predicted greater working memory ($b = 0.001$, $t(31) = 2.10$, $p = 0.04$, $r^2 = 0.08$, 95% CI [0.00004, 0.003]), and smaller left caudate

volume predicted greater procedural memory learning ($b = -0.0002$, $t(25) = -2.38$, $p = 0.03$, $r^2 = 0.14$, 95% CI $[-0.0003, -0.00002]$). Within the lower-SES group, smaller left DLPFC volume predicted greater procedural memory learning ($b = -0.00007$, $t(25) = -2.80$, $p = 0.01$, $r^2 = 0.37$, 95% CI $[-0.0001, -0.00002]$). No models reached significance after FDR correction for the 12 comparisons made within each SES group.

4.4 Discussion

SES was differentially associated with the behavioral and neural correlates of working and procedural memory. Lower-SES adolescents had worse working memory (reduced complex working memory span), but equivalent procedural memory (probabilistic classification learning) compared to the higher-SES adolescents. This behavioral disparity was reflected in the neural structures supporting these memory systems: hippocampal and DLPFC volumes (critical for working memory) were larger in higher-SES adolescents, whereas caudate volumes (critical for procedural memory) did not differ between the groups. This is the first study to show that SES selectively affects hippocampal-prefrontal-dependent working memory, while not affecting striatal-dependent procedural memory.

The findings that lower-SES was associated with reduced working memory and reduced hippocampal and DLPFC volumes are consistent with prior studies. Lower-SES has been associated with worse working memory (Herrmann and Guadagno, 1997; Farah et al., 2006; Noble et al., 2007; Evans and Schamberg, 2009; Sarsour et al., 2011; Hackman et al., 2015), smaller hippocampal volumes (Hanson et al., 2011; Noble et al., 2012, 2015), and smaller DLPFC volumes (Lawson et al., 2013; Mackey et al., 2015; Noble et al., 2015).

The same MRI data were examined in a whole-brain analysis relating cortical thickness to the income-achievement gap (Mackey et al., 2015), but that study did not examine subcortical volumes or specific memory abilities. Mackey et al. (2015) found that the higher-SES adolescents had higher scores on statewide tests of academic achievement and greater cortical thickness in all lobes of the brain than the lower-SES adolescents. The differences in cortical thickness by SES accounted for almost half of the income-achievement gap. The current study extends the prior findings by showing that SES does not have a global influence on brain and behavior, but rather affects some structures and functions more than others.

One potential explanation for the selective effect of SES on working vs. procedural memory is the differential developmental course of these two memory systems. Working memory develops slowly, continuing to mature into young adulthood (Hale et al., 1997; Gathercole, 1999; Klingberg et al., 2002). This slow development may render the neural systems underlying working memory susceptible to environmental influences, such as the chaotic home environment and poor school quality often associated with lower-SES (Evans, 2004). Procedural memory, on the other hand, develops early (Meulemans et al., 1998; Thomas and Nelson, 2001; Amso and Davidow, 2012). Indeed, 10-year-olds have shown adult-like learning on the probabilistic classification task despite lower levels of performance than adults on measures of complex working memory capacity and declarative memory (Finn et al., 2016). This early development may render the neural systems underlying procedural memory less vulnerable to environmental influences. Thus, SES may not have the same negative impact on procedural memory as it does on working memory due to the differential rate of maturation of these two memory systems.

Another possible explanation of the selective effect of SES on working vs. procedural memory is the association between lower-SES and higher exposure to stress (Baum et al., 1999; Lupien et al., 2001; Chen et al., 2006; McEwen and Tucker, 2011; although we did not measure stress). Both human and animal research have shown that stress negatively impacts the hippocampus and DLPFC (Sapolsky, 1996; Kim and Yoon, 1998; Arnsten, 2009). Indeed, chronic stress in rodents actually enhances the use of signal-response striatal learning and increases neuronal growth in dorsolateral striatum, imperative for habit formation (Kim et al., 2001; Dias-Ferreira et al., 2009; Schwabe and Wolf, 2013). Thus, stress may selectively impair hippocampus and PFC but spare striatal structure and function.

This differential effect of stress on particular brain regions may be especially meaningful for probabilistic classification task performance. Neuroimaging indicates that the probabilistic classification task engages both MTL and striatal systems in a competing fashion (Poldrack et al., 1999, 2001; Foerde et al., 2006). Both rodent and human studies have shown that stress biases learning to be caudate-based rather than hippocampal-based (Kim et al., 2001; Schwabe and Wolf, 2013). For probabilistic classification in particular, neuroimaging indicates that in experimentally stressed participants, learning on this task is correlated with caudate activation, while in non-stressed participants, learning is correlated with hippocampal activation. Strikingly, overall learning was equivalent in both groups (Schwabe and Wolf, 2012). Thus, it is possible that effective caudate-based procedural learning was available to all participants in our study regardless of differential exposure to stress in the two groups.

Although there is compelling lesion evidence that striatum-dependent procedural memory is dissociable from declarative memory in general, and for probabilistic classification in particular (Knowlton et al., 1996), there are many ways in which the DLPFC-MTL and striatal

memory systems interact. In regards to working memory, the striatum appears to play a role because patients with striatal dysfunction due to Parkinson's disease have reduced complex working memory capacity (Gabrieli et al., 1996). Further, there is evidence that the basal ganglia play a distinctive role in working memory relative to DLPFC (Awh and Vogel, 2008; McNab and Klingberg, 2008; Voytek and Knight, 2010).

In terms of the probabilistic-learning measure of procedural memory, both MTL and striatal systems appear to be engaged in different ways. In one study, amnesic patients showed intact early learning, but reduced later learning (Knowlton et al., 1994), suggesting that over time learning may shift from a procedural-striatal basis to a declarative-MTL basis. Functional neuroimaging has also shown that probabilistic learning engages both striatal and MTL systems, but indicates that striatal activation is tightly linked to feedback-based learning (Poldrack et al., 1999, 2001; Seger and Cincotta, 2005), whereas MTL activation is related to paired-association learning (Poldrack et al., 2001). This distinction is supported by evidence from lesion studies where Parkinson's patients perform well on a non-feedback based version of the probabilistic classification task (Shohamy et al., 2004) and hypoxic amnesic patients, with specific damage to the hippocampus, showed impaired learning on the feedback based version of this task (Hopkins et al., 2004).

Although the lesion literature provides a conceptual framework for how separable neural systems support different kinds of learning, the influence of a higher- or lower-income environment on both brain and behavior is quite different from a neurological disease. The patient literature involves acute or late-onset degenerative lesions that often affect most of a particular brain region. SES in childhood involves the more subtle development of multiple neural circuits. Thus, although lower-SES adolescents have reduced working memory scores and

MTL and DLPFC volumes relative to higher-SES adolescents, they have substantial memory abilities that are far higher than those of amnesic patients. Consequently, lower-SES adolescents can utilize significant declarative and working memory abilities to support learning, including probabilistic learning. Furthermore, there may be interactions between striatal regions and MTL and DLPFC across development. Studies examining a broader age range could examine such developmental interactions among SES, brain volumes, and learning abilities.

The current study has some limitations. First, we report null results, showing a lack of differences in probabilistic classification learning or caudate volumes between SES groups (although this problem has applied to all examples of spared learning in patients with brain lesions). For the procedural learning, this concern is mitigated by the fact that the lower-SES group showed slightly better (although not significant) learning than the higher-SES group. For the brain measures, there were significantly reduced DLPFC and hippocampal volumes in the lower-SES group, but the caudate volumes were also somewhat (albeit non-significantly) smaller in the lower-SES group. Further studies should probe this result in a larger sample. Second, the current study lacked brain volume–behavior relationships. This could be due to small sample sizes within each SES group and should be explored in future studies with larger samples. Third, the current study only explored one measure of procedural memory, but there are multiple kinds of procedural memory that depend on a range of neural structures outside of the striatum, such as cerebellum and other neocortical regions (Gabrieli, 1998). Thus, future studies should probe the range and limits of procedural learning broadly that are unaffected by SES. Fourth, although the complex working memory measure has the advantage of being sensitive to both DLPFC and MTL integrity, a future study could employ separate measures of working memory and conventional declarative memory (delayed recall and recognition without additional cognitive

demands). Finally, we lacked measures of stress in our participants, which precludes direct evidence that stress was a critical mechanism underlying the dissociation between different forms of memory as opposed to other factors, such as environmental enrichment, that are also correlated with SES.

Knowledge of the scope and limits of memory abilities in lower-SES adolescents could be of interest for two reasons. First, such knowledge could suggest how environmental variables differentially influence the development of specific memory systems. Second, there is concern about the growing income-achievement gap, the difference in academic achievement between students from higher- and lower-income backgrounds (Reardon, 2011). The findings here raise the possibility that SES may not impair procedural learning, and such learning may be an important resource for individuals from lower-SES backgrounds. At the same time, much of education is targeted toward the accumulation of knowledge that is supported by hippocampal-declarative systems, so it is unclear as to how much a potentially unaffected striatal-procedural system could support school learning.

Perhaps valuable interventions would be those that could enhance hippocampal volume and declarative memory. Although no study has shown hippocampal volume growth in an educational intervention with children, studies of exercise have provided evidence for plasticity in hippocampal volume and declarative memory processes most associated with the hippocampus (relational memory; Cohen and Eichenbaum, 1993; Davachi, 2006). In older adults, an aerobic exercise intervention increased hippocampal volume (Erickson et al., 2011). In children, greater aerobic fitness has been associated with better relational memory (Chaddock et al., 2011) and larger hippocampal volume (Chaddock et al., 2010), and an aerobic fitness intervention enhanced relational memory (Monti et al., 2012). Thus, hippocampal plasticity in

children may arise from effective educational interventions. Future research may reveal whether the enhancement of education in lower-SES children is best achieved by exploiting the strengths of their striatal-dependent procedural memory, ameliorating the weaknesses of their hippocampal-dependent working memory, or both.

Chapter 5

The neural correlates of reasoning differ by socioeconomic status in development

Abstract

Although lower socioeconomic status (SES) is generally negatively associated with performance on cognitive assessments, some children from lower-SES backgrounds perform as well as their peers from higher-SES backgrounds. Yet little research has examined whether the neural correlates of individual differences in cognition vary by SES. The current study explored whether relationships between cortical structure and fluid reasoning differ by SES in early childhood. Fluid reasoning, a non-verbal component of IQ, is supported by a distributed frontoparietal network, with evidence for a specific role of rostrolateral prefrontal cortex (RLPFC). In a sample of 115 4-7 year olds, bilateral thickness of RLPFC differentially related to reasoning by SES: thicker bilateral RLPFC positively correlated with reasoning ability in children from lower-SES backgrounds, but not in children from higher-SES backgrounds. This result replicated in an independent sample of 59 12-16 year olds. Furthermore, young children from lower-SES backgrounds with strong reasoning skills showed a unique developmental time course of RLPFC: they were the only group to show a positive relationship between RLPFC thickness and age. In sum, we found that relationships between cortical thickness and cognition differ by SES during development.

5.1 Introduction

The gap in academic achievement between children from higher- and lower-socioeconomic status (SES) backgrounds is present early in childhood, even before children enter school (Duncan & Magnuson, 2011). However, some children from lower-SES backgrounds have strong cognitive skills and excel in school, performing just as well as or better than their peers from higher-SES backgrounds (Borman & Overman, 2004; Masten, 2001; Waxman, Gray, & Padron, 2003; Werner & Smith, 2001). Understanding neural correlates of cognition in young children from lower-SES backgrounds could help elucidate how the environment influences brain-behavior relationships, and, ultimately, set targets for early interventions. Research on brain-behavior correlations, and on brain development more generally (LeWinn, Sheridan, Keyes, Hamilton, & McLaughlin, 2017), has often implicitly assumed that such correlations are generalizable across SES. However, an evolutionary-developmental perspective suggests that variation in early experience may lead to specific neural and cognitive adaptations to fit these environments (Ellis, Bianchi, Griskevicius, & Frankenhuis, 2017). By this view, optimal brain-behavior development may differ across SES. Here, we aimed to test whether cognition in children from lower-SES environments is supported by different patterns of neural structure than cognition in children from higher-SES backgrounds.

Many studies linking neural structure to cognition have focused on full-scale IQ. Full-scale IQ is composed of two components: verbal IQ and performance IQ. Verbal IQ relies on crystallized knowledge, such as vocabulary. Performance IQ includes visuospatial skills, working memory, processing speed, and fluid reasoning, and is less dependent on prior knowledge (Cattell, 1943). In adults, higher IQ is related to thicker cortex in rostralateral prefrontal cortex (RLPFC), and in posterior temporal and visual areas (Choi et al., 2008; Narr et

al., 2007). Two developmental studies have found results that are consistent with this adult pattern (9-24 year olds in Menary et al., 2013; 6-18 year olds in Karama et al., 2009). However, two other developmental studies have shown the reverse pattern, with thinner cortex being associated with superior performance. Thinner parietal cortices related to better performance on verbal and non-verbal cognitive measures in 12-14 year olds (Squeglia, Jacobus, Sorg, Jernigan, & Tapert, 2013) and globally thinner cortex related to higher IQ between the ages of 10-20 (Schnack et al., 2015). Inconsistencies in associations between cortical thickness and IQ could be due to factors including methodological differences, data quality, and demographics of the sample, such as age and SES.

Longitudinal studies have shown that the trajectory of cortical development, rather than thickness at a single time point, best relates to IQ (Schnack et al., 2015; Shaw et al., 2006). Individuals with higher IQs show greater changes in cortical thickness across the lifespan: greater cortical thickening from age 7 until age 12 and then greater thinning until age 25. In contrast, individuals with lower IQs show consistent thinning throughout the lifespan. However, it is currently unknown how cortical thickness changes relate to cognition before age 7 and how this relationship varies by SES.

Lower-SES has been related to reduced gray matter volume, surface area, thickness, and in turn, lower cognitive skills (Farah, 2017). The relationship between cortical thickness and SES varies by age: thickness-SES relationships are small in early childhood, grow in adolescence, then narrow again in adulthood (Piccolo et al., 2016). However, the diversity of brain structure and cognitive performance *within* lower-SES students is poorly understood. One study found that SES moderates relationships between cortical thickness and cognition: In children with thicker cortex, SES correlated positively with executive function, and in children with thinner cortex,

SES correlated positively with language abilities (Brito, Piccolo, Noble, & Pediatric Imaging, Neurocognition, and Genetics Study, 2017). Yet differences in cortical thickness, averaged across the whole brain, do not provide a mechanistic account for how specific brain regions support cognition differentially by SES. Furthermore, as this study was conducted in a large age range (3-18), it leaves open the question of whether SES differences in brain-behavior relationships differ by age.

In the current study, we focused on fluid reasoning, a component of performance IQ that is highly correlated with academic performance (Ferrer & McArdle, 2004; Floyd, Evans, & McGrew, 2003; Fuchs et al., 2006) and differs by SES (Finn et al., 2016; Platt et al., 2018). Fluid reasoning, commonly measured by matrix reasoning tests (Raven, 1965), has been well-characterized from a neural perspective: it relies on a distributed frontoparietal network, with RLPFC playing a specific role in relational reasoning (Bunge, Helskog, & Wendelken, 2009; Christoff et al., 2001; Crone et al., 2009; Dumontheil 2014; Wendelken, Chung, & Bunge, 2012; Wendelken, Ferrer, Whitaker, & Bunge, 2016; Wendelken, O'Hare, Whitaker, Ferrer, & Bunge, 2011). We asked whether relationships between fluid reasoning and cortical structure differed by SES in early childhood. Due to the exploratory nature of this analysis, we aimed to replicate our results in an independent sample of adolescents. Given evidence that the rate of thinning, rather than static thickness, relates to cognition, we also explored whether associations between cortical thickness and age differed by SES and reasoning ability. To our knowledge, this is the first study to examine whether relationships between brain structure and reasoning differ by SES during development.

5.2 Methods

This study was approved by the Committee on the Use of Humans as Experimental Subjects at the Massachusetts Institute of Technology (MIT). Participants under the age of seven provided verbal assent, and participants older than seven provided written assent. All parents provided written consent.

5.2.1 Participants

5.2.1.1 *Early Childhood Sample (ECS)*

Children were recruited from the Greater Boston Area as part of two larger studies: one on executive function development and the other exploring a parenting intervention (only data prior to the intervention were included). Recruitment for the executive function study occurred through postings on parent forums, magazine ads, community family events, and Head Start programs. Recruitment for the intervention study occurred mainly through charter schools. Across both studies, a total of 130 children underwent structural imaging. In screening interviews for both studies, parents reported whether their children were born prematurely or had medically diagnosed neurological or psychiatric disorders. Children were excluded from analysis if they had a medical diagnosis ($n = 8$), excessive motion artifacts ($n = 6$; see Structural Imaging Analysis) or missing information on maternal education ($n = 1$). The final sample consisted of 115 children (56 female, mean age (SD) = 5.85(0.96), age range: 4-7 years).

5.2.1.2 *Adolescent Sample (AS)*

Adolescents were recruited from the Greater Boston Area as part of a larger study exploring SES, brain development, and educational outcomes. Analyses of subsets of this dataset

have been published previously (Finn et al., 2016; Leonard, Mackey, Finn, & Gabrieli, 2015; Mackey et al., 2015). Participants ($n = 91$ in total) were excluded in the current analysis if they didn't complete a structural scan ($n = 7$), have complete data on matrix reasoning ($n = 2$), or data reported on maternal education ($n = 23$). The final sample consisted of 59 adolescents (28 female, mean age (SD) = 14.44(0.55), age range: 12-16 years).

5.2.2 Matrix reasoning

The early childhood sample completed the Matrix Reasoning subscale of the Wechsler Preschool and Primary Scale of Intelligence (WPPSI-IV; Wechsler, 1967). Children in the executive function study completed testing in a quiet room, while most of the children in the intervention study completed testing in school settings. Matrix reasoning did not differ by study (Standard score: $t(112) = 1.24, p = .219$). One child was missing an age-adjusted standard score due to being older than the WPPSI age norms (limit is 7.58 years, child was 7.92 years). Matrix reasoning raw scores were used in brain imaging analyses, which control for age.

The adolescent sample completed the Test of Nonverbal Intelligence (Version B, (Brown, Sherbenou, & Johnsen, 2010)) which measures matrix reasoning ability. Raw scores were used in brain analyses, which control for age.

5.2.3 Socioeconomic status

SES was operationalized as the highest level of maternal education in years, a measure that is more stable than income and a better index of children's cognitive environments (Davis-Kean, 2005; ECS: $M(SD) = 15.47 (2.91)$; AS: $M(SD) = 15.42 (3.24)$). For some analyses, children were split into two groups: children whose mothers did not complete college, referred to

throughout as the Lower-SES group (ECS: $n = 52$, 24 F; AS: $n = 25$, 12 F), and children whose mothers did complete college, referred to as the Higher-SES group ($n = 63$, 29 F; Adolescent sample: $n = 34$, 16 F). These groups did not differ in age or gender (ECS age: $t(113) = -0.16$, $p = .877$; Gender: $\chi^2(1, n = 115) = 0.03$, $p = .863$; AS age: $t(57) = -1.03$, $p = .307$; Gender: $\chi^2(1, n = 59) = 0.04$, $p = .841$).

5.2.4 Neuroimaging data acquisition

Data were acquired at the Athinoula A. Martinos Imaging Center at MIT. Before the MRI, participants acclimated to the scanning environment and practiced staying still by undergoing a ‘mock scan’. Scanning was performed using a Siemens MAGNETOM Trio Tim 3T MRI scanner with a 32 channel coil. A whole-brain, high-resolution, T1-weighted multi-echo structural scan (MPRAGE) was collected (ECS acquisition parameters: TR = 2530 ms, TE = 1.64 ms/3.5 ms/5.36 ms/7.22 ms, flip angle = 7° , voxel size = 1 mm isotropic, matrix size = 192 x 192, 176 sagittal slices, FOV = 192 mm; AS: TR = 2530 ms; TE = 1.64 ms/3.44 ms/5.24 ms/7.04 ms; flip angle = 7° ; resolution = 1 mm isotropic). This sequence was optimized for participants with high motion (Tisdall et al., 2012).

5.2.5 Structural imaging analyses

Trained coders who were blind to participant information visually inspected structural images for quality on a scale of 1 (highest quality) to 4 (lowest quality) based on a visual guide of artifacts associated with motion. If ratings differed by 1 point or more, a third coder made a final decision. For the early childhood sample, ratings were Z-scored within study (Executive function $M(SD) = 2.55 (0.82)$; Intervention $M(SD) = 2.05 (0.58)$). Ratings did not significantly

relate to maternal education (ECS: $r(113) = -.00, p = .971$; AS: $r(57) = .04, p = .737$), matrix reasoning (ECS: $b = -0.04, 95\% \text{ CI } [-0.09, 0.00], t(112) = -1.82, p = .072$; AS: $b = 0.00, 95\% \text{ CI } [-0.01, 0.02], t(56) = 0.37, p = .715$; models control for age), or matrix reasoning by maternal education in an interaction (ECS: $b = 0.01, 95\% \text{ CI } [-0.01, 0.02], t(110) = 0.74, p = .459$; AS: $b = 0.00, 95\% \text{ CI } [0.00, 0.01], t(54) = 1.03, p = .305$; model controls for age). All models with brain data control for quality rating.

Structural analyses were conducted in FreeSurfer Version 5.3 (Fischl et al., 2002, 2004). Surfaces were edited as needed, and final surfaces were checked by a blind coder. Six children in the early childhood sample were excluded for low image quality resulting in inaccurate surfaces. Each participant's surface was resampled to a standard brain (fsaverage) and smoothed with a 15-mm full-width half-maximum kernel.

A general linear model was constructed to test for an interaction between maternal education and matrix reasoning on cortical thickness, defined as the distance between the white matter and pial surface at each cortex location (Fischl & Dale, 2000). We ran whole-brain analyses relating cortical thickness to matrix reasoning within the low- and high-SES subgroups (controlling for maternal education). Main effects of maternal education, matrix reasoning, and age on cortical thickness were evaluated separately. All analyses controlled for age (except for the main effect analysis of age), gender, study, and image quality. Whole-brain analyses were cluster-corrected for multiple comparisons using Monte Carlo simulation (cluster-wise $p < .05$, adjusted for both hemispheres; Hagler, Saygin, & Sereno, 2006). A cluster-forming threshold was set to $p < .005$ (Greve & Fischl, 2017). For full transparency of how effects change across thresholds, results are shown at multiple cluster-forming thresholds.

We ran three-way interaction models with age, maternal education, and matrix reasoning on thickness in left and right rostral middle frontal gyrus (RMFG), the anatomical location of RLPG, based on an automated gyral-based parcellation from FreeSurfer (Desikan et al., 2006). These regions were selected based on the whole-brain interaction results between maternal education and matrix reasoning. For post-hoc linear models, we split the data into four groups: first based on SES, and then again within SES groups based on median matrix reasoning scores.

Finally, given the exploratory nature of our analyses, we aimed to replicate our results in an independent sample of 59 adolescents. Due to the smaller size of the replication sample, we focused our analyses on *a priori* regions of interest identified in the early childhood sample: left and right RMFG (as defined above). In these regions, we tested for correlations between thickness and matrix reasoning within lower- and higher-SES groups. We also tested for main effects of age, matrix reasoning, and maternal education, as well as for a 3-way interaction amongst age, maternal education, and matrix reasoning.

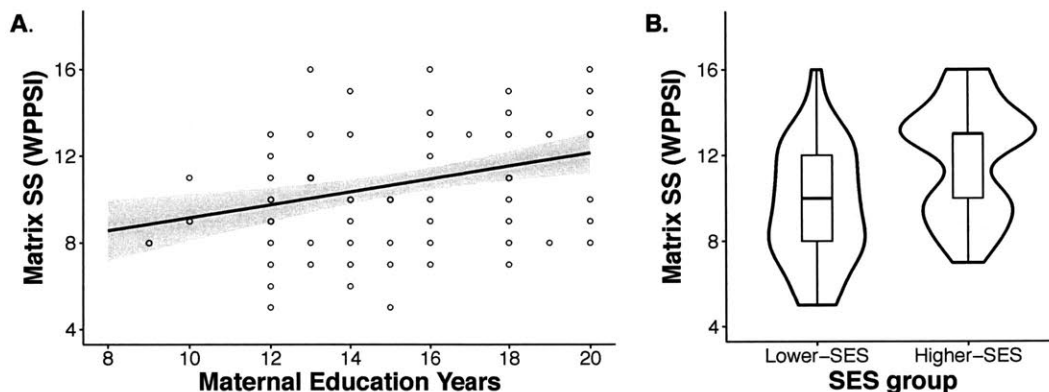
5.3 Results

5.3.1 Early childhood sample

Maternal education positively correlated with matrix reasoning scores ($r(112) = .31$, $p = .001$; Figure 5.1A). Splitting the sample into two groups based on maternal education (< 16 years or ≥ 16 years) revealed high variability within group (Figure 5.1B), and a significant mean difference between groups ($t(112) = -4.45$, $p < .001$). Matrix reasoning was positively related to right lateral occipital cortex thickness, and age was negatively related to left pericalcarine thickness (Figure 5.2). There were no main effects of maternal education on

cortical thickness at the cluster-forming threshold of $p < .005$ (for more lenient thresholds, see Figure 5.2).

Early Childhood Sample



Adolescent Sample

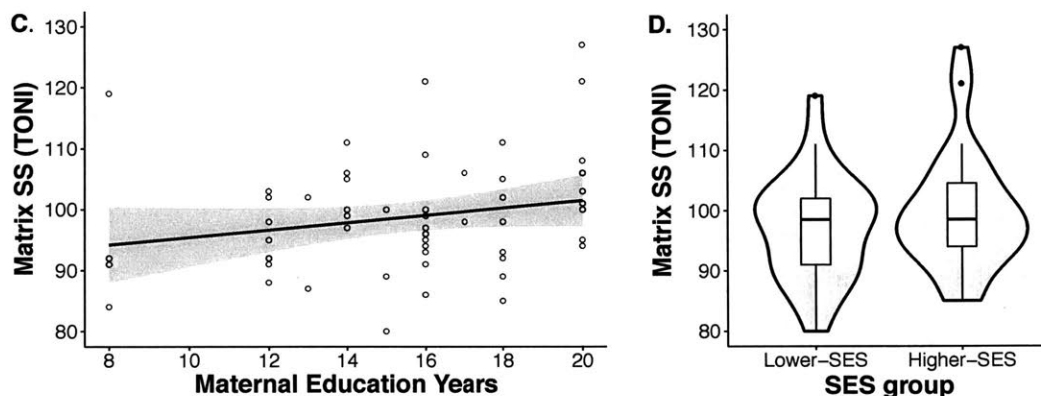


Figure 5.1. Maternal Education correlated with Matrix Reasoning standard score (SS) in the early childhood sample and adolescent sample. Matrix reasoning was measured using the *Wechsler Preschool and Primary Scale of Intelligence (WPPSI)* matrix reasoning subtest in the early childhood sample and the *Test of Nonverbal Intelligence (TONI)* in the adolescent sample. A. Maternal education in years correlated with matrix reasoning age-normed standard score in the early childhood sample (Matrix SS) ($r(112) = .31, p = .001$). B. Matrix SS differed by SES group in the early childhood sample (Lower-SES: maternal education < 16 years, Higher-SES: maternal education ≥ 16 years) ($t(112) = -4.45, p < .001$). C. There was a positive trend between maternal education and matrix reasoning standard score in the adolescent sample ($r(57) = .24, p = .071$). D. Matrix SS did not differ by SES group in the adolescent sample ($t(57) = 1.33, p = .189$).

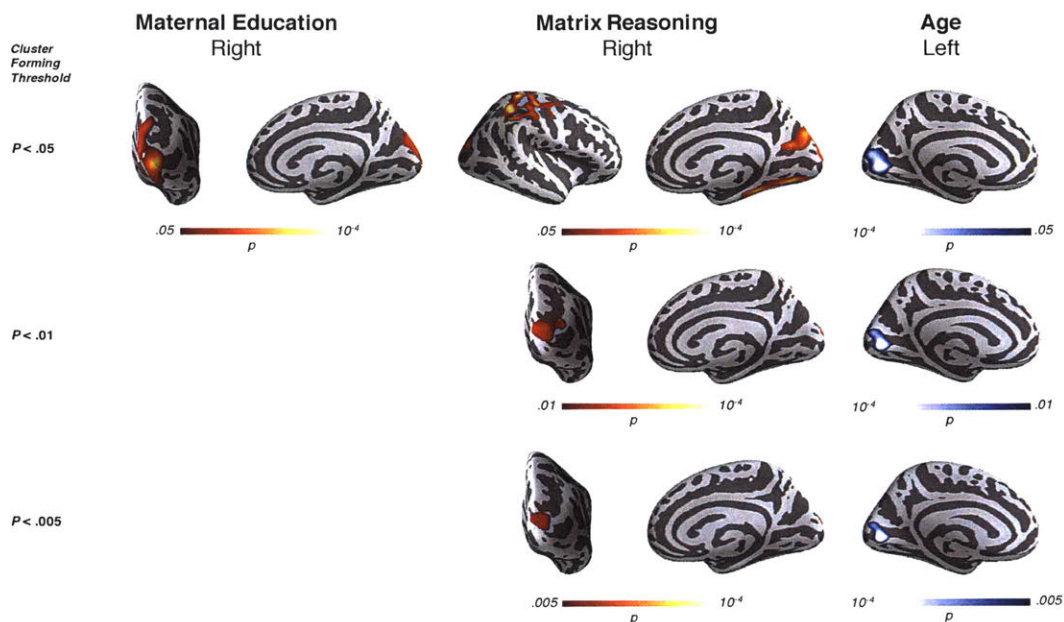


Figure 5.2. Main effects of maternal education, matrix reasoning, and age on cortical thickness in the early childhood sample. Age, gender, image quality, and study were included as covariates in all models (age was not a covariate in the model of age). Results were cluster corrected for multiple comparisons using Monte Carlo simulations and are shown here at cluster-forming $p < .05$, $.01$, and $.005$ (cluster-wise $p < .05$, adjusted for both hemispheres).

There was a significant interaction between maternal education and matrix reasoning on cortical thickness in RLPFC (Figure 5.3). To understand whether the interaction was driven by the higher- or lower-SES group, we extracted parameter estimates from the two significant clusters (left and right RLPFC). The relationships between thickness in both clusters and matrix reasoning were positive and significant only in the lower-SES group (L RLPFC: $b = 0.02$, 95% CI [0.00, 0.03], $t(46) = 2.90$, $p = .006$; R RLPFC: $b = 0.02$, 95% CI [0.01, 0.03], $t(46) = 3.53$, $p = .001$). In the higher-SES group, relationships between RLPFC thickness and matrix reasoning were not significant (L RLPFC: $b = 0.00$, 95% CI [-0.01, 0.01], $t(57) = -0.51$, $p = .609$; R RLPFC: $b = -0.01$, 95% CI [-0.01, 0.00], $t(57) = -1.19$, $p = .239$). Within the

lower-SES group, reasoning was positively related to cortical thickness in right cuneus and bilateral RLPFC thickness ($p < .01$, Figure 5.4). No relationships between reasoning and cortical thickness were observed in the higher-SES group.

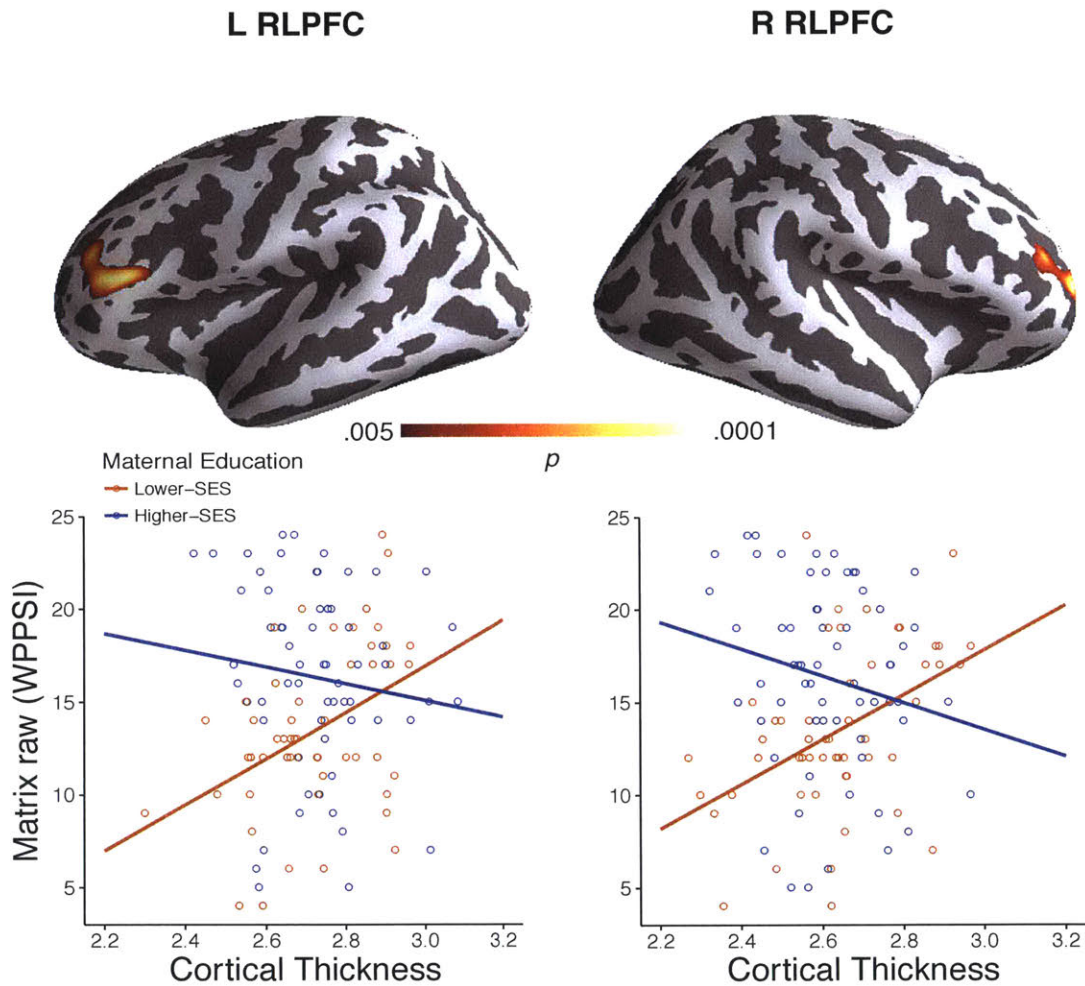


Figure 5.3. Interaction between matrix reasoning and maternal education on cortical thickness in the early childhood sample. Age, gender, image quality, and study were included as covariates. Results were cluster corrected for multiple comparisons using Monte Carlo simulations (cluster-forming $p < .005$, cluster-wise $p < .05$, adjusted for both hemispheres). Scatterplots show interaction results with extracted parameter estimates (adjusted for covariates and referred to as “std. residuals”) in right and left rostrolateral prefrontal cortex (RLPFC). Matrix reasoning was measured with the *Wechsler Preschool and Primary Scale of Intelligence* (WPPSI). Maternal education is plotted as a binary variable for display purposes only (Lower-SES group, orange: maternal education < 16 years, Higher-SES group, blue: maternal education ≥ 16 years).

Lower-SES: Matrix Reasoning

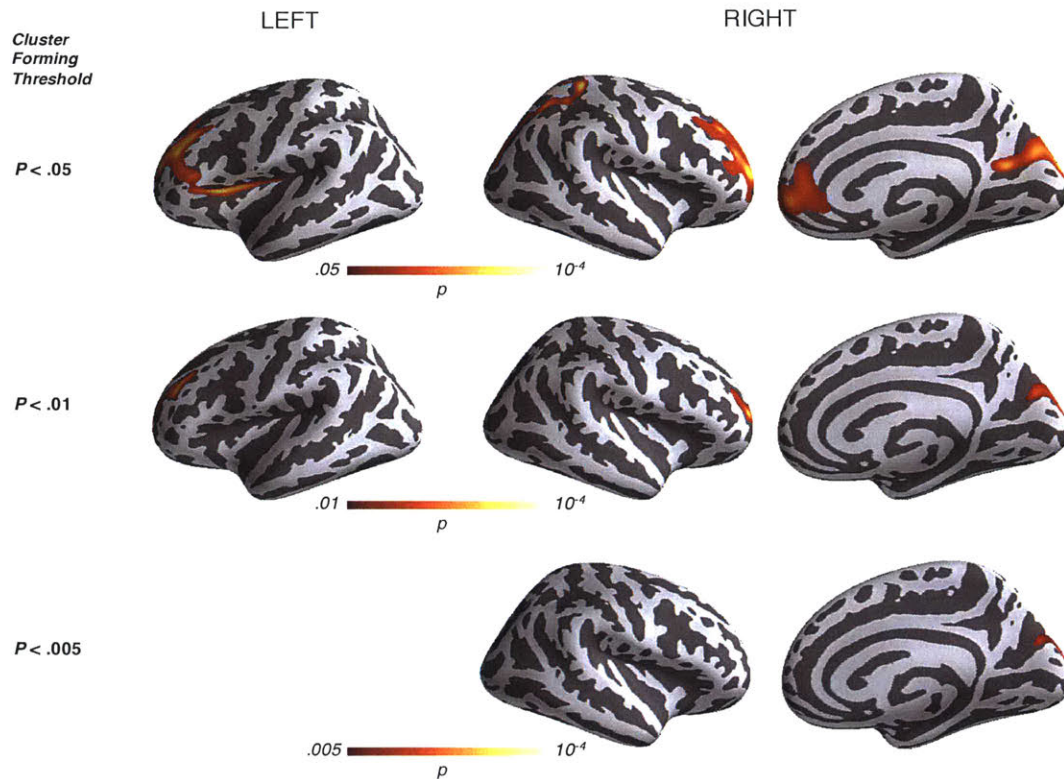


Figure 5.4. Matrix reasoning and cortical thickness in the lower-SES group in the early childhood sample. Age, gender, image quality, maternal education, and study were included as covariates. Results were cluster corrected for multiple comparisons using Monte Carlo simulations (cluster-forming $p < .05$, $.01$, and $.005$, cluster-wise $p < .05$, adjusted for both hemispheres). Results were non-significant in the higher-SES group.

To test whether relationships between RLPFC thickness and age differed by SES and reasoning ability, we ran age X maternal education X matrix reasoning interactions on cortical thickness in anatomically-defined bilateral rostral middle frontal gyrus (RMFG). The 3-way interaction was significant for left RMFG (Table 5.1, Figure 5.5). Specifically, children from lower-SES backgrounds with high reasoning ability showed a significant and positive relationship between L RMFG thickness and age ($b = 0.08$, 95% CI [0.03, 0.14], $t(22) = 3.28$, $p = .003$), while those with low reasoning ability showed no relationship ($b = -0.03$, 95% CI

[-0.13, 0.06], $t(20) = -0.70$, $p = .491$). Children from higher-SES backgrounds showed no relationships between L RMFG thickness and age in either reasoning group (high reasoning: $b = -0.02$, 95% CI [-0.06, 0.03], $t(30) = -0.90$, $p = .376$; low reasoning: $b = -0.01$, 95% CI [-0.07, 0.05], $t(22) = -0.25$, $p = .801$). There were no main effects of age, maternal education, or matrix reasoning with left or right RMFG when evaluated in separate models (all $p > .3$).

Table 5.1. Three-way interaction of age, maternal education, and matrix reasoning on the thickness of left and right rostral middle frontal gyrus (RMFG) in the early childhood sample. L RMFG model: $F(10, 104) = 2.28$, $p = .019$, adj. $R^2 = 0.10$. R RMFG model: $F(10, 104) = 2.10$, $p = .031$, adj. $R^2 = 0.09$.

Parameter	Estimate	SE	<i>t</i>	<i>p</i>
<i>L MFG</i>				
Intercept	5.59	1.53	3.66	< .001
Mother Education	-0.18	0.09	-1.89	.062
Matrix Raw	-0.20	0.11	-1.75	.084
Age	-0.61	0.27	-2.22	.029*
Sex	0.04	0.03	1.48	.143
Image Quality	-0.00	0.01	-0.06	.950
Study	-0.05	0.03	-1.83	.070
Mother Education x Matrix Raw	0.01	0.01	1.87	.064
Mother Education x Age	0.04	0.02	2.20	.030*
Matrix Raw x Age	0.04	0.02	2.22	.029*
Mother Education x Matrix Raw x Age	-0.00	0.00	-2.30	.024*
<i>R MFG</i>				
Intercept	4.58	1.53	2.99	.003
Mother Education	-0.12	0.10	-1.24	.217
Matrix Raw	-0.08	0.11	-0.73	.470
Age	-0.48	0.27	-1.76	.081
Sex	0.02	0.03	0.70	.486
Image Quality	-0.01	0.01	-0.47	.641
Study	-0.04	0.03	-1.48	.143
Mother Education x Matrix Raw	0.01	0.01	0.80	.424
Mother Education x Age	0.03	0.02	1.76	.081
Matrix Raw x Age	0.03	0.02	1.35	.179
Mother Education x Matrix Raw x Age	-0.00	0.00	-1.42	.160

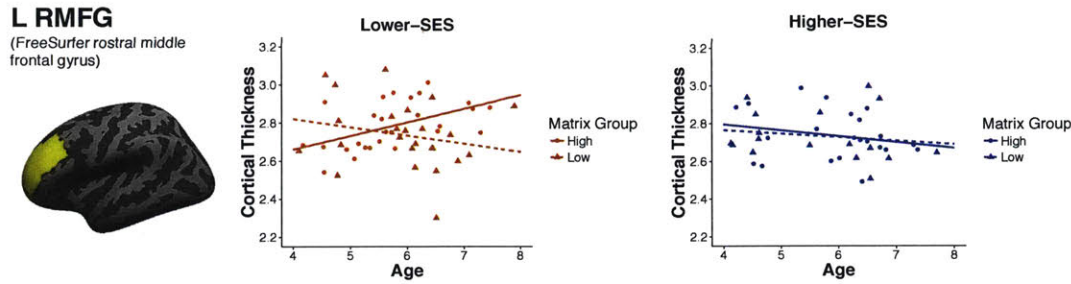


Figure 5.5. Three-way interaction between age, maternal education, and matrix reasoning on left rostral middle frontal gyrus (L RMFG) thickness in the early childhood sample. For plotting purposes only, children were split into two maternal education groups based on whether their mothers completed 4-year college (Lower-SES group, orange: maternal education < 16 years, Higher-SES group, blue: maternal education \geq 16 years). For plotting purposes only, children were split into high (solid line) and low (dashed line) matrix reasoning groups based on the median matrix reasoning standard score within each SES group (high = circle, low = triangle).

5.3.2 Replication in adolescents

In the adolescent sample ($n = 59$), there was a positive trend between maternal education and matrix reasoning ($r(57) = .24, p = .071$; Figure 5.1C). Splitting the sample into two groups based on maternal education showed high variability in scores within groups, and no significant group difference ($t(57) = 1.33, p = .189$; Figure 5.1D).

To replicate the early childhood findings in this smaller sample, we focused our analyses on left and right RMFG (FreeSurfer aparc 2005). Within adolescents from low-SES backgrounds, greater cortical thickness in both left and right RMFG correlated with better reasoning scores (L RMFG: $b = 0.01, 95\% \text{ CI } [0.00, 0.02], t(20) = 2.19, p = .040$; R RMFG: $b = 0.01, 95\% \text{ CI } [0.00, 0.02], t(20) = 2.37, p = .028$; Figure 5.6). No significant relationships were found between RMFG thickness and reasoning scores in adolescents from higher-SES backgrounds (L RMFG: $b = 0.00, 95\% \text{ CI } [-0.01, 0.00], t(29) = -0.15, p = .883$; R RMFG: $b = 0.00, 95\% \text{ CI } [-0.01, 0.01], t(29) = -0.12, p = .907$). There were no main effects of age or matrix reasoning ($p > .2$), and there was a trend for maternal education

(L RMFG: $b = 0.01$, 95% CI [0.00, 0.02], $t(55) = 1.66$, $p = .103$; R RMFG: $b = 0.01$, 95% CI [0.00, 0.02], $t(55) = 1.61$, $p = .113$). Three-way interactions amongst age, maternal education, and matrix reasoning were not significant (Table 5.2).

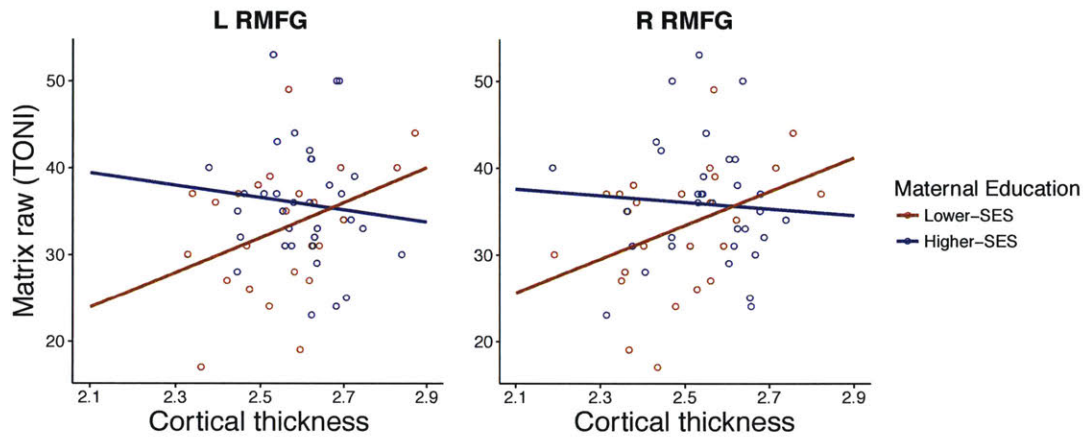


Figure 5.6. Relationships between matrix reasoning and cortical thickness by SES group in the adolescent sample. Age, gender, and image quality, were included as covariates. Scatterplots show the relationship between each ROI's thickness (defined from Freesurfer aparc 2005 parcellations, adjusted for covariates) and reasoning by SES group (Lower-SES group, orange: maternal education < 16 years, Higher-SES group, blue: maternal education \geq 16 years). Matrix reasoning was measured with the Test of Nonverbal Intelligence (TONI).

Table 5.2. Three-way interaction of age, maternal education, and matrix reasoning on thickness of left and right rostral middle frontal gyrus (RMFG) in the adolescent sample. L RMFG model: $F(9, 149) = 1.40, p = .205, \text{adj. } R^2 = 0.06$. R RMFG model: $F(9, 49) = 1.80, p = .092, \text{adj. } R^2 = 0.11$.

