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SES affects infant cognitive flexibility

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ABSTRACT

Cognitive flexibility requires processing multiple sources of information and flexible adaptation of behavioral responses. Poverty negatively impacts cognitive control in young children, but its effects on infants are not well-understood. This study investigated longitudinally the development of cognitive flexibility in low-income infants. Thirty-two infants (15 low-SES, 17 high-SES) were tested at 6, 9, and 12 months of age. Cognitive flexibility was measured with a perseverative reaching task, where infants were taught to reach to one location and then asked to switch to a second location. High-SES infants replicated the typical developmental trajectory, reaching randomly at 6 months, perseverating at 9 months, and reaching correctly at 12 months. In contrast, the low-SES infants showed a delayed pattern, reaching correctly at 6 months, randomly at 9 months, and perseverating at 12 months. Links between cognitive flexibility and frontal cortex development are explored as a potential mechanism.

Cognitive flexibility refers to an individual's ability to switch between response sets and process multiple sources of information simultaneously (Anderson, 2002). Cognitive flexibility encompasses processes such as divided attention, working memory, conceptual transfer, and feedback utilization. Studies of cognitive flexibility often use procedures that involve performing a task according to a certain rule that specifies criteria for correct responding, and then making a switch that requires completing the same task using a new rule or set of rules (e.g., Espy, 1997; Müller, Dick, Gela, Overton, & Zelazo, 2006). The ability to monitor one's performance and modify behavior according to verbal feedback is important for success on these kinds of tasks (Bohlmann & Fenson, 2005). Children who are capable of flexibly shifting their behavior on tests of cognitive flexibility also tend to have stronger working memories than children who do not demonstrate flexible behavior on the same task (Blackwell, Cepeda, & Munakata, 2009).

Underdeveloped or deficient flexibility often manifests as perseverative errors, or a tendency to repeat strategies that have been successful in the past, even if those strategies are no longer effective. This general notion of perseveration as a lack of cognitive flexibility has been observed in a variety of different tasks at different ages. One classic test of cognitive flexibility for pre-schoolers, the Dimensional Change Card Sort (DCCS), asks children to sort cards according to one rule (e.g., color), and then asks them to make a switch where cards are now sorted according to a new, conflicting rule (e.g., shape). Pre-schoolers are able to accurately sort by the initial rule, but tend to perseverate after the switch (Bohlmann & Fenson, 2005; Müller et al., 2006; Müller, Zelazo, Lurye, & Liebermann, 2008). This pattern of behavior reflects the fact that young children are unable to conceptualize a task in a new way once they have learned to respond to it in one way; they are unable to flexibly respond when the demands of the task have changed, tending to repeat past successful strategies instead.

Cognitive flexibility can also be measured in young infants using an adaptation of Piaget's (1954) A-not-B task (e.g., Smith, Thelen, Titzer, & McLin, 1999). Originally developed to measure infants' sense of object permanence, this task has

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been widely used as a measure of cognitive flexibility in infant and preschool populations (see Zelazo & Müller, 2002). In the original task, an infant was presented with two wells covered with identical lids. A desirable toy was hidden under one of the lids (the A location) while the infant watched, and the infant was allowed to reach for the hidden toy after a time delay of a few seconds. After several trials of reaching to A, the experimenter would then hide the toy under the other lid (the B location), again while the infant watched. This change to the B location represents a critical shift in the task, and the ability to accurately follow this switch by reaching to the B location indicates cognitive flexibility. More recent research shows that a simpler adaptation of this task can be used to the same effect. In this version of the task (outlined in Smith et al., 1999), no hidden toys are used. Instead, infants are simply presented with two identical objects and their attention is drawn to one of the two objects for several trials, and then their attention is directed to the second object. Infants' patterns of reaching on this version of the task do not differ from their response when hidden objects are used (Smith et al., 1999).

A longitudinal study of infants' behavior in this perseverative reaching task shows a surprising developmental trajectory (Clearfield, Diedrich, Smith, & Thelen, 2006). The task is typically used on 8–10-month-old infants, who reliably perseverate (e.g., Munakata, 1997; Smith et al., 1999). This longitudinal study tested infants monthly beginning at 5 months of age (the youngest age at which infants can reliably reach for a target) through 8 months of age (when perseveration is expected). The 5-month-old infants actually tended to either reach correctly on all trials, including the critical switch trial, or exhibited an unstable pattern of response (reaching incorrectly on the first set trials and randomly on switch trials). Infants reached randomly on both kinds of trials at 6 and 7 months, and only reliably perseverated at 8 months of age (Clearfield et al., 2006). Additional studies confirm that by 12 months, infants typically attain true flexibility on the task, reaching correctly on all trials (e.g., Diamond, 1985).

Two related models can account for infants' behavior on the critical shift trial in the perseverative reaching task. The Parallel Distributed Processing (PDP) model (Munakata, 1998) explains the task in terms of an interaction between active (faster) and latent (slower) memory traces. Active traces arise as a result of infants' immediate response to each trial, and decay rapidly over time, while latent traces build as a result of a cumulative history of active traces. The Dynamic Field Theory model (DFT) (e.g., Smith et al., 1999) also explains the task dynamics in terms of faster and slower memories. In this explanation, the fast memories depend on an infant's response to the specific, immediate stimuli of each trial, whereas the slow memories are a consequence of a repeated motor reach to a certain location. Despite important differences, both of these explanations conceptualize infants' reaching behavior on this task in terms of flexibility, or the ability of the infant to modify behavior in response to changes in the specific demands of the task.

Both models offer insight on the surprising developmental trajectory, based on the interaction between past action and memory. At 5 months, infants do not form strong memories for a particular behavioral pattern as a result of experience (Clearfield et al., 2006). Because they rely solely on immediate stimuli in the environment, they are able to readily adapt their behavior, exhibiting a kind of immature flexibility. The development of perseveration between 8 and 10 months reflects the ability to apply past experience to a current problem. Although at this age this kind of stable responding is overextended, in the sense that it leads infants to make errors (Diedrich, Highlands, Spahr, Thelen, & Smith, 2001), it represents an important component of cognitive flexibility. Because true flexibility requires a balance of both adaptable responses to novelty and stability across similar situations, perseveration represents an important step in the development of truly flexible behavior. By the end of the first year, infants are able to adapt to the changing task demands without being overwhelmed by their past experiences, thus demonstrating true cognitive flexibility.

This developmental trajectory makes the perseverative reaching task particularly well-suited to exploring the development of cognitive flexibility in an at-risk population: infants living in poverty. The negative developmental consequences of growing up in poverty have been well-documented (e.g., Bradley & Corwyn, 2002; Brooks-Gunn & Duncan, 1997; Duncan & Brooks-Gunn, 2000; Duncan, Yeung, Brooks-Gunn, & Smith, 1998; Evans, 2004). Children living in poverty are more likely than their non-poor peers to be under- or malnourished and to live in crowded, substandard housing situations (e.g., Bradley & Corwyn, 2002; Evans, 2004). They are less likely to receive adequate health care, have access to stimulating learning materials, and their parents are less likely to engage with them or provide educational experiences. These factors contribute to an overall risk for negative social, emotional, and cognitive outcomes for poor children.

Links between poverty and lowered academic achievement have also been well-established in the literature (e.g., Bradley & Corwyn, 2002), and children in poverty consistently perform worse than their non-poor counterparts on measures of cognitive ability. Poor children are twice as likely to repeat a grade, and 1.4 times more likely to have a learning disability, compared to their non-poor peers (Duncan & Brooks-Gunn, 2000). Children in families with incomes less than $15,000 complete almost a full year less of school and are 4.1 times less likely to complete high school than children in families with incomes between $15,000 and $25,000 (Duncan et al., 1998). Poor children are also 1.3 times more likely than non-poor children to experience cognitive developmental delays (limited or long-term) between the ages of 0 and 17 (Brooks-Gunn & Duncan, 1997).

These cognitive delays have been linked to stress reactivity in children living in poverty. For example, Blair, Granger, & Razza (2005) found that for low-income school aged children, moderate stress reactivity (as measured by change in cortisol levels) was positively associated with cognitive flexibility. Those children who performed particularly poorly on measures of cognitive flexibility tended to exhibit particularly low stress reactivity. This suggests a link between the physiological stress response and cognition for children growing up in a particularly stressful environment.

Although there is a substantial body of research that has examined the cognitive, emotional, and social impacts of growing up in poverty, the vast majority of this research has focused on preschool and school-aged children (see Bradley & Corwyn, 2002; Brooks-Gunn & Duncan, 1997; Duncan & Brooks-Gunn, 2000). Most of the studies that have looked at developmental outcomes for younger children have relied on standardized measures that assess the infant-mother relationship (the HOME assessment) and general infant IQ (the Bayley; e.g., Bradley, Corwyn, McAdoo, & Coll, 2001; Klebanov, Brooks-Gunn, McCarton, & McCormick, 1998; Mackner, Black, & Starr, 2003). Although both of these measures are valuable, neither one addresses the specific processes underlying cognition in general, or cognitive flexibility specifically. One exception is a study of A-not-B performance on low and high income Argentinean infants that were 6–14 months of age (Lipina, Martelli, Vuelta, & Colombo, 2005). Infants were presented with a complex perseverative reaching task, where a toy was hidden in 1 location for 2 trials, and then switched to a second location. If infants reached correctly on that switch trial, the procedure was repeated with increasing delays until the infant reached incorrectly. With this procedure, poor infants made more perseverative errors and nonperseverative errors compared to their non-poor peers, suggesting that perseveration is impacted by poverty (Lipina et al., 2005). While these results are a promising start, the study was cross-sectional (with 13–20 infants tested for each age group), and the multiple reversal procedure may elicit more random reaching than perseveration. Recent experimental evidence (Diedrich et al., 2001; Smith et al., 1999), meta-analyses (Marcovitch & Zelazo, 1999) and mathematical models (Thelen, Schoner, Scheier, & Smith, 2001) all show that the number of reaches to A (the first location) strictly determines whether infants will reach to B (switch to the second location) (Diedrich et al., 2001; Smith et al., 1999). In the multiple reversal method used in Lipina et al., the number of reaches to A or B is unconstrained, leaving some questions about whether infants were reaching randomly or truly perseverating.

The present study investigated longitudinally the development of cognitive flexibility in low-income infants. Low- and high-income infants were tested at six, nine, and twelve months of age, with the simpler perseverative reaching task. Typically-developing infants exhibit random patterns of reaching at six months, perseverate at nine months, and reach correctly at twelve months. Based on the established developmental trajectory, it was predicted that high-SES infants would replicate this trajectory and low-SES infants would lag behind. Specifically, low-SES infants should reach correctly at 6 months, randomly at nine months, and perseverate at twelve months.

1. Methods

1.1. Participants

Thirty-two infants participated in the study (15 from low-SES families and 17 from high-SES families). Infants were 6 months old (±2 weeks) at the first visit, 9 months (±2 weeks) at the 2nd visit, and 12 months (±2 weeks) at the 3rd visit. Of the thirty-two participating infants, 21 were male and 11 female (with 25 Caucasian and 7 Hispanic infants). Families were recruited from advertisements in the local newspaper, flyers, through a developmental learning center, and by word of mouth. None of the infants who participated were born prematurely or had other diagnosed developmental problems. Participating families received a gift card of $20 to Wal-Mart or books for each visit.

SES was determined in two ways. First, a parent of the participating infant completed a needs assessment (outlined by Zuckerman, 2009). The assessment inquired into the families' abilities to meet their needs with regards to food, housing, money, and their ability to access help, using a four point scale (e.g., for money, options range from "I don't have enough money for basic needs" to "I have some extra money without help"). The second way SES was determined was through maternal education, a commonly used method that has been shown to correlate with family SES (e.g., D'Angiulli, Herdman, Stapells, & Hertzman, 2008; Noble, McCandliss, & Farah, 2007; Stevens, Lauinger, & Neville, 2009). Mothers with more than 1 year of college were considered high SES, and those with 1 year or less of college were considered low SES.

1.2. Materials

Infants were tested on the perseverative reaching task using two identical objects placed on a display box. The objects were brown lids (round disks with a diameter of 9.5 cm, with knobs 1.5 cm tall in the center), and the display box (23.5 cm × 29.5 cm × 5.5 cm) was the same color as the lids to make them visually ambiguous. A JVC hard disk camcorder, model GZ-MG130, was used to record all sessions.

1.3. Procedure

The majority of infants were tested in their homes (97%) (three infants were tested in the lab, based on parental preference, one low-SES and two high-SES). The perseverative reaching task used in the present study was identical to that in Clearfield et al. (2006). For each session, the infant sat on the parent's lap at a table. At the start of the session, the experimenter allowed the infant to play with one of the lids for a few seconds to get used to the object. Then, the two lids were placed at midline on the display box in front of the experimenter. The experimenter cued one lid (the A object) by waving it and tapping it on the display box for several seconds, until she captured the attention of the infant. The experimenter then placed the A object on the front edge of the display box so that it was closer to the infant than the B object. After a 3-second delay, the experimenter pushed the box into the infant's reaching space, and the infant was allowed to reach. This procedure was repeated three more times, with the A object being moved progressively back on the display box until, on the fourth trial, it was even with the B object at midline. Two more trials were conducted with both objects even with each other (for a total of six A trials).

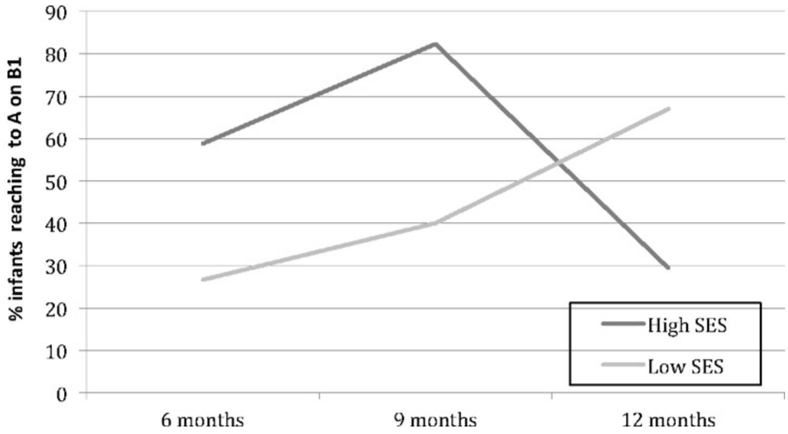

Fig. 1. Percentage of infants who reached to A on the B1 trial by age and SE.

The critical shift occurred after the sixth A trial. The experimenter drew the infant's attention to the B object by waving it and tapping it on the display box. Then, the object was placed at mid-line (even with the B object) and after a 3-second delay, the box was pushed forward and the infant was allowed to reach. Two trials were conducted with the B object cued. The side cued as A (left or right) was counterbalanced across infants, and across sessions for each infant. All sessions were video-taped for coding purposes.

1.4. Data coding

Each infant's reach on each trial was coded as a reach either to A or to B. The side coded was determined based on the lid that the infant touched first, even if the infant did not grasp or pick up the lid. In trials where an infant appeared to reach to both lids at the same time, a frame-by-frame analysis was used to determine which lid was touched first. To check for inter-rater reliability, 30% of infants were coded by a second rater who was blind to the SES of the participants. Both raters initially agreed on 97% of all trials; any disagreement on the coding of a trial was settled by both raters watching the trial together and coming to a consensus regarding its outcome until inter-rater agreement was 100%. As is standard in the literature (e.g., Smith et al., 1999), the data from the second B trial are only analyzed if infants do not reach on the first B trial. Here, all infants reached on the first B trial, so only data from that trial are reported (although there were no differences in reaching patterns between the first and second B trials).

Cognitive flexibility was assessed in two ways. First, in accordance with the literature, infants were categorized based on where they reached on the critical switch trial, B1. A second, more detailed, categorization aimed to classify infants based on their pattern of reaching across all A trials and the first B trial (the 2nd B trial was analyzed only if infants refused to reach on the first B trial). Infants were categorized according to one of three patterns of reaching: (1) reaching correctly (correct on A trials and the first B trial); (2) reaching randomly (reaching to B on some A trials); (3) perseveration (correct on A trials and reaching to A on the first B trial). Infants were considered reaching correctly on A if they reached to A on at least five of the six A trials (Clearfield et al., 2006).

2. Results

The most frequently used measure of performance on the A-not-B perseverative reaching task is infant response on the switch trial, or trial B1 (e.g., Clearfield et al., 2006; Diedrich et al., 2001). Fig. 1 shows the percentage of infants who reached to A on that trial at each age by SES. A chi-squared test of independence across sessions revealed significant differences, $X^2(5) = 15.72$, $p < .01$. Follow-up comparisons confirm that high SES infants perseverated significantly more than low SES infants at 6 and 9 months (6 months: $X^2(1) = 3.35$, $p = .05$; 9 months: $X^2(1) = 6.10$, $p < .05$). At 12 months, the pattern reversed: low-SES infants perseverated significantly more than high-SES infants, $X^2(1) = 3.95$, $p < .05$.

