G Model
DCN-322; No. of Pages 8
ARTICLE IN PRESS

Developmental Cognitive Neuroscience xxx (2015) xxx–xxx

Contents lists available at ScienceDirect

Developmental Cognitive Neuroscience

journal homepage: http://www.elsevier.com/locate/dcn

Selective attention neutralizes the adverse effects of low socioeconomic status on memory in 9-month-old infants

Julie Markant[a,*], Laura K. Ackerman[b], Kate Nussenbaum[b], Dima Amso[b]

[a] *Department of Psychology, Tulane University, USA*
[b] *Cognitive, Linguistic, & Psychological Sciences, Brown University, USA*

ARTICLE INFO

Article history:
Received 28 May 2015
Received in revised form 29 October 2015
Accepted 30 October 2015
Available online xxx

Keywords:
Selective attention
Infancy
Socioeconomic status
Memory
Resilience

ABSTRACT

Socioeconomic status (SES) has a documented impact on brain and cognitive development. We demonstrate that engaging spatial selective attention mechanisms may counteract this negative influence of impoverished environments on early learning. We previously used a spatial cueing task to compare target object encoding in the context of basic orienting ("facilitation") versus a spatial selective attention orienting mechanism that engages distractor suppression ("IOR"). This work showed that object encoding in the context of IOR boosted 9-month-old infants' recognition memory relative to facilitation (Markant and Amso, 2013). Here we asked whether this attention-memory link further interacted with SES in infancy. Results indicated that SES was related to memory but not attention orienting efