Revised text of:

Effects of socioeconomic status on brain development, and how Cognitive Neuroscience may contribute to leveling the playing field

Rajeev D. S. Raizada[1*] and Mark M. Kishiyama[2]

[1]Neukom Institute for Computational Science, HB 6255, Dartmouth College, Hanover NH 03755.
[2]Helen Wills Neuroscience Institute, 132 Barker Hall, UC Berkeley, CA 94720-3190.

[*]To whom correspondence should be addressed: rajeev.raizada@dartmouth.edu

Abstract

The study of socioeconomic status (SES) and the brain finds itself in a circumstance unusual for Cognitive Neuroscience: large numbers of questions with both practical and scientific importance exist, but they are currently under-researched and ripe for investigation. This review aims to highlight these questions, to outline their potential significance, and to suggest routes by which they might be approached. Although remarkably few neural studies have been carried out so far, there exists a large literature of previous behavioural work. This behavioural research provides an invaluable guide for future neuroimaging work, but also poses an important challenge for it: how can we ensure that the neural data contributes predictive or diagnostic power over and above what can be derived from behaviour alone? We discuss some of the open mechanistic questions which Cognitive Neuroscience may have the power to illuminate, spanning areas including language, numerical cognition, stress, memory, and social influences on learning. These questions have obvious practical and societal significance, but they also bear directly on a set of longstanding questions in basic science: what are the environmental and neural factors which affect the acquisition and retention of declarative and nondeclarative skills? Perhaps the best opportunity for practical and theoretical interests to converge is in the study of interventions. Many interventions aimed at improving the cognitive development of low SES children are currently underway, but almost all are operating without either input from, or study by, the Cognitive Neuroscience community. Given that longitudinal intervention studies are very hard to set up, but can, with proper designs, be ideal tests of causal mechanisms, this area promises exciting opportunities for future research.

Conflict-of-interest statement:
The authors have no competing financial, personal, or professional interests relevant to this publication.

1 Introduction

The neural maturation and plasticity which underpin children's cognitive development provide an endless source of important questions for Cognitive Neuroscience. In some children, this development runs into problems. Consider the example of dyslexia, which, depending upon the criteria that are used, is thought to affect between five and ten percent of all children. Although much remains unknown and there is no definitive cure, a great deal has been discovered about dyslexia's cognitive and neural bases, a large number of different interventions have been developed and rigorously tested, and the behavioural and neural consequences of several such interventions have been longitudinally explored (e.g., Ahissar, 2007; Ramus & Szenkovits, 2008; Shaywitz et al., 2008; Gabrieli, 2009). From the perspective of basic science, such research has helped to illuminate questions about how the brain normally learns and processes language. In terms of practical consequences, it has helped to improve the reading of many children, to destigmatise the difficulties they are experiencing, and to show them that needing some additional reading instruction is not at all the same thing as being unintelligent. Perhaps the only downside of this impressive body of work is that it is harder these days to carry out novel dyslexia research than it used to be.

In contrast, consider exactly the same questions about the cognitive and neural consequences of growing up in a low SES environment. According to the 2007 Census, 17.4% of children in the United States live in poverty (U.S. Bureau of the Census, 2007, Information retrieved from the Univ. of Michigan National Poverty Center, at http://www.npc.umich.edu/poverty/). As is described in detail in the sections below, there have been a substantial number of behavioural studies of the effects on children's development, and also many intervention studies, but comparatively few of these have had the benefit of rigorously controlled randomised designs. There have been a handful of neuroimaging studies: enough to warrant optimism that this is a promising area of investigation, but a tiny number in comparison to the studies of dyslexia or other learning disabilities. Although there are many crucial basic science questions about how differences in the environment shape neural development, the large environmental differences shaping human neural development have scarcely been addressed. While some interventions have appeared promising, there is much uncertainty about how enduring their effects are, and about what the necessary ingredients of a truly successful intervention should be. Far from destigmatising the learning difficulties caused by low SES, the less-than-distant history of academic psychology has contained some rather unsavoury episodes of seeking to attribute these difficulties to genetic inferiority. Perhaps the only upside of the relative scarcity of research on SES is that this area contains a great many interesting and potentially consequential open questions for Cognitive Neuroscience, ripe for investigation.

2 The aims of this review, and how it differs from others

There have been a number of recent publications reviewing the role of SES in cognitive development. Table 1 points the reader to several of them, grouped by their area of focus. In the present paper, we seek to highlight two questions which have not yet received much attention: first, we describe the large and open research opportunities, both pure and applied, which currently exist in this subject area. Despite its direct relevance to many questions which are central to Cognitive Neuroscience, remarkably few studies have so far been carried out. Second, we discuss how neuroimaging can work to ensure that it contributes useful information over and above what can be obtained from purely behavioural studies, especially in terms of diagnostic and predictive power.

Domain	Type of data	Focus	References
Cognitive Neuroscience	Neural & behav.	Brain development	Hackman & Farah (2009); Lipina & Colombo (2009)
Cognitive Psychology	Behav. only	Home environment	Bradley & Corwyn (2002)
		Interaction with environment	Conger & Donnellan (2007)
		Societal context	Huston & Bentley (2009)
		Environmental stressors	Evans (2006)
		Cost-effectiveness of early intervention	Reynolds & Temple (2008)
		Books on early childhood intervention	Shonkoff & Meisels (2000); Feldman (2004); Nisbett (2009)
		Books on language in home environment	Heath (1983); Hart & Risley (1995)
Economics	Behav. only	Inequality and child development	Heckman (2006); Borghans et al. (2008)
	Neural & behav.	Inequality, plasticity and development	Knudsen et al. (2006)
NICHD longitudinal study	Behav. only	Effects of reduced time for maternal care	Brooks-Gunn et al. (2002)
		Effects of different types of child care	NICHD Early Child Care Research Network (2006)
		Long term effects of early child care	Belsky et al. (2007)
		Parental support for children's autonomy	NICHD Early Child Care Research Network (2008)
Intervention & follow-up	Behav. only	Perry Preschool Program	Weikart (1998); Belfield et al. (2006); Muennig et al. (2009)
		Abecedarian Program	Ramey & Ramey (1998a); Campbell et al. (2001)
		Chicago Longitudinal Study	Reynolds & Temple (1998); Reynolds et al. (2001, 2007)
Clinical	Neural & behav.	Interventions from pediatric perspective	Herrod (2007); Bonnier (2008); Bertrand et al. (2008)
	Behav. only	Public health & developing countries	Grantham-McGregor et al. (2007); Beddington et al. (2008)

Table 1: Summary of recent reviews on the relations between SES and cognitive development, from diverse fields.

3 An opportunity for neuroimaging: lots of behavioural data, but very little known about underlying mechanisms

As the list of reviews in Table 1 shows, there is a remarkable disconnect at present between the large amount of behavioural data which is available and the almost complete absence of corresponding neural data. This presents quite a research opportunity.

However, we wish to argue that simply measuring the "neural correlates" of SES-disparities would be insufficient. The behavioural data is compelling in its own right, and the mere process of adding of brain pictures may not in itself add any explanatory, diagnostic or predictive power, despite its seductive allure (Weisberg et al., 2008).

Fortunately, there are several ways in which neuroimaging may indeed be able to add substantively to our understanding, particularly in the area of intervention research. We now consider some possible approaches.

4 Ways in which neuroimaging can contribute over and above behaviour

The ideal circumstance for neuroimaging to make a contribution is when two people seem the same from outside the head, but actually differ inside the head. This information from inside the head is especially valuable if it contributes diagnostic or predictive power, over and above what purely behavioural measures can provide.

Examples of this are studies in which neuroimaging data helps to predict the degree to which subjects benefit from a subsequent intervention. This model has clear potential relevance to intervention studies in low-SES populations. For example, in studies of depression, activation in frontal and limbic regions has been found to be predictive of patient response to antidepressant drugs (Mayberg et al., 1997; Perlis et al., 2003; Langenecker et al., 2007) and to Cognitive Behavioural Therapy (Siegle et al., 2006). Similar results have been found in predicting gains from movement therapy in stroke patients (Dong et al., 2006). In a study of foreign-language learning in normal adults, Golestani et al. (2007) found that a structural measure, namely white-matter density in left Heschl's gyrus, predicted subjects' abilities to learn non-native speech sounds. In dyslexia research, a number of studies have shown that neural measures can predict subsequent reading ability, using ERPs in infants (Guttorm et al., 2005) and preschool children (Maurer et al., 2009), and using functional and structural MRI (Hoeft et al., 2007). This last study, by Hoeft et al., is especially notable, as it used cross-validation techniques to ensure that the extra predictive power due to the neural measures was genuinely present, as opposed to potentially being an artifact of over-fitting.

There are other ways for neuroimaging to contribute beyond behavioural studies, other than by making prospective longitudinal predictions. Another potentially valuable service is retrospective: probing the neural changes which underlie intervention-induced behavioural changes. For example, dyslexics often manage to improve their reading via a variety of ad hoc compensatory strategies. Although their reading performance appears outwardly to have gained, it is often supported by different neural systems than those found in normal readers, and is less fluent as a result (Shaywitz et al., 2003). After remediation programs, dyslexics' brain activation tends to becomes more similar to that of normal readers, suggesting that the training has succeeded in acting upon the brain's canonical reading circuits, rather than simply producing another compensatory work-around (Temple et al., 2003; Shaywitz et al., 2003). Similar questions could be investigated after interventions in low-SES children. However, we are not aware of any such study which has been carried out to-date, illustrating yet again the many open opportunities for Cognitive Neuroscience in this area.

It is not only in intervention studies that neuroimaging has the opportunity to carry information over and above what is available from behaviour. In a study of five-year-old children, Raizada et al. (2008) investigated the relations between SES, fMRI activity and a battery of standardised test scores, and found that SES was strongly correlated with the degree of hemispheric specialisation in Broca's area, as measured by left-minus-right fMRI activation during a rhyming task. However, that fact in itself does not suffice to show that the neural measure is conveying additional information. Both SES and Broca's asymmetry would be expected to correlate with the children's language-test scores also correlated, as indeed was found to be the case, and so the correlation between SES and Broca's could potentially be merely a trivial consequence of both measures' correlation with the language scores. However, this concern was ruled out by using partial correlation: the SES-Broca's link remained significant even after the effects of the language scores were removed. This does not imply that SES was influencing Broca's via some kind of non-linguistic pathway. A more likely explanation is that the fMRI is a more sensitive measure of the development of Broca's than any of the behavioural tests are; each behavioural score is a compound function of perception, cognition, attention and motor control, whereas fMRI can probe Broca's more directly. Thus, neuroimaging may be able to provide us with a means to tease apart neural representational competence from behaviourally-measured performance.

It should be noted that neural correlates of, and possible predictors for, SES-related impacts on behaviour are unlikely to be isolated to particular localised brain areas. Standard fMRI analysis takes a massively univariate approach, in which signals from the brain are analysed one voxel at a time. However, it is likely that multiple parts of the brain may act together in concert, especially in relation to a multifaceted phenomenon such as SES. Recently developed multivariate pattern-based methods of fMRI analysis are able to capture such multivoxel effects; for a review of the application of these methods to developmental cognitive neuroscience, see Bray et al. (2009) in this volume. These pattern-based fMRI analyses have an additional advantage: by measuring the similarity of the distributed patterns of neural activation that are elicited by different task conditions, they can study the structure of people's neural representations (Kriegeskorte et al., 2008). This allows fMRI to distinguish between neural representations which are well-structured for performing a given task and representations which are poorly structured (Raizada et al., 2009), thereby providing another route to teasing apart neural representational competence and behaviourally-measured performance. This distinction may have particular relevance to the puzzle discussed in Section 6.2 below, in which intervention-induced changes seem to "fade-out" in the short term, but then to produce significant improvements in people's later lives: it could be that while behavioural performance fades out, an underlying increase in neural representational competence may persist, lying latent for several years but then re-manifesting itself in improved behaviour later in life.

5 What are the behavioural and neural differences associated with low SES?

As mentioned above, there is a substantial disconnect between the amount of behavioural and neural data available on SES disparities. However, there is also a large disconnect between general diagnostics of cognitive ability and academic achievement and assessments of specific cognitive processes. For example, previous research has found that children from low SES backgrounds perform below children from higher SES backgrounds on tests of intelligence and academic achievement (Bradley & Corwyn, 2002; Duncan et al., 1994). Children from low SES backgrounds are also more likely to fail courses, be placed in special education, and drop out of high school compared to high SES children (McLoyd, 1998).

Although intelligence tests and academic achievement reflect cognitive ability, they are not particularly informative about brain regions associated with specific cognitive processes (i.e., neurocognitive systems). Accordingly, specific neuropsychological assessments have been employed in recent investigations to decompose cognitive function. In particular, Farah and colleagues used these techniques to derive several relatively independent neurocognitive systems (Noble et al., 2005; Farah et al., 2006; Noble et al., 2007; Hackman & Farah, 2009). These systems are anatomically and functionally defined by neuropsychological studies with brain-damaged patients and activation studies using neuroimaging techniques with healthy subjects.

Table 2 summarises some of the main SES-related findings in these neurocognitive systems. Collectively, these studies present substantial evidence that the playing field is indeed unlevel. In the following section, we consider a range of interventions which have attempted to level it, and how these interventions create an exciting and also pressing opportunity for Cognitive Neuroscience.

6 Interventions: towards leveling the playing field

Given the large body of behavioural data described above, along with the very small but growing body of neural data, there is little doubt that children's development takes place on an unlevel playing field: lower SES children experience environments which are more stressful and less cognitively enriching than those of higher SES children. This immediately raises the question: what can be done to improve the conditions for these children's development?

As was remarked upon in the introduction to this paper, Cognitive Neuroscience finds itself in an unusual and potentially very fruitful position here. There are many intervention programs already on-

Domain	Type of data	Task	Subjects	Finding	References
Language	Behav. only	Lang. in home	Children	SES corrs. with richness of language environment	Heath (1983); Hart & Risley (1995)
	Behav. only	Lang. in home	4-5yo children	SES corrs. with maternal and child syntax	Huttenlocher et al. (2002)
	Behav. only	Lang. in home	2yo children	SES corrs. with maternal and child vocabulary	Hoff (2003)
	Behav. only	Standardised tests	5yo children	SES corrs. with vocab., phon.awareness, grammar	Noble et al. (2005)
	Struct. MRI	Phon. awareness	11yo children	SES does not corr. with planum temporale asym.	Eckert et al. (2001)
	fMRI	Reading ability	Dyslexic adults	Compensated readers were at higher SES schools	Shaywitz et al. (2003)
	fMRI	Phon. awareness	6-9yo children	Higher SES have less typical brain-behav. relation	Noble et al. (2006)
	fMRI	Rhyming task	5yo children	SES corrs. with left-minus-right Broca's activation	Raizada et al. (2008)
Math	Behav. only	Number tasks	3-5yo children	Low-SES children worse in verbal math problems	Jordan et al. (1994)
	Behav. only	Number intervention	4-5yo children	Low-SES math improved by Number Worlds	Griffin et al. (1994)
	Behav. only	Number intervention	3-4yo children	Low-SES math improved by Pre-K Math	Starkey et al. (2004)
	Behav. only	Number intervention	4-5yo children	Low-SES math improved by linear board game	Siegler & Ramani (2008)
	Behav. only	Home env., math	3-10yo children	SES is a predictor of math attainment at age 10	Melhuish et al. (2008)
	Behav. only	General math	Young children	General reviews of SES and math	Jordan & Levine (2009)
Attention, Exec.func.	Behav, cortisol	Cogn. tasks, cortisol	6-16yo children	Age-dependent cortisol and attention SES diffs	Lupien et al. (2001)
	Behav. only	Attent. Network Test	6yo children	Low-SES children had reduced attentional control	Mezzacappa (2004)
	Behav. only	A-not-B task (exec.)	6-14mo infants	Low-SES infants made more errors	Lipina et al. (2005)
	Behav. only	Working mem./Exec.	5yo children	Low-SES had reduced working mem. & exec.func	Noble et al. (2005)
	Behav. only	Working mem./Exec.	10-13yo children	Low-SES had reduced working mem. & exec.func	Farah et al. (2006)
	Behav. only	Working mem./Exec.	6-7yo children	Low-SES had reduced working mem. & exec.func	Noble et al. (2007)
	ERP, behav.	Auditory attention	11-14yo children	Nd ERP in high but not low SES, no behav. diff	D'Angiulli et al. (2008)
	ERP, behav.	Visual attention	7-12yo children	Low SES: reduced visual and novelty (N2) ERPs	Kishiyama et al. (2009)
	ERP, behav.	Auditory attention	3-8yo children	Low SES: less ERP suppression of unattended	Stevens et al. (2009)
Memory	Behav. only	Memory	Adults	General review of SES and memory	Herrmann & Guadagno (1997)
	Behav. only	Incidental learning	6-13yo children	Low SES had reduced incidental learning	Farah et al. (2006); Noble et al. (2007)
	ERP, behav.	Recency/recognition	Adults	Elderly low-SES worse on recency task	Czernochowski et al. (2008)
Stress	Behav, cortisol	Cortisol, surveys	6-10yo children	Low SES: higher cortisol, maternal depression	Lupien et al. (2000)
	Behav, cortisol	Cogn. tasks, cortisol	6-16yo children	Age-dependent cortisol and attention SES diffs	Lupien et al. (2001)
	Behav, physiol.	Cortisol, blood press.	13yo children	Poverty corrs. with impaired stress reactivity	Evans & Kim (2007)
	Behav, physiol.	Working mem., stress	Young adults	Poverty corrs. with poorer working mem.	Evans & Schamberg (2009)
	Struct. MRI	Parental care, MRI	Young adults	Parental nurturance corrs. with hippocampal vol.	Rao et al. (2010)

Table 2: Some of the main experimental findings on SES and cognitive development. From the very small number of neural studies, together with the large number of behavioural findings, it can be seen that there are great opportunities for new research.

going, and more still about to start up, but almost all are operating without either input from, or study by, the Cognitive Neuroscience community. There is clearly an opportunity here to start addressing questions which are important not only from a societal point of view but also in terms of basic science. What kinds of interventions produce enduring neural changes? What kinds of intervention-induced neural changes are most predictive of longer term post-intervention behavioural gains?

6.1 Examples of successful interventions, tested with proper controls

Although many interventions have been attempted, there have been relatively few which meet the strict scientific criteria of a rigorous randomised trial. The confidence with which claims of effectiveness can be made is therefore not as high as it could be. However, there have been a number of studies which do meet these standards, and of those some have provided invaluable longitudinal data about the interventions' enduring effects from childhood into adulthood. In the following section, we wish to highlight the neuroscientific questions and opportunities which some of these interventions suggest, to discuss what the successes and shortcomings of such interventions might tell us about underlying neural mechanisms, and to emphasise the untapped potential for new neuroscientific studies which such interventions offer.

The two best examples of randomised interventions with long-term longitudinal follow-up data are the Abecedarian Program (Barnett & Masse, 2007; Ramey & Ramey, 1998b; Campbell et al., 2001, 2008), and the Perry Preschool Program (Weikart, 1998; Muennig et al., 2009; Belfield et al., 2006). A third source of longitudinal data on the effects of intensive intervention is the Child-Parent Center (CPC) Program, whose follow-up branch is called the Chicago Longitudinal Study (Reynolds & Temple, 1998; Reynolds et al., 2001, 2007). That intervention treated all of its enrolled children and hence did not have a randomised design, but its follow-up studies have used a quasi-experimental cohort design by selecting randomised and matched control groups. All three programs concentrated on low-SES, predominantly ethnic minority children. In the present discussion, we will focus on the two fully randomised studies, namely the Perry Preschool and Abecedarian programs.

The Perry program enrolled 64 children at ages three and four, and consisted of intensive daily sessions lasting two and a half hours each, and also a weekly 90-minute home visit to build parental involvement. This lasted for thirty weeks each year, for four years. Longitudinal follow-up is ongoing, with the most recent paper describing the participants 37 years later (Muennig et al., 2009). The Abecedarian program was larger, with 111 children, and was even more intensive, involving full-day care from 7:30am to 5:30pm, five days per week, 50 weeks per year, with free transportation provided. The children started at an average age of 4.4 years, and remained in the program until age 8. Longitudinal follow-up continued until age 21.

The interventions described above all seek to address a broad range of cognitive skills simultaneously. There also exist several low-SES-targeted interventions which are more tailored towards addressing specific skills, some of which have been mentioned in the discussion of different neurocognitive systems above. Examples include the math interventions listed in Table 2 (Griffin et al., 1994; Starkey et al., 2004; Ramani & Siegler, 2008; Siegler & Ramani, 2008), and the "Tools of the Mind" intervention aimed at improving executive function in pre-school children, which is discussed further in Section 6.4 below (Diamond et al., 2007), and, also in the domain of executive function, an ongoing training study aimed at improving children's fluid reasoning ability (Mackey & Bunge, 2009). These more skill-specific studies have not yet been followed up with long-term longitudinal data, the crucial question of their enduring impact is as yet unaddressed. The longitudinal follow-up data that we do possess shows a puzzling pattern, which Cognitive Neuroscience may be very well positioned to help explain. In the following section, we consider that puzzle and the possible opportunity which it brings with it.

6.2 The problem of fade-out, and the puzzle of longer term gains

The Abecedarian and Perry Preschool programs described above were clearly major undertakings. One would expect such strenuous efforts to be almost guaranteed to produce beneficial effects in the participating children, at least in the short term. That was indeed found to be the case, as the references cited above describe. However, they both exhibited a puzzling effect, which is almost tailor made for a Cognitive Neuroscience investigation: after the children left the program, the benefits in IQ and other test scores appeared to "fade out". Remarkably, though, longitudinal follow-up decades later revealed that the participants did much better than comparable non-enrolled children on several important life-measures, including the proportion who graduated high-school, who studied in a 4-year college, or who owned their own home. A concise summary of these results can be found in Knudsen et al. (2006). Chapter 7 of Nisbett (2009) also provides an excellent discussion of these and related findings.

This is an encouraging long-term result, but also a puzzling one. If intervention-induced gains fade out relatively quickly, then there might seem to be even less chance that any gains would be observed decades later, in adult life. It might appear that the effects of such interventions on cognition might be a little like the weight-loss achieved by a crash diet: once the intervention is ended, the benefits tend to "fade out." The Head Start program in particular has been criticised on these grounds, with a possible cause of the fade-out being the poor quality schools that children are fed into after their participation in Head Start ends (Currie & Thomas, 2000; Fryer & Levitt, 2004). However, such claims are controversial, and it has been argued that much of the apparent fade-out is an artifact of attrition and poor design in follow-up studies (Barnett & Hustedt, 2005).

Although the data for Head Start may be unclear, the data illustrating short-term fade-out in the Perry Preschool Program is unequivocal, and can be clearly seen in Fig.1 of Knudsen et al. (2006): in their first two years of participation in the Perry program, children's average IQs increased by 10 to 15 points compared to a control group, but by the age of 10, two years after the children had left the program, these gains had completely faded out, with no difference between the intervention and control groups. Despite that, the data showing real longer-term gains is equally clear: it is especially striking to compare the fade-out at age 10 shown in Fig.1 with the major improvements in life circumstances at age 27 which are summarised in Fig.2A of the same paper. Similar results emerged for the Abecedarian Program, also summarised in the same figures. Clearly this is a puzzle in need of explanation. In the following section, we suggest this constitutes a particularly promising opportunity for Cognitive Neuroscience to make a contribution.

6.3 An opportunity for Cognitive Neuroscience: what are the neural changes that endure while behavioural changes are fading out?

As was argued in Section 4 above, the ideal circumstance for neuroimaging to make a contribution is when two people seem the same from outside the head, but actually differ inside the head, especially if these internal neural differences can provide predictive power, over and above what purely behavioural measures can provide.

This is precisely the case in the situation described here of short-term fade-out followed by longer-term gains. Looking only at the behavioural measure of IQ scores, a 10-year-old child who had previously participated in the Perry Preschool Program would have seemed no different from a 10-year-old in a non-intervention control group. However, something about those children must have been different, as the Perry participants went on to be much more likely graduate from high school, to own a home, and to stay off welfare.

One possibility, which has yet to be explored, is that differences in neural maturation and neural representational capacity may be induced by interventions, but that they may manifest themselves in behaviour only gradually over the course of many years. Two newly built houses may both look good upon completion, but the one with more firmly built foundations and more weather-proof paint will be in much better shape after ten or fifteen years. Neuroimaging could, potentially, be able to reveal how an intervention acts to strengthen the neural foundations upon which a child's later cognitive development depends. Which neural measures, if any, might turn out to have the greatest long-term predictive power is a potentially important empirical question which is currently completely open.

6.4 Metacognitive skills: self-control, perseverance, and long-term benefits

Another possible explanation for the occurrence of longer-term gains after short-term fade-out, and one which is not at all exclusive of the neural hypothesis suggested above, is that the intervention programs may have induced greater powers of self-regulation and self-control in the children, and that these enhanced executive skills may have manifest themselves in greater academic attainment much later in life. In kindergarten, improved self-control may have only a weak effect on how much a child learns, but in high-school, when self-directed study and homework start to become important, the effect could be substantial.

In an important series of studies, Duckworth and colleagues have shown that such self-discipline and perseverance, which they capture using the term "grit", is more predictive of academic performance than are more conventional measures such as IQ (Duckworth & Seligman, 2005; Duckworth et al., 2007; Duckworth & Quinn, 2009).

Such powers of self-regulation may be trainable from a young age. Working with low-SES preschool children, Diamond and colleagues (Diamond et al., 2007) have recently produced exciting evidence that self-control and executive function can be increased, using an intervention called "Tools of the Mind" which is based on Vygotsky's principles of executive function and development (Bodrova & Leong, 1996). The children in the study showed improved accuracy on tests that measure core aspects of executive function. In a follow-up study, Barnett et al. (2008) replicated these effects on executive function, but found only small improvements in language development. It will be important to carry out long-term follow-up of such studies, to see whether academic gains may start to emerge later in high-school, when self-regulatory skills start to have a more direct impact on academic outcomes via homework, revision for exams and so on.

Given these considerations, it is possible that the longer-term gains exhibited by the Perry Preschool and Abecedarian Program participants may have stemmed from enduring improvements in self-regulation. Such gains may have little effect on measured IQ scores, but may make all the difference in helping children to avoid dropping out of high-school. This possibility also suggests several specific neural and cognitive hypotheses that could be tested, using the prefrontal/executive tasks such as stop-signal inhibition and Stroop interference (Stuss & Alexander, 2000).

6.5 Positive feedback loops: how a small intervention may eventually have large effects

One particularly appealing aspect of training executive function in young children is that it could potentially trigger a long-term self-reinforcing trend, with improved self-control enabling greater attentiveness and learning, which would in turn help to make a child's educational experiences more rewarding, thereby facilitating yet more intellectual growth. That rather rosy-sounding scenario of course raises the question of whether such positive feedback loops can in fact be induced.

One phrase that has been used to describe such phenomena is "the Matthew effect" (Merton, 1968), based on the following text from the Gospel of St. Matthew: "For unto every one that hath shall be given, and he shall have abundance: but from him that hath not shall be taken away even that which he hath" (XXV:29). In other words, the rich get richer and the poor get poorer. In the domain of cognitive development, Stanovich (1986) argued that learning to read can produce precisely such effects: the better a child can read, the more likely they are to seek out and find new reading material, thereby improving their reading ability still further. Conversely, a child who experiences reading difficulties may become more and more likely to avoid reading, thus dropping further and further behind. The degree to which this phenomenon actually holds true in reading development is a topic of some debate (Shaywitz et al., 1995; Scarborough & Parker, 2003; Morgan et al., 2008). It may well hold true in interventions of the sort considered in the present review: in a meta-analysis of interventions aimed at making children's home environments more conducive for cognitive development, it was found that higher SES households showed more improvements than did lower SES ones (Bakermans-Kranenburg et al., 2005).

In two studies reported in Science, Cohen and colleagues have shown that brief self-affirmation writing assignments aimed at reducing feelings of academic threat in ethnic minority high-school students had the effect of producing significant improvements in grade-point average, which endured over a period of two years (Cohen et al., 2006, 2009). They argue that this small intervention can induce large effects precisely due to triggering a positive feedback loop, writing that "because initial psychological states and performance determine later outcomes by providing a baseline and initial trajectory for a recursive process, apparently small but early alterations in trajectory can have long-term effects" (Cohen et al., 2009).

Another source of evidence that seemingly small interventions can have large effects if they induce enduring changes in mindset comes from the work of Carol Dweck and colleagues (Dweck, 2007; Blackwell et al., 2007). They have shown that teaching children a "growth mindset", in which achievement is viewed by the child as deriving from hard work and therefore being under their individual control, as opposed to a "fixed mindset", in which achievement is viewed as being determined by how much innate ability one happens to have, can lead to markedly improved long-term educational outcomes. Specifically, in an intervention study with 7th graders drawn from a range of SES and ethnic backgrounds, Blackwell et al. (2007) found that the math scores of children who had been taught the growth mindset increased with respect to a fixed-mindset group over a period of one and a half years.

6.6 KIPP, the Harlem Children's Zone, and a coming wave of interventions in need of neural measures

The Perry Preschool and Abecedarian studies described above show that sustained and intensive interventions can indeed make lasting differences in the lives of low-SES children. However, those studies were of very limited size, raising the question of whether they can be scaled up in order to help larger populations of children. Naturally, the larger a program becomes, the harder it is to preserve sustained and intense high-quality intervention. Some exciting programs attempting to do precisely that are taking place right now.

One such effort is an organisation of charter schools called the "Knowledge is Power Program", or KIPP (http://www.kipp.org). Founded in 1994, KIPP currently includes 82 schools across 19 states with around 20,000 students in all. The KIPP students are drawn almost entirely from low-SES neighbourhoods, with more than 80% of the children being eligible for free or subsidised school lunches, and are highly intensive. There is a strong emphasis on self-discipline and commitment to learning, and children receive small monetary reward "paychecks" each week, based on their academic performance and standards of behaviour (Mathews, 2009).