In order to examine infants' performance on the switch trial in the context of their past responses, we analyzed performance across all trials. As outlined previously, infants were categorized into three groups based on their pattern of reaching across A and B trials: correct on all trials, random, or perseverating. The results are presented in Fig. 2. At 6 months, the dominant pattern for low SES infants was reaching correctly, while the dominant pattern for high SES infants was perseverating (60% perseverated, which is still at chance levels). A chi-squared test of independence comparing the frequencies of each response type at 6 months confirmed that the differences were statistically significant, $X^2(2) = 7.30$, $p < .05$. At 9 months, the dominant pattern for low SES infants was reaching randomly, while the dominant pattern for high SES infants was perseverating. Again, a chi-squared test of independence comparing the frequencies of each response type at 9 months confirmed that these differences were statistically significant, $X^2(2) = 6.17$, $p < .05$. Finally, at 12 months, the dominant pattern for low SES infants was perseverating, while the dominant pattern for high SES infants was reaching correctly. A chi-squared test of

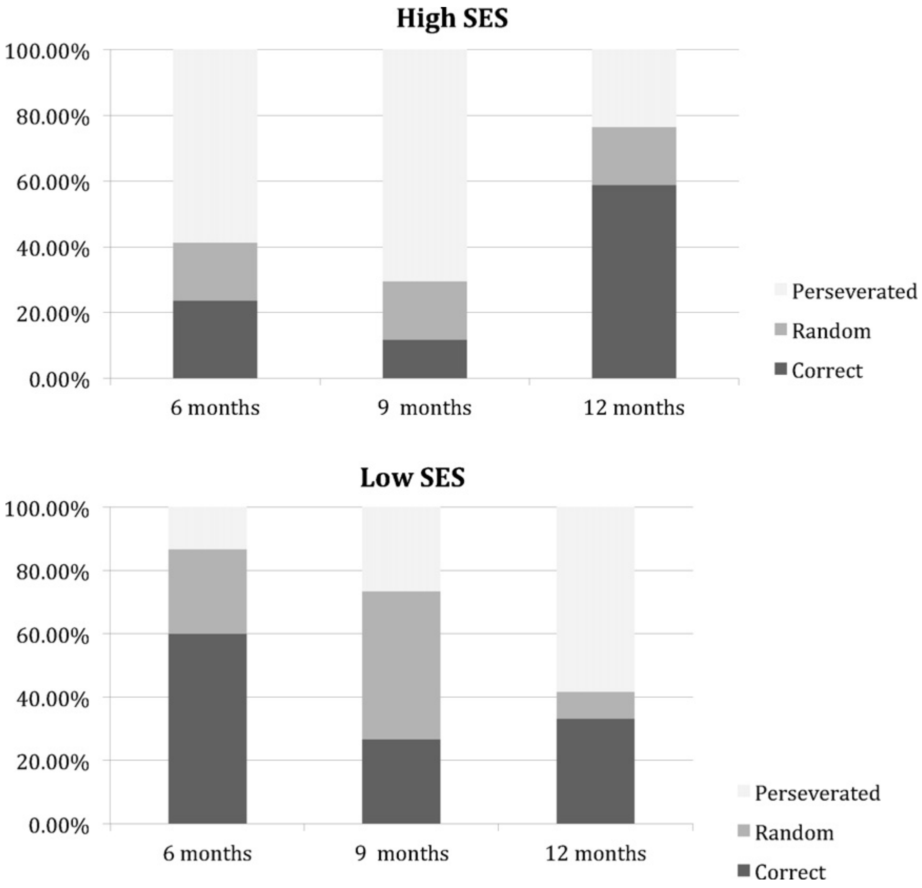

Fig. 2. Perseverative responses by age and SE.

independence comparing the frequencies of each response type at 12 months confirmed statistically significant differences, $X^2(2) = 3.95$, $p < .05$.

3. Discussion

By the time children enter school, cognitive delays associated with poverty are readily observable (Bradley & Corwyn, 2002; Brooks-Gunn & Duncan, 1997; Duncan et al., 1998; Evans, 2004). The present study suggests that these cognitive delays may actually emerge as early as 6 months of age, and remain stable through the first year.

The high-SES infants generally replicated the developmental trajectory described in earlier studies (Clearfield et al., 2006). At 6 months of age, the high-SES infants tended to reach randomly or perseverate. According to Clearfield et al. (2006), infants at this age should be transitioning from correct reaching to perseveration, so some will demonstrate each of these patterns, and the majority should reach randomly. Infants in the present sample perseverated more than any other pattern, although not more than chance. At 9 months, most infants perseverated, and by 12 months, most reached correctly. This pattern replicates the well-established developmental trajectory from the literature (e.g., Bell & Fox, 1992; Diamond, 1985).

In contrast, the low-SES infants in this sample lagged a step behind. At 6 months, these infants reached correctly more than any other pattern of response. This is the typical response of 5-month-olds, and indicates a lack of strong motor memory or a stronger tendency towards the more immediate stimulation without interference from longer-term memory (Clearfield et al., 2006; Munakata, 1998). At 9 months, when infants generally perseverate, the low-SES infants reached randomly. And at 12 months, when most infants, including the high-SES infants in the present study, reach correctly, the low-SES infants perseverated. These data lend further support that low-SES infants demonstrate delays in cognitive flexibility (Lipina et al., 2005).

Critically, the low-SES infants demonstrate the delay at all 3 test sessions, implying that the delays are stable over time. This is consistent with numerous studies that show that emotional, behavioral and cognitive consequences of poverty become less favorable the longer children live in poverty (Duncan & Brooks-Gunn, 2000; Evans, 2004; Evans & Schamberg, 2009). This body of research suggests that the delays observed in the present study are likely to remain stable over time, especially if these infants continue to live in poverty.

The finding that cognitive flexibility is visibly impaired by SES in early infancy highlights the fact that SES exerts a powerful influence on development at a much earlier age than is typically studied. Early changes in the brain might explain performance on the perseverative reaching task. Both longitudinal and cross-sectional research has shown that infants between the ages of 7 and 12 months who are more able to reach correctly on A-not-B after a longer delay also show higher electroencephalography (EEG) activity in the frontal cortex, relative to infants who only reach correctly after a short delay (Bell & Fox, 1992). Infants who tolerated longer delays also showed changes over time in frontal EEG power, whereas those infants who could not tolerate longer delays showed little change in their frontal EEGs over time (Bell & Fox, 1992). Although these findings do not specifically address the effect of SES on these patterns, they present the possibility that the delays observed in low-SES infants be related to differing patterns of brain development, specifically in the frontal cortex.

Moreover, physiological differences between the brains of high and low-SES children might be explained by the fact that poverty is associated with elevated exposure to stress and different biological responses to stress (e.g., Blair et al., 2005; Evans, 2004; Evans & English, 2002). Children between 3 and 9 years of age who grow up in poverty have difficulty regulating their cortisol levels, and these difficulties have been directly associated with lowered performance on various cognitive tasks (Blair et al., 2005). There is also some evidence to suggest that the way infants respond to stress is influenced by SES while the child is still in the womb (Keenan, Gunthorpe, & Grace, 2007). Thus, patterns of stress exposure and response may help explain why cognitive differences associated with SES are emerging so early in development.

The amount of maternal sensitivity and the extent to which mothers provide verbal stimulation for their infants may also partially account for early cognitive delays. Mothers' linguistic and cognitive stimulation of their children is significantly associated with infant cognitive development between 14 and 36 months (Chang, Park, Singh, & Sung, 2009). Verbal stimulation provided by the mother is also a significant predictor of cognitive development between 8 and 12 months (Page, Wilhelm, Gamble, & Card, 2010). Children in low-SES families tend to receive harsher punishments, less maternal social support and warmth, and less cognitive stimulation from their parents than do children in higher-SES families (e.g., Evans, 2004). These differences in parental responsiveness have been documented even in early infancy. The fact that poverty is typically associated with decreased quality of mother–child interactions may help account for the early disparities in cognitive development observed in the present study.

The present study represents a critical step in determining when the well-established cognitive delays associated with poverty emerge, and the specific kinds of processes that are affected. Although the precise mechanism has yet to be determined, these results indicate that further studies on mechanism must begin much earlier, as early as the first few months of life. These results also provide a critical impetus for developing new and early interventions for infants in low income families. If policies can be created that address the risk of cognitive delays in infancy, it may be possible to alleviate the cognitive and academic gap observed between low and high-SES children in preschools and schools.

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