Parameter	Estimate	SE	<i>t</i>	<i>p</i>
<i>L RMFG</i>				
Intercept	-6.20	11.92	-0.52	.605
Matrix Raw	0.18	0.36	0.50	.621
Mother Education	0.78	0.76	1.02	.311
Age	0.56	0.82	0.68	.502
sex	0.05	0.04	1.54	.131
Image Quality	0.02	0.05	0.33	.743
Matrix Raw x Mother Education	-0.02	0.02	-0.77	.447
Matrix Raw x Age	-0.01	0.02	-0.45	.653
Mother Education x Age	-0.05	0.05	-0.98	.333
Matrix Raw x Mother Education x Age	0.00	0.00	0.73	.469
<i>R RMFG</i>				
Intercept	1.88	12.77	0.15	.884
Matrix Raw	-0.07	0.39	-0.17	.862
Mother Education	-0.12	0.81	-0.15	.885
Age	-0.01	0.88	-0.01	.991
Sex	0.08	0.04	2.05	.045*
Image Quality	0.04	0.06	0.65	.517
Matrix Raw x Mother Education	0.01	0.02	0.40	.693
Matrix Raw x Age	0.01	0.03	0.21	.831
Mother Education x Age	0.01	0.06	0.19	.848
Matrix Raw x Mother Education x Age	-0.00	0.00	-0.43	.667

5.4 Discussion

Neuroanatomical correlates of fluid reasoning differed by SES in children and adolescents. In young children from lower-SES backgrounds, but not from higher-SES backgrounds, thicker RLPFC was related to better reasoning ability. This pattern of results

replicated in an independent sample of adolescents. In the early childhood sample, we found that children from lower-SES backgrounds with higher reasoning ability showed a positive relationship between left RLPFC thickness and age, while those with lower reasoning ability showed a non-significant negative relationship. No interaction between age, reasoning ability, and cortical thickness was found in the higher-SES group. Thus, high achieving children from lower-SES backgrounds may have a unique developmental time course of RLPFC in early childhood. Consistent with the evolutionary-developmental literature showing that individuals adapt to fit their environment, the current work suggests that the neural correlates of successful reasoning differ by early life environment (Ellis et al., 2017).

The location of the interaction between matrix reasoning and SES in RLPFC is consistent with evidence that this area is important for fluid reasoning, especially the relational reasoning needed for more challenging problems (Bunge et al., 2009; Christoff et al., 2001; Crone et al., 2009; Wendelken et al., 2011; 2012; 2016). Greater cortical thickness in this region could reflect increased local neural computational resources, an interpretation that would align with the finding that thicker RLPFC is also related to higher IQ later in development and adulthood (Choi et al., 2008; Karama et al., 2009; Menary et al., 2013; Narr et al., 2007). It is unclear why we do not observe relationships between cortical thickness and reasoning in individuals from higher-SES backgrounds in either age group. It is possible that these relationships emerge after age 16, or that there is greater heterogeneity in the higher-SES group.

Our results are consistent with other studies showing differences in brain-behavior relationships by SES, across functional and structural imaging modalities. Variability in arithmetic performance in children from lower-SES backgrounds was linked to activation of visuospatial areas, while variability in children from higher-SES backgrounds was linked to

activation of verbal areas (Demir, Prado, & Booth, 2015). During a reading task, phonological awareness correlated with greater activation of fusiform cortex in children from lower, but not higher, SES backgrounds (Noble, Wolmetz, Ochs, Farah, & McCandliss, 2006). Adolescents from higher-SES backgrounds exhibited greater positive relationships between parietal activation on a working memory task and standardized math test scores than adolescents from lower-SES backgrounds (Finn et al., 2016). SES has also been shown to moderate relationships between brain structure and cognition: Among children with thicker cortices, SES was more predictive of executive function, and less predictive of language skills (Brito et al., 2017). Other research has also shown that SES impacts relationships between brain structure and age (LeWinn et al., 2017). The present study goes beyond past research by examining how brain-behavior relationships differ by SES at multiple stages of development, with a focus on fluid reasoning.

Children with strong reasoning skills from lower-SES backgrounds had a unique developmental time course of RLPFC: a significant positive relationship between RLPFC thickness and age. All other groups of participants showed nonsignificant negative relationships between RLPFC thickness and age. However, the positive relationship between RLPFC thickness and age in high-performing children from lower-SES backgrounds was not significant in the adolescent sample, indicating that this relationship may be specific to early childhood development. While we do not know why differential early RLPFC development specifically benefits children from lower-SES backgrounds, one possibility is that slower development (thickening instead of thinning) is beneficial because it allows the brain to be more flexible and responsive to learning (Shaw et al., 2006; Yeatman, Dougherty, Ben-Shachar, & Wandell, 2012). Another possibility is that increased neural resources are required to reason well in a challenging environment, so as other children are beginning to show effects of pruning, children from lower-

SES environments with strong reasoning skills continue to show growth of RLPFC during early childhood.

Main effects of reasoning, SES, and age were limited to occipital cortex in the early childhood sample. We observed a positive relationship between matrix reasoning and cortical thickness only in lateral occipital cortex, in contrast to previous studies linking full-scale IQ to cortical thickness in older and broader age ranges (Choi et al., 2008; Karama et al., 2009; Menary et al., 2013; Narr et al., 2007). We saw a negative relationship between age and thickness of pericalcarine cortex, which contains primary visual cortex, consistent with multiple studies that show cortical thinning in sensory areas first, followed by thinning in association regions (Gogtay et al., 2004; Shaw et al., 2006; Sowell et al., 2004; Walhovd, Fjell, Giedd, Dale, & Brown, 2016). We only found an effect of maternal education on cortical thickness at a lenient cluster-forming threshold in lateral occipital cortex, consistent with small cortical thickness differences by SES in early childhood (Piccolo et al., 2016) (note: SES-related volume differences have been observed in infancy, but may be driven by surface area rather than thickness (Betancourt et al., 2016; Hanson et al., 2013)). It is unclear why main effects clustered in occipital cortex, but it could be that relations between SES and cognition emerge as development progresses: in early childhood, these relationships are apparent in early-developing sensory regions, but the cortical footprint of such relationships spread throughout development.

This study has several limitations. First, it was cross-sectional, precluding direct evidence about relationships between age-related changes in cortical thickness and cognitive development. Second, this study relied on maternal education as a proxy measure of SES. Third, this study included only one measure of fluid reasoning, so it is unclear whether our findings would generalize across multiple measures of reasoning, or across cognitive measures more broadly.

Finally, the study did not include measures of early academic skills, so we could not test whether differential relationships between cortical thickness and reasoning are related to, or predictive of, performance in school. Future longitudinal research with a wider set of environmental, cognitive, and academic measures is necessary to more fully understand whether optimal structural brain development differs by environment.

Understanding how neural correlates of cognition differ by childhood environment could inform the use of neural markers in intervention evaluation. Many interventions that work to narrow the income-achievement gap take years for effects to present (e.g., Perry PreSchool Project (Schweinhart & Barnes, 2005), Abecedarian Project (Ramey et al., 2000)) and subsequently years to evaluate. Neuroimaging could be used as a “checkpoint” or surrogate endpoint to provide more immediate feedback on the effectiveness of an intervention, as changes can appear in the brain prior to changes in behavior (Dumontheil & Klingberg, 2012; Gabrieli, Ghosh, & Whitfield-Gabrieli, 2015; Hoeft et al., 2007, 2011; Supekar et al., 2013; Ullman, Almeida, & Klingberg, 2014). However, most work on positive brain development has focused on children from higher-SES backgrounds, and, as we have demonstrated here, the principles of positive brain development may differ across SES environments. Thus, it is crucial to understand how positive brain development occurs differentially across varied SES experiences so as to promote brain development in a way that is valid for each child according to his or her environment.

Chapter 6

Discussion

This thesis examined how social factors impact children's learning across different time scales. Chapters 2 and 3 focused on how short-term social manipulations affect children's decisions to persist through challenges. Chapters 4 and 5 explored how long-term social factors impact children's brain development and in turn, their capacity to learn. In this Chapter, I discuss the contributions of these four experiments to the larger questions posed in the introduction of this thesis and conclude with limitations and future directions.

6.1 Summary of findings

6.1.1 Chapters 2 and 3

Chapters 2 and 3 looked at how young children use information from other people's actions and words to decide how hard to try on novel tasks. Effort in young children appears to be highly malleable. In other words, persistence is not simply a stable personality trait, but rather can be modified by social context. Because persistence is related to long-term academic outcomes (Duckworth et al., 2007; Eskreis-Winkler et al., 2014), this finding demonstrates that children can learn to be more persistent, and in turn potentially garner the benefits that come with increased persistence. Importantly, this work suggests a potential way to shape motivated behavior in early development: through observation of adult models of persistence.

Previous studies have focused on persistence in children and adolescents, who have years of prior experience that influence their orientation towards challenges. I show, for the first time, how persistence can be affected even in one-year-olds. Understanding the development of persistent behavior early in life is critical as motivational behaviors in infancy set children on trajectories of positive cognitive outcomes (e.g., Messer et al., 1986). Thus, this work provides a proof of concept that short-term effortful behavior can be changed in infancy, suggesting the possibility of, and a potential approach towards, early motivational interventions.

Across both studies in Chapter 2 and Chapter 3, children were selective and rational about persistence. Children don't try when persistence seems futile, such as when the adult model fails to reach her goal. These findings are in line with a large literature on young children's rational inductive learning from multiple forms of data (see Tenenbaum et al., 2011). Thus, young children are not always overly optimistic about their abilities, as some research suggests (e.g., Lockhart, Chang, & Story, 2002; Schneider, 1998); rather they are sensitive to other people's success and failure and use these data to update the probability of their own success. Appreciating that children are rational about effort can help researchers better understand situations in which children do and do not try.

Notably, children do not just imitate adult actions in these studies. Children do not persist when the adult model persists and fails to reach her goal (Chapter 2) and children persist more on a novel task after watching an adult demonstrate persistence on two distinct tasks (Chapter 3). Rather children seem to be drawing a more general inference about the benefit of hard work from adult models of effort.

Perhaps most importantly, these studies provide a potentially powerful way to intervene in young children's persistence. Collectively, this work shows that children learn to work harder

after watching adults demonstrate persistence and succeed at their goal. Chapter 2 suggests that perhaps the most critical element of this modeling is to show children that some tasks are possible to achieve, thus giving children reason to believe that they too can reach this goal. Furthermore, adults' words can have an additive effect: if adults 'practice what they preach' (give a pep talk or state their value of effort in conjunction with showing effortful success,) children persist to a higher degree.

6.1.2 Chapters 4 & 5

Chapters 4 & 5 explored the relationship between SES, the brain, and cognition through the lens of an "adaptive framework," examining the specific ways that children from lower-SES backgrounds might adapt, neurally and cognitively, to best fit their environment. Previous work has shown that SES impacts measures of cortical thickness and surface area globally across the brain (Mackey et al., 2015; Noble et al., 2015). However, findings in Chapter 4 suggest that SES does not have a uniform impact on the brain, rather some neural structures are affected more than others. In particular, I find that SES selectively impacts hippocampal and DLPFC volume (and working memory), but not the caudate volume (and procedural memory). This finding is in line with the adaptive framework, which posits that all organisms live in a world of limited resources and energy spent in one domain comes at the expense of investment in competing domains. While some work suggests that enhanced working memory trades off against strong procedural memory (Decaro, Thomas, & Beilock, 2008), we did not find this tradeoff in our study. Rather we found a relationship between declarative memory, hippocampal volume, and PFC volume with SES, and no relationship between procedural memory and caudate volume with SES. Perhaps under specific circumstances or with a larger sample size, we would find stronger

procedural learning in individuals from lower- compared to higher-SES backgrounds, as Dang and colleagues (2016) found with added monetary incentives taxing working memory. However, the current work emphasizes that SES effects on brain structure and associated learning abilities are not global, but rather selective.

Chapter 4 also demonstrated for the first time that SES does not relate to procedural memory performance or its underlying neural structure in the striatum. This is in line with previous work finding selective effects of SES on neurocognitive systems. Specifically, strong associations have been found between SES and language, declarative memory and executive function abilities (as reviewed in Chapter 1) while no or small relationships have been found between SES and reward processing, visual cognition, or dexterity (Noble et al., 2007, 2005; internal lab data). Differential effects of SES on cognition may arise from a number of factors including the developmental time course of cognitive systems (rendering them more or less vulnerable to environmental influence), whether the neural structures supporting them are sensitive to factors highly related to SES such as stress (e.g., the hippocampus, amygdala, and PFC), environmental statistics (such as linguistic input), and finally, the sensitivity of the measure. Notably, other research groups have replicated the results from Chapter 4, finding no relationships between SES and procedural learning (personal communication with Martha Farah; Dang et al., 2016).

Finally, the results of Chapter 5 suggest that the neural correlates of strong fluid reasoning, a core component of IQ, vary by early life environment. This finding contradicts the alternative hypothesis that IQ has a uniform neural correlate across environments. Indeed, most studies that relate neural structure to IQ make this assumption (Choi et al., 2008; Karama et al., 2009; Menary et al., 2013; Narr et al., 2007) and don't test for interactions by early life

environment. These findings have implications at both the basic and applied level. On a basic level, this study suggests that neuroimaging research should 1) attempt to recruit a more representative sample of the larger population and 2) test if brain-behavior relationships vary by early life environment to better classify the myriad ways that the brain can support strong cognitive skills. On an applied level, this work speaks to research using neuroimaging in intervention evaluation. Many interventions aimed at closing the income-achievement gap have “sleeper” effects, taking years for effects to present (Ramey et al., 2000; Schweinhart & Barnes, 2005). Neuroimaging has the potential to be used as a surrogate endpoint, since neural changes can present before behavioral ones (Dumontheil & Klingberg, 2012; Gabrieli, Ghosh, & Whitfield-Gabrieli, 2015; Hoeft et al., 2007, 2011; Supekar et al., 2013; Ullman, Almeida, & Klingberg, 2014). However, if we want to use neuroimaging as a surrogate endpoint, we need to know what “optimal” neural signature to look for in children from diverse SES who *will be* high-performing. Chapter 5 suggests that one should expect efficacious interventions to result in unique neural changes by SES and provides one signature to look for in the domain of reasoning: RLPFC thickness in children from lower-SES backgrounds.

6.2 Limitations and future directions

6.2.1 Chapters 2 and 3

How do the results of Chapters 2 and 3 translate from the lab into the real world? For example, are children who observe persistence amongst their parents, teachers, and peers in real-world settings more likely to be highly persistent? And what dosage and time-scale of exposure to models of persistence are necessary to cause impactful long-term behavioral change? One way

to explicitly test these questions is through an intervention that trains parents to model persistence in front of their children. The outcome measures would be children's short-term and long-term persistent behavior and changes in their beliefs about the relationship between effort and outcomes. However, it is unclear what children might learn from longer-term exposure to effortful models. On the one hand, they may infer that effort is valuable in general or with some set of toys in some context. On the other hand, they may infer that the adult, who they have seen effortlessly succeed many times, is suddenly not very competent on many different tasks. Furthermore, it is unclear whether pedagogical cues (which boost learning in Chapter 3) are necessary for a longer-term effort intervention based on modeling. It may be that having constant, implicit evidence that your parent works hard is enough to convey the value of effort. Importantly, interventions shouldn't be aimed at globally increasing children's persistence, but rather increasing persistence when there is a high chance of success or learning. Thus, one approach would be to create an intervention based on good decision making about effort allocation. This might involve having parents make choices between two items, choosing the more logical one (perhaps it is in their zone of proximal development - not too hard and not too easy) to persist on. Intervention work related to modeling of effort is a necessary future area of research to test how these findings translate into practice.

The proposed intervention above is aimed at changing parents' behavior, but another open question is whether children can learn the value of effort from other sources, including teachers, friends, or even social robots. Some work has demonstrated that adults and children use peer models to calibrate effort (Schunk & Hanson, 1985; Schunk et al., 1987). However, perceived similarity to the modeler mediates this effect. College students who view themselves as similar in competence to a model who succeeds at an anagram task persist more than students

who view themselves as less competent than the model (Brown & Inouye, 1978). Yet in the studies discussed in this thesis, children are able to learn the value of effort from adult models, who they know are more knowledgeable than they are (e.g., Lutz & Keil, 2002). Perhaps individual differences in perceived similarity to the adult model underlie the large variation we see across experiments in the effort success conditions. Presumably other factors, such as competence and trust in the modeler, also impact children's learning (Koenig, Clément, & Harris, 2004; Lane, Wellman, & Gelman, 2013). Future work should explore both the specific features of the modeler and the relationship between modeler and learner that enable optimal learning about effort.

Cultural factors also likely play a role in children's learning from adult models about effort. All the studies discussed in this thesis took place in one cultural context: The United States of America. Many Americans value perseverance (Ames & Archer, 1987), but unlike in other cultures, children in America are not as involved in adult work and their learning takes place primarily through mastering skills adults already know. Thus, the value of persistence, as well as the efficacy of learning from adult models, might very well differ by culture. Indeed, first-grade children in Japan, a country that arguably values hard work more than the USA, demonstrate more task persistence than American children (Binco, 1992). Children also imitate adult models with higher fidelity if the demonstrator says that a task is conventional and in line with societal norms versus instrumental (Legare, Wen, Herrmann, & Whitehouse, 2015). Future research should probe which aspects of social learning about effort are universal, and which are culturally specific.

6.2.2 Chapters 4 & 5

An overarching limitation of the work in Chapters 4 & 5 is the simplified definition of SES as either income (indexed based on receiving free or reduced price lunch or not) or maternal education. Different dimensions of SES may uniquely impact neural architecture and cognition, suggesting distinctive targets for intervention. For example, Noble and colleagues (2012) found that income, but not parent education, relates to hippocampal volume. Conversely, the same study also found that parent education, but not income, relates to amygdala volume.

Furthermore, McLaughlin and Sheridan (2016) posit distinct ways in which two correlates of SES, deprivation (lack of cognitive stimulation) and threat (violence and abuse), impact child development. Deprivation relates to diminished executive function (Sheridan, Peverill, Finn, & McLaughlin, 2017) and threat relates to impairments in fear learning (McLaughlin et al., 2016). Future work should better characterize children's environments by measuring a variety of constructs such as stress, chaos, environmental enrichment, and language exposure to test how these features specifically relate to child development.

Another puzzle is the lack of brain-behavior relationships in the higher-SES group in Chapter 5. Strikingly, other groups have found this same pattern of brain-behavior relationships in preschool-age children from lower-, but not higher-, SES backgrounds: white matter coherence relates to reading in lower-, but not higher-, SES children (Ozernov-Palchik et al., submitted) and language input relates to cortical thickness in lower-, but not higher-, SES children (Romeo et al., in prep). One potential explanation for this pattern is that there could be more ways to achieve successful cognition in higher-SES, enriched environments, eliminating any perceivable group effects. In contrast, there may be less wiggle room in lower-SES

environments for individual variation in mechanisms to support reasoning (especially in Charter Schools, which are oversampled in these studies). This theory is similar to work showing increased plant species diversity in environments with high temperatures, nutrient-rich soil and abundant water compared to less lush environments (Pausas & Austin, 2001). Similarly, although genetic inheritance may be uniform by environment (a controversial topic - see Tahmasbi, Evans, Turkheimer, & Keller, 2017; Turkheimer, Haley, Waldron, D'Onofrio, & Gottesman, 2003), more phenotypic diversity can be expressed in enriched environments (Lewontin, 1976). However, in adults we do find singular brain-behavior relationships in higher-SES samples, suggesting that at some point individuals from higher-SES backgrounds conform to a specific neural mechanism for cognitive processes. Future work is needed to fully test this hypothesis of a prolonged development of brain-behavior relationships in children from higher-SES backgrounds.