An even more ambitious program, although currently not operating on as large a scale, is the Harlem Children's Zone, or HCZ (http://www.hcz.org). This program seeks to create a continuous "pipeline" to promote the cognitive development of low-SES children, starting from birth and continuing through preschool, elementary school and middle school. One of the main aims of having such an unbroken chain of high quality care is to prevent fade-out from having any opportunity to arise. An excellent description of the program and its creation can be found in Tough (2008).

Unlike the much smaller Perry Preschool and Abecedarian programs, there is no randomised control group available against which the KIPP or HCZ schools' performance can be compared, and indeed such an arrangement at so large a scale would probably be impossible. Thus, studies of their effectiveness must be interpreted with caution. With that borne in mind, initial results are promising: KIPP children's scores on California State and national language and math tests were markedly higher than those of children from comparison schools (Woodworth et al., 2008), and Harlem Children's Zone students ranked in the top fifth of all 8th grade classes in the whole of New York City, a comparison group in which most of the schools are from higher SES neighborhoods than Harlem (Tough, 2008).

In what may by now be a familiar refrain to readers of this review, we wish to point out that this very large scale intervention program has, as far as we are aware, been not yet been accompanied by any Cognitive Neuroscience measures whatsoever, not even at the behavioural level. Clearly there are potential research opportunities here, although the absence of a pre-existing randomised control group means that, in order to be statistically valid, studies may need to use very carefully controlled prospective longitudinal designs.

In 2008, more than 10,000 children were enrolled in the various sections of the Harlem Children's Zone program. However, it is likely that over the coming two to three years, a far larger number of children will participate in such programs: the Obama administration has proposed in its 2010 budget plan to set up "Promise Neighborhoods" in urban centers across the country, directly modeled on the Harlem program. (See http://www.whitehouse.gov/omb/fy2010_key_education). As we discuss in Section 7.2 below, this coming wave of large-scale intervention programs constitutes a pressing opportunity for Cognitive Neuroscience. They could either be a source of invaluable data about the impact of cognitive stimulation on neural development, or they could become yet another example of a major behavioural study passing by, without any knowledge being gained about the underlying neural mechanisms that the intervention is fundamentally acting upon.

7 Challenges, opportunities and future directions

7.1 Minefields associated with investigating SES, and approaches for defusing them

Any researcher who starts to investigate the relation between cognitive development and SES will quickly find that this is very much a touchy topic. There is often a suspicion that some attempt may be made to put a scientific veneer of respectability onto a claim that people from lower socioeconomic backgrounds are somehow inferior or undeserving. From the current authors' own perspective, which we have no reason to believe is atypical of the field in general, this is absolutely the opposite of what is intended. On the contrary, the hope would in fact be to provide scientific support for educational and social intervention programs which would help to reduce socioeconomic disparities. In order pre-emptively to fend off misunderstandings of this sort, it may be wise to make such intentions as explicit and salient as possible. We hope that the title of this paper reflects that.

Another objection frequently leveled against studies of SES, and not always without some justification, is that scientific studies may take too reductive a view of the complex and multifaceted environments in which children grow up. A variety of factors interact at multiple scales, including parents, schools, social peer groups, and neighbourhood communities, yet despite that SES is often characterised by just a single number. Such a one-dimensional measure is undoubtedly an over-simplification, but such over-simplifications can be useful at least as an initial step, especially for trying to find important trends in large and complex datasets. Fortunately, much more detailed and multidimensional measures of children's environments are available, such as the HOME Inventory of Bradley, Caldwell and colleagues (Bradley et al., 1988, 2001). Recent reviews emphasising the importance of viewing SES in a sociological context can be found in Conger & Donnellan (2007) and Huston & Bentley (2009).

A related potential criticism is the suggestion that Cognitive Neuroscience studies portray being of low SES as some kind of "deficit". Here again, it seems to us that a helpful response is to emphasise that the aim is quite the opposite, namely to help build the foundations for improving children's educational opportunities. There can also be an understandable discomfort about having a bunch of rich, white university professors coming along and trying to tell poorer people how they should raise their children. A promising solution to this problem is exemplified by the Harlem Children's Zone, which is staffed by people who have lived and grown up in the in the local community.

Unfortunately, the suspicion of academic psychology described above has not always been unwarranted. The field has, in the not very distant past, been associated with some rather unsavoury claims that socioeconomic achievement gaps are caused by some alleged genetic inferiority. The best known expression of this view is the book "The Bell Curve" (Herrnstein & Murray, 1994). Several very detailed and thorough dismantlings of that thesis have been published, perhaps most notably the books by Gould (1996) and, more recently, Nisbett (2009). Without attempting to repeat all those arguments here, we wish to highlight two points in particular. First, as Nisbett (2009) argues in detail, studies that appear to measure heritability may in large part be measuring environmental homogeneity. If all children grew up in exactly the same environment, then all characteristics would appear to be 100% hereditary and 0% due to environmental variation: no effects can be accounted for by environmental variation if there is no environmental variation in the first place. In terms of providing environments conducive to children's cognitive development, the households of adoptive parents or of high-SES families may in fact be highly homogeneous, with them all containing educated adults who play with and read to their children. In contrast, the environments in lower SES households may have much greater variability. Based purely on these environmental homogeneity considerations, one would therefore predict that intelligence should appear to be much more heritable in high-SES families than in low-SES families. Indeed, this is precisely what is observed (Turkheimer et al., 2003). A second point worth making, which is not discussed in Nisbett (2009), is that the whole premise of the nature-vs.-nurture debate is rendered highly questionable by recent discoveries in genetics. Although our genes remain the same, the *expression* of those genes, i.e. whether those genes are turned on or off, is hugely influenced by the environment throughout life (Champagne & Mashoodh, 2009). Indeed, the activation and deactivation of genes within the nuclei of neurons is precisely the pathway via which the environment makes long-term changes to our synapses during learning (McClung & Nestler, 2008). Given this dynamic interplay between genes and the environment, with influence running in both directions, old controversies about nature-vs.-nurture may have hinged upon a distinction that is false.

7.2 A pressing opportunity: ongoing intervention programs without any Cognitive Neuroscience studies

Longitudinal intervention studies are perhaps the most difficult of all types of experiments to set up and run. They are time-intensive and very costly, and pose major challenges of subject recruitment and retention. This is true enough when the participants are well-off middle class families with their own transportation and the ability to find free time, but is greatly more difficult when they are low SES families struggling to get by. However, longitudinal intervention studies are also the only way to address many of the most important questions about cognitive development.

From this perspective, it would seem like quite a missed opportunity if several large-scale longitudinal interventions serving low SES children were to take place and run their course without any study by, or input from, the Cognitive Neuroscience community. Yet this is precisely what is happening right now, and what will be happening on a broader nationwide scale if a network of Promise Neighbourhoods is set up across the country without any neuroscientific measures being made. There is clearly an opportunity here to start addressing questions which are important not only in from an applied point of view but also in terms of basic science. What kinds of interventions produce enduring neural changes? What kinds of neural changes are most predictive of longer term post-intervention behavioural gains? Which neural processes fade away without constant support, and which can trigger self-sustaining improvements? In scientific and also societal terms, the impact from starting to answer these questions could be substantial.

References

Ahissar, M. (2007). Dyslexia and the anchoring-deficit hypothesis. *Trends Cogn Sci*, *11*(11), 458–65.

Bakermans-Kranenburg, M., van Ijzendoorn, M., & Bradley, R. (2005). Those who have, receive: The matthew effect in early childhood intervention in the home environment. *Review of educational research*, *75*(1), 1–26.

Barnett, W. & Hustedt, J. (2005). Head start's lasting benefits. *Infants & Young Children*, *18*, 16.

Barnett, W., Jung, K., Yarosz, D., Thomas, J., Hornbeck, A., Stechuk, R., & Burns, S. (2008). Educational effects of the tools of the mind curriculum: A randomized trial. *Early Childhood Research Quarterly*, *23*(3), 299–313.

Barnett, W. & Masse, L. (2007). Comparative benefit–cost analysis of the Abecedarian program and its policy implications. *Economics of Education Review*, *26*(1), 113–125.

Beddington, J., Cooper, C. L., Field, J., Goswami, U., Huppert, F. A., Jenkins, R., Jones, H. S., Kirkwood, T. B. L., Sahakian, B. J., & Thomas, S. M. (2008). The mental wealth of nations. *Nature*, *455*(7216), 1057–60.

Belfield, C., Nores, M., Barnett, S., & Schweinhart, L. (2006). The High/Scope Perry Preschool Program: Cost benefit analysis using data from the age-40 follow-up. *Journal of Human Resources*, *XLI*(1), 162.

Belsky, J., Vandell, D. L., Burchinal, M. R., Clarke-Stewart, K. A., McCartney, K., Owen, M. T., & National Institute of Child Health and Human Development Early Child Care Research Network (2007). Are there long-term effects of early child care? *Child development*, *78*(2), 681–701.

Bertrand, J., Williams, R., & Ford-Jones, E. L. (2008). Social paediatrics and early child development - the practical enhancements: Part 2. *Paediatrics & child health*, *13*(10), 857–61.

Blackwell, L. S., Trzesniewski, K. H., & Dweck, C. S. (2007). Implicit theories of intelligence predict achievement across an adolescent transition: a longitudinal study and an intervention. *Child development*, *78*(1), 246–63.

Bodrova, E. & Leong, D. (1996). *Tools of the mind: the Vygotskian approach to early childhood education*. Englewood Cliffs, N.J.: Merrill.

Bonnier, C. (2008). Evaluation of early stimulation programs for enhancing brain development. *Acta Paediatr*, *97*(7), 853–8.

Borghans, L., Duckworth, A. L., Heckman, J. J., & Weel, B. (2008). The economics and psychology of personality traits. *Journal of Human Resources*, *43*(4), 972.

Bradley, R. H., Caldwell, B. M., & Rock, S. L. (1988). Home environment and school performance: a ten-year follow-up and examination of three models of environmental action. *Child development*, *59*(4), 852–67.

Bradley, R. H. & Corwyn, R. F. (2002). Socioeconomic status and child development. *Annu. Rev. Psychol.*, *53*, 371–99.

Bradley, R. H., Corwyn, R. F., Burchinal, M. R., McAdoo, H. P., & Coll, C. (2001). The home environments of children in the United States part II: Relations with behavioral development through age thirteen. *Child development*, *72*, 1868 – 1886.

Bray, S., Chang, C., & Hoeft, F. (2009). Applications of multivariate pattern classification analyses in developmental neuroimaging of healthy and clinical populations. *Frontiers in Human Neuroscience*, *This volume*.

Brooks-Gunn, J., Han, W.-J., & Waldfogel, J. (2002). Maternal employment and child cognitive outcomes in the first three years of life: the NICHD study of early child care. *Child development*, *73*(4), 1052–72.

Campbell, F. A., Pungello, E. P., Miller-Johnson, S., Burchinal, M. R., & Ramey, C. T. (2001). The development of cognitive and academic abilities: growth curves from an early childhood educational experiment. *Developmental psychology*, *37*(2), 231–42.

Campbell, F. A., Wasik, B., Pungello, E. P., Burchinal, M. R., Barbarin, O. A., Kainz, K., Sparling, J., & Ramey, C. T. (2008). Young adult outcomes of the Abecedarian and care early childhood educational interventions. *Early Childhood Research Quarterly*, *23*(4), 452–466.

Champagne, F. & Mashoodh, R. (2009). Genes in context: Gene–environment interplay and the origins of individual differences in behavior. *Current Directions in Psychological Science*, *18*, 127–131.

Cohen, G. L., Garcia, J., Apfel, N., & Master, A. (2006). Reducing the racial achievement gap: a social-psychological intervention. *Science*, *313*(5791), 1307–10.

Cohen, G. L., Garcia, J., Purdie-Vaughns, V., Apfel, N., & Brzustoski, P. (2009). Recursive processes in self-affirmation: intervening to close the minority achievement gap. *Science*, *324*(5925), 400–3.

Conger, R. D. & Donnellan, M. B. (2007). An interactionist perspective on the socioeconomic context of human development. *Annu. Rev. Psychol.*, *58*, 175–99.

Currie, J. & Thomas, D. (2000). School quality and the longer-term effects of Head Start. *Journal of Human Resources*, *35*, 755–774.

Czernochowski, D., Fabiani, M., & Friedman, D. (2008). Use it or lose it? SES mitigates age-related decline in a recency/recognition task. *Neurobiol Aging*, *29*(6), 945–58.

D'Angiulli, A., Herdman, A., Stapells, D., & Hertzman, C. (2008). Children's event-related potentials of auditory selective attention vary with their socioeconomic status. *Neuropsychology*, *22*(3), 293–300.

Diamond, A., Barnett, W. S., Thomas, J., & Munro, S. (2007). Preschool program improves cognitive control. *Science*, *318*(5855), 1387–8.

Dong, Y., Dobkin, B. H., Cen, S. Y., Wu, A. D., & Winstein, C. J. (2006). Motor cortex activation during treatment may predict therapeutic gains in paretic hand function after stroke. *Stroke*, *37*(6), 1552–5.

Duckworth, A. L., Peterson, C., Matthews, M. D., & Kelly, D. R. (2007). Grit: perseverance and passion for long-term goals. *Journal of personality and social psychology*, *92*(6), 1087–101.

Duckworth, A. L. & Quinn, P. D. (2009). Development and validation of the short grit scale (grit-s). *Journal of personality assessment*, *91*(2), 166–74.

Duckworth, A. L. & Seligman, M. E. P. (2005). Self-discipline outdoes IQ in predicting academic performance of adolescents. *Psychological science : a journal of the American Psychological Society / APS*, *16*(12), 939–44.

Duncan, G. J., Brooks-Gunn, J., & Klebanov, P. K. (1994). Economic deprivation and early childhood development. *Child Dev*, *65*(2 Spec No), 296–318.

Dweck, C. S. (2007). The secret to raising smart kids. *Scientific American Mind*, *18*, 36–43.

Eckert, M. A., Lombardino, L. J., & Leonard, C. M. (2001). Planar asymmetry tips the phonological playground and environment raises the bar. *Child Dev*, *72*(4), 988–1002.

Evans, G. W. (2006). Child development and the physical environment. *Annu. Rev. Psychol.*, *57*, 423–51.

Evans, G. W. & Kim, P. (2007). Childhood poverty and health: cumulative risk exposure and stress dysregulation. *Psychological science : a journal of the American Psychological Society / APS*, *18*(11), 953–7.

Evans, G. W. & Schamberg, M. A. (2009). Childhood poverty, chronic stress, and adult working memory. *Proc Natl Acad Sci USA*, *106*(16), 6545–9.

Farah, M. J., Shera, D. M., Savage, J. H., Betancourt, L., Giannetta, J. M., Brodsky, N. L., Malmud, E. K., & Hurt, H. (2006). Childhood poverty: specific associations with neurocognitive development. *Brain Res*, *1110*(1), 166–74.

Feldman, M. A. (2004). *Early intervention: the essential readings*. Malden, MA, USA: Blackwell Pub.

Fryer, R. & Levitt, S. (2004). Understanding the black-white test score gap in the first two years of school. *Review of Economics and Statistics*, *86*(2), 447–464.

Gabrieli, J. D. E. (2009). Dyslexia: a new synergy between education and cognitive neuroscience. *Science*, *325*(5938), 280–3.

Golestani, N., Molko, N., Dehaene, S., LeBihan, D., & Pallier, C. (2007). Brain structure predicts the learning of foreign speech sounds. *Cereb Cortex*, *17*(3), 575–82.

Gould, S. J. (1996). *The mismeasure of man* (Rev. and expanded, with a new introduction ed.). New York: W.W. Norton.

Grantham-McGregor, S. M., Cheung, Y. B., Cueto, S., Glewwe, P., Richter, L., Strupp, B., & International Child Development Steering Group (2007). Developmental potential in the first 5 years for children in developing countries. *Lancet*, *369*(9555), 60–70.

Griffin, S., Case, R., & Siegler, R. S. (1994). Rightstart: Providing the central conceptual prerequisites for first formal learning of arithmetic to students at risk for school failure. In K. McGilly (Ed.), *Classroom lessons: Integrating cognitive theory and classroom practice* (pp. 25– 49). Cambridge, MA: MIT Press.

Guttorm, T., Leppänen, P., Poikkeus, A., Eklund, K., Lyytinen, P., & Lyytinen, H. (2005). Brain event-related potentials (ERPs) measured at birth predict later language development in children with and without familial risk for dyslexia. *Cortex*, *41*(3), 291–303.

Hackman, D. A. & Farah, M. J. (2009). Socioeconomic status and the developing brain. *Trends Cogn Sci*, *13*(2), 65–73.

Hart, B. & Risley, T. R. (1995). *Meaningful differences in the everyday experience of young American children*. Baltimore: P.H. Brookes.

Heath, S. B. (1983). *Ways with words: language, life, and work in communities and classrooms*. Cambridge: Cambridge University Press.

Heckman, J. J. (2006). Skill formation and the economics of investing in disadvantaged children. *Science*, *312*(5782), 1900–2.

Herrmann, D. & Guadagno, M. (1997). Memory performance and socio-economic status. *Applied Cognitive Psychology*, *11*(2), 113–120.

Herrnstein, R. J. & Murray, C. A. (1994). *The Bell Curve: Intelligence and Class Structure in American Life*. New York: Free Press.

Herrod, H. G. (2007). Do first years really last a lifetime? *Clin Pediatr (Phila)*, *46*(3), 199–205.

Hoeft, F., Ueno, T., Reiss, A. L., Meyler, A., Whitfield-Gabrieli, S., Glover, G. H., Keller, T. A., Kobayashi, N., Mazaika, P., Jo, B., Just, M. A., & Gabrieli, J. D. E. (2007). Prediction of children's reading skills using behavioral, functional, and structural neuroimaging measures. *Behav Neurosci*, *121*(3), 602–13.

Hoff, E. (2003). The specificity of environmental influence: socioeconomic status affects early vocabulary development via maternal speech. *Child development*, *74*(5), 1368–78.

Huston, A. & Bentley, A. (2009). Human development in societal context. *Annu. Rev. Psychol.*, *10.1146/annurev.psych.093008.100442*.

Huttenlocher, J., Vasilyeva, M., Cymerman, E., & Levine, S. (2002). Language input and child syntax. *Cogn Psychol*, *45*(3), 337–74.

Jordan, N., Huttenlocher, J., & Levine, S. (1994). Assessing early arithmetic abilities: Effects of verbal and nonverbal response types on the calculation performance of middle-and low-income children. *Learning and Individual Differences*, *6*(4), 413–432.

Jordan, N. C. & Levine, S. C. (2009). Socioeconomic variation, number competence, and mathematics learning difficulties in young children. *Developmental disabilities research reviews*, *15*(1), 60–8.

Kishiyama, M. M., Boyce, W. T., Jimenez, A. M., Perry, L. M., & Knight, R. T. (2009). Socioeconomic disparities affect prefrontal function in children. *J Cogn Neurosci*, *21*(6), 1106–15.

Knudsen, E. I., Heckman, J. J., Cameron, J. L., & Shonkoff, J. P. (2006). Economic, neurobiological, and behavioral perspectives on building America's future workforce. *Proc Natl Acad Sci USA*, *103*(27), 10155–62.

Kriegeskorte, N., Mur, M., & Bandettini, P. (2008). Representational similarity analysis - connecting the branches of systems neuroscience. *Front Syst Neurosci*, *2*, 4.

Langenecker, S. A., Kennedy, S. E., Guidotti, L. M., Briceno, E. M., Own, L. S., Hooven, T., Young, E. A., Akil, H., Noll, D. C., & Zubieta, J.-K. (2007). Frontal and limbic activation during inhibitory control predicts treatment response in major depressive disorder. *Biol Psychiatry*, *62*(11), 1272–80.

Lipina, S., Martelli, M., Vuelta, B., & Colombo, J. (2005). Performance on the A-not-B task of Argentinean infants from unsatisfied and satisfied basic needs homes. *Interamerican Journal of Psychology*, *39*, 49–60.

Lipina, S. J. & Colombo, J. A. (2009). *Poverty and brain development during childhood: an approach from cognitive psychology and neuroscience*. Washington, DC: American Psychological Association.

Lupien, S. J., King, S., Meaney, M. J., & McEwen, B. S. (2000). Child's stress hormone levels correlate with mother's socioeconomic status and depressive state. *Biol Psychiatry*, *48*(10), 976–80.

Lupien, S. J., King, S., Meaney, M. J., & McEwen, B. S. (2001). Can poverty get under your skin? Basal cortisol levels and cognitive function in children from low and high socioeconomic status. *Development and Psychopathology*, *13*(03), 653–676.

Mackey, A. & Bunge, S. (2009). Differential effects of two cognitive training programs in children. Conference on Neurocognitive Development.

Mathews, J. (2009). *Work hard. Be nice.: How two inspired teachers created the most promising schools in America* (1st ed ed.). Chapel Hill, N.C.: Algonquin Books of Chapel Hill.

Maurer, U., Bucher, K., Brem, S., Benz, R., Kranz, F., Schulz, E., van der Mark, S., Steinhausen, H.-C., & Brandeis, D. (2009). Neurophysiology in preschool improves behavioral prediction of reading ability throughout primary school. *Biological Psychiatry*, *66*(4), 341–8.

Mayberg, H., Brannan, S., Mahurin, R., Jerabek, P., Brickman, J., Tekell, J., Silva, J., McGinnis, S., Glass, T., Martin, C., & Fox, P. (1997). Cingulate function in depression: a potential predictor of treatment response. *Neuroreport*, *8*(4), 1057–61.

McClung, C. A. & Nestler, E. J. (2008). Neuroplasticity mediated by altered gene expression. *Neuropsychopharmacology*, *33*(1), 3–17.

McLoyd, V. C. (1998). Socioeconomic disadvantage and child development. *The American psychologist*, *53*(2), 185–204.

Melhuish, E. C., Sylva, K., Sammons, P., Siraj-Blatchford, I., Taggart, B., Phan, M. B., & Malin, A. (2008). The early years. preschool influences on mathematics achievement. *Science*, *321*(5893), 1161–2.

Merton, R. K. (1968). The Matthew effect in science. The reward and communication systems of science are considered. *Science*, *159*(810), 56–63.

Mezzacappa, E. (2004). Alerting, orienting, and executive attention: developmental properties and sociodemographic correlates in an epidemiological sample of young, urban children. *Child development*, *75*(5), 1373–86.

Morgan, P. L., Farkas, G., & Hibel, J. (2008). Matthew effects for whom? *Learning disability quarterly*, *31*(4), 187–198.

Muennig, P., Schweinhart, L., Montie, J., & Neidell, M. (2009). Effects of a prekindergarten educational intervention on adult health: 37-year follow-up results of a randomized controlled trial. *American journal of public health*, *99*(8), 1431–7.

NICHD Early Child Care Research Network (2006). Child-care effect sizes for the NICHD study of early child care and youth development. *The American psychologist*, *61*(2), 99–116.

NICHD Early Child Care Research Network (2008). Mothers' and fathers' support for child autonomy and early school achievement. *Developmental psychology*, *44*(4), 895–907.

Nisbett, R. E. (2009). *Intelligence and how to get it: why schools and cultures count* (1st ed ed.). New York: W.W. Norton & Co.

Noble, K. G., McCandliss, B. D., & Farah, M. J. (2007). Socioeconomic gradients predict individual differences in neurocognitive abilities. *Developmental Sci*, *10*(4), 464–480.

Noble, K. G., Norman, M. F., & Farah, M. J. (2005). Neurocognitive correlates of socioeconomic status in kindergarten children. *Developmental Science*, *8*(1), 74–87.

Noble, K. G., Tottenham, N., & Casey, B. J. (2005). Neuroscience perspectives on disparities in school readiness and cognitive achievement. *The Future of children / Center for the Future of Children, the David and Lucile Packard Foundation*, *15*(1), 71–89.

Noble, K. G., Wolmetz, M. E., Ochs, L. G., Farah, M. J., & McCandliss, B. D. (2006). Brain-behavior relationships in reading acquisition are modulated by socioeconomic factors. *Developmental Science*, *9*(6), 642–54.

Perlis, R., Iosifescu, D., & Renshaw, P. (2003). Biological predictors of treatment response in affective illness. *Psychiatr Clin North Am*, *26*(2), 323–44, vii.

Raizada, R. D. S., Richards, T. L., Meltzoff, A. N., & Kuhl, P. K. (2008). Socioeconomic status predicts hemispheric specialisation of the left inferior frontal gyrus in young children. *Neuroimage*, *40*(3), 1392–401.

Raizada, R. D. S., Tsao, F.-M., Liu, H.-M., & Kuhl, P. K. (2009). Quantifying the adequacy of neural representations for a cross-language phonetic discrimination task: Prediction of individual differences. *Cereb Cortex*, *Advance Online Publication: DOI:10.1093/cercor/bhp076*.

Ramani, G. B. & Siegler, R. S. (2008). Promoting broad and stable improvements in low-income children's numerical knowledge through playing number board games. *Child development*, *79*(2), 375–94.

Ramey, C. T. & Ramey, S. L. (1998a). Early intervention and early experience. *The American psychologist*, *53*(2), 109–20.

Ramey, C. T. & Ramey, S. L. (1998b). Prevention of intellectual disabilities: early interventions to improve cognitive development. *Preventive medicine*, *27*(2), 224–32.

Ramus, F. & Szenkovits, G. (2008). What phonological deficit? *Q J Exp Psychol (Colchester)*, *61*(1), 129–41.

Rao, H., Betancourt, L., Giannetta, J. M., Brodsky, N. L., Korczykowski, M., Avants, B. B., Gee, J. C., Wang, J., Hurt, H., Detre, J. A., & Farah, M. J. (2010). Early parental care is important for hippocampal maturation: evidence from brain morphology in humans. *Neuroimage*, *49*(1), 1144–50.

Reynolds, A. J. & Temple, J. A. (1998). Extended early childhood intervention and school achievement: age thirteen findings from the Chicago Longitudinal Study. *Child development*, *69*(1), 231–46.

Reynolds, A. J. & Temple, J. A. (2008). Cost-effective early childhood development programs from preschool to third grade. *Annual review of clinical psychology*, *4*, 109–39.

Reynolds, A. J., Temple, J. A., Ou, S.-R., Robertson, D. L., Mersky, J. P., Topitzes, J. W., & Niles, M. D. (2007). Effects of a school-based, early childhood intervention on adult health and well-being: a 19-year follow-up of low-income families. *Archives of pediatrics & adolescent medicine*, *161*(8), 730–9.

Reynolds, A. J., Temple, J. A., Robertson, D. L., & Mann, E. A. (2001). Long-term effects of an early childhood intervention on educational achievement and juvenile arrest: A 15-year follow-up of low-income children in public schools. *JAMA*, *285*(18), 2339–46.

Scarborough, H. & Parker, J. (2003). Matthew effects in children with learning disabilities: Development of reading, IQ, and psychosocial problems from grade 2 to grade 8. *Annals of dyslexia*, *53*, 47–71.

Shaywitz, B., Holford, T., & Holahan, J. (1995). A Matthew effect for IQ but not for reading: Results from a longitudinal study. *Reading Research Quarterly*, *30*, 894–906.

Shaywitz, S. E., Morris, R., & Shaywitz, B. A. (2008). The education of dyslexic children from childhood to young adulthood. *Annu Rev Psychol*, *59*, 451–75.

Shaywitz, S. E., Shaywitz, B. A., Fulbright, R. K., Skudlarski, P., Mencl, W. E., Constable, R. T., Pugh, K. R., Holahan, J. M., Marchione, K. E., Fletcher, J. M., Lyon, G. R., & Gore, J. C. (2003). Neural systems for compensation and persistence: young adult outcome of childhood reading disability. *Biol Psychiatry*, *54*(1), 25–33.

Shonkoff, J. P. & Meisels, S. J. (2000). *Handbook of early childhood intervention* (2nd ed ed.). Cambridge: Cambridge University Press.

Siegle, G., Carter, C., & Thase, M. (2006). Use of fMRI to predict recovery from unipolar depression with cognitive behavior therapy. *Am J Psychiatry*, *163*(4), 735–8.

Siegler, R. S. & Ramani, G. B. (2008). Playing linear numerical board games promotes low-income children's numerical development. *Developmental Science*, *11*(5), 655–61.

Stanovich, K. (1986). Matthew effects in reading: Some consequences of individual differences in the acquisition of literacy. *Reading Research Quarterly*, *21*(4), 360–407.

Starkey, P., Klein, A., & Wakeley, A. (2004). Enhancing young children's mathematical knowledge through a prekindergarten mathematics intervention. *Early Childhood Research Quarterly*, *19*, 99–120.

Stevens, C., Lauinger, B., & Neville, H. J. (2009). Differences in the neural mechanisms of selective attention in children from different socioeconomic backgrounds: an event-related brain potential study. *Developmental Science*, *12*(4), 634–646.

Stuss, D. T. & Alexander, M. P. (2000). Executive functions and the frontal lobes: a conceptual view. *Psychol Res*, *63*(3-4), 289–98.

Temple, E., Deutsch, G. K., Poldrack, R. A., Miller, S. L., Tallal, P., Merzenich, M. M., & Gabrieli, J. D. E. (2003). Neural deficits in children with dyslexia ameliorated by behavioral remediation: evidence from functional MRI. *Proc Natl Acad Sci U S A*, *100*(5), 2860–5.

Tough, P. (2008). *Whatever it takes: Geoffrey Canada's quest to change Harlem and America*. Boston: Houghton Mifflin Co.

Turkheimer, E., Haley, A., Waldron, M., D'Onofrio, B., & Gottesman, I. I. (2003). Socioeconomic status modifies heritability of IQ in young children. *Psychological science : a journal of the American Psychological Society / APS*, *14*(6), 623–8.

U.S. Bureau of the Census (2007). Income, poverty, and health insurance coverage in the United States.

Weikart, D. P. (1998). Changing early childhood development through educational intervention. *Prev Med*, *27*(2), 233–7.

Weisberg, D. S., Keil, F. C., Goodstein, J., Rawson, E., & Gray, J. R. (2008). The seductive allure of neuroscience explanations. *J Cogn Neurosci*, *20*(3), 470–7.

Woodworth, K., David, J., Guha, R., Wang, H., & Lopez-Torkos, A. (2008). San Francisco Bay Area KIPP schools: A study of early implementation and achievement.