Chapter 4 and 5 focused specifically on memory and reasoning. However, other cognitive skills may relate differentially to SES both on a cognitive and neural level. Research that explores unique adaptations to other harsh environments can potentially inform areas to explore in future SES-related work. For example, children exposed to physical threat and abuse are faster at detecting angry facial expressions (Pollak, Messner, Kistler, & Cohn, 2009) and previously institutionalized children are more likely to exploit resources rather than explore (Humphreys et al., 2015). Features of neglect and abuse relate to SES, suggesting the potential that enhanced emotional detection and increased exploitation over exploration may also vary by SES. Other work suggests that the unique cognitive advantages that develop in response to harsh early life environments are only present under matched conditions evoking these environments. For example, Mittal and colleagues (2015) found that adults who grew up in unpredictable

environments had enhanced attention shifting only under primed conditions of economic uncertainty. Similarly, individuals from lower-SES backgrounds only show superior procedural memory under primed conditions of financial demand (Dang et al., 2016). Thus, future work should explore whether certain cognitive abilities, such as attention shifting or procedural learning, are boosted in individuals from lower-SES backgrounds when tested in contexts that mimic lower-SES environments (perhaps with increased chaos, noise, or stress).

While much of this work aims to uncover the unique cognitive skills children develop in response to lower-SES environments, it remains unclear how to utilize these skills for academic learning. For example, the results from Chapter 4 suggest that interventions to close this gap might consider focusing on procedural memory. While this seems appealing, most of the learning that takes place in schools is geared towards explicit memory, so it is not obvious exactly how procedural memory could be exploited in this setting. Future work should explore whether there are creative ways to harness procedural memory to boost academic learning. However, just as important is research examining ways to enhance explicit memory.

If children from lower-SES backgrounds are successful in academic contexts, it may come at a price. From Chapter 5 for example, it is unclear whether thicker RLPFC and better reasoning skills are advantageous for children from lower-SES backgrounds in the long term, or whether there are costs associated with cognitive resilience. Thicker RLPFC in adults is associated with greater perceived stress (Michalski et al., 2017), and there is evidence that children from disadvantaged backgrounds with high self-control and high academic achievement show health problems consistent with elevated allostatic load (Brody et al., 2013; Chen et al., 2015; Miller et al., 2015). Furthermore, it is unclear whether there are costs associated with strong procedural memory in children from lower-SES backgrounds. At least one study found

that enhanced procedural learning trades off against strong working memory abilities (Decaro et al., 2008). Understanding how specific adaptations to lower-SES environments come at the cost of developing other skills is a necessary area for future research.

6.3 Broader directions

6.3.1 Connecting long-term social context to persistence

A goal for future work is to bridge the gap between short- and long-term social contexts to specifically explore individual children's approach to learning. Some research suggests that long-term social contexts do impact children's persistence: children from lower-income backgrounds demonstrate less persistent behavior than their higher-income peers (Brown, 2009; Evans, 2016). A constantly chaotic environment may mediate the relationship between SES and persistence (Evans et al., 2016). Lack of consistency and structure trigger feelings of helplessness and low self-efficacy (Peterson, Maier, & Seligman, 1993), and causal manipulations that vary the predictableness of children's environment show that unpredictability leads to less persistence on a delay of gratification task (Kidd, Palmeri, & Aslin, 2013). However, other theories posit that it is not the unreliability of the environment (which encompasses unpredictability of both good and bad events) that leads to learned helplessness, but rather the frequency of rewards in the environment given ones' efforts (Teodorescu & Erev, 2014). A lack of persistence in a lower-SES environment may be a rational adaptation: if you don't know that effort will bring success or reward, why try? However, this does not mean that children from lower-SES backgrounds are uninterested in persisting or impervious to evidence about when effort will pay off. Instead, it could be the case that different types of evidence have

a unique impact on persistence in children from lower and higher SES backgrounds. Future work should empirically test how specific information in children's environment, including access to challenges, the frequency of reward and controllability of surroundings, inform children's persistent behavior.

6.3.2 Individual differences in children's persistence

Individual differences in goal structure (what one is trying to achieve with any given task) surely impact perseverance. For example, a child may decide to work hard on homework because of external rewards (wanting a good grade, fearing parents being upset if she does poorly), internal rewards (knowing that mastering this skill will lead to a dream career), or just because it is intrinsically pleasurable to learn. Furthermore, while one is learning a new task, they could be motivated to optimize 1) success 2) avoiding failure or 3) improvement over time. These motivational frameworks are not mutually exclusive. While individual differences in goal structure may lead to the same motivated behavior, understanding these differences is key as they suggest unique interventions. One potential way to gain traction on individual goal structure is through computational modeling of behavior on learning tasks using a reinforcement learning (RL) framework (Gottlieb, Oudeyer, Lopes, & Baranes, 2013; Oudeyer & Kaplan, 2009). With RL, one can vary how rewards are maximized to uncover individual's motivational structure, whether it is optimizing competency over time or avoiding mistakes (Sayali & Badre, 2018). However, these paradigms usually require the participant to engage in tedious tasks for long periods of time in order to get enough data to model. Furthermore, most studies are focused on group effects and not individual differences. A fruitful area for future work is the development of engaging games for children that can be used to model individual differences in goal

frameworks. Along this line of work, one could also probe whether goal structure or persistent behavior is consistent across contexts and over time or whether it varies based on transient factors like mood or fatigue.

6.3.3. Neural correlates of persistence in young children

Little is known about the neural correlates of persistence in children. One challenge is that persistence as a construct is not well characterized in the field of neuroimaging or psychology. For example, some define it as sticking to a singular strategy on a task (Jung et al., 2010), while others define it as the decision to wait for a reward (McGuire & Kable, 2015). This makes it challenging to compare across studies that claim they are looking at persistence. In this thesis, I characterize persistence as deploying continued effort towards reaching a goal. Some research in adult neuroimaging has explored aspects of persistence defined this way. Broadly, this work points to two potential neural networks: the cognitive control network (frontoparietal network) and the valuation network (ventromedial prefrontal cortex (VMPFC) and nucleus accumbens (nACC)). This work has shown that there is top-down control of “cool” cognitive control areas on “hot” valuation areas during cognitive tasks where motivation is increased (Pochon et al., 2002) and on tasks requiring inhibition of responses to alluring cues (Casey et al., 2011). However, McGuire and Kable (2015) found that only activity in the VMPFC part of the valuation network, and not any part of the “cognitive control network,” explained variance in one’s decision to wait for a reward. This suggests that the extent to which a goal is valued is a primary driver of persistence. Furthermore, studies that operationalize persistence as sticking to a strategy in the face of uncertainty have shown that persistent adults have increased VMPFC-nACC functional-connectivity and activity during task (Gusnard et al., 2003; Jung et al., 2010).

Thus, there is reason to believe that “valuation” networks may provide more explanatory power in persistent behavior than “cognitive control” networks in adults.

This seems especially plausible in development, when medial regions of the cortex mature earlier than lateral regions (Shaw et al., 2008), suggesting that VMPFC may be more involved than lateral prefrontal cortex (lateral PFC – part of the cognitive control network) in governing children’s persistent behavior. Alternatively, the differential maturation of these two frontal areas could lead to a different hypothesis, whereby individual differences in the extent to which lateral PFC develops is the variable that governs persistent behavior in children. Thus, understanding how these neural systems support persistence in development could help elucidate how children’s effortful behavior is driven by both value judgments and cognitive control.

6.3.4 Defining “positive development”

A constraint of this work is that many times the ‘optimal outcome’ we are aiming for is academic achievement. Yet this definition of success, while predictive of many life outcomes, is narrow and largely ignores other ways children can thrive. For example, is it not equally important to raise a moral and kind child? However, if what we seek is to increase children’s intelligence, then we should also consider children’s problem solving and expertise outside the classroom (something psychologists rarely test). For example, rural Kenyan children who perform poorly in school have extensive knowledge of the natural herbal medicines that can fight parasitic infections (Sternberg et al., 2001). Street vendors in Brazil can quickly and accurately solve math problems involving pricing of goods but unable to solve equivalent math problems in an abstract verbal or written context (as is normally used in school; Schliemann & Carraher,

2002). These forms of intelligence, that shine in children's natural setting but not the classroom, should also be considered.

A further difficulty with operationalizing success as academic achievement is that it requires a mismatch between the environment children from lower-SES backgrounds were born into and the environment in which they need to prosper. In other words, children from lower-SES backgrounds spend their early years, starting in utero, adapting to an environment that is different from the academic one in which they are asked to succeed. Perhaps the most famous example of the detriments of environmental mismatch is the Dutch Hunger Winter study. In 1944, the German Occupation limited food rations in the western regions of the Netherlands resulting in famine. The children of the pregnant woman from this time later grew up to have higher rates of obesity than those born before or after the war (Schulz, 2010). This exemplifies how in utero adaptations to a food-deprived environment were maladaptive when these individuals were later exposed to a food-rich environment. A similar mismatch may be true for SES, brain development, and academic achievement. One hypothesis is that children from lower-SES backgrounds have accelerated cortical development, rendering their brain less vulnerable to negative environmental input. While this may be protective against harsh environmental influences, it also yields the brain less amenable to learning from positive aspects of the environment, which could be provided in school. Thus, the mismatch between how children develop in one context and how they are asked to perform in school causes researchers to underestimate specific adaptations, and pressures children into a "one size fits all" model of success. Future work should 1) reflect upon the definition of an "optimal" outcome for children, 2) test multiple forms of intelligence and 3) explore how to apply each child's unique skill base to enhance their learning both in the classroom and in the world at large.

6.4 Concluding remarks

“The best thing parents can do is to teach their children to love challenges, be intrigued by mistakes, enjoy effort, and keep on learning” – Carol Dweck

As adults, we have a great influence on children’s development. This thesis shows that from just a quick demonstration of working hard and reaching a goal, we can encourage young children to do the same. Furthermore, as parents, we provide the larger social context that shapes children’s neural and cognitive development. Taken together, this work suggests that to foster resilience in the next generation we should focus not only on supporting positive behavior in children but also in the adults around them.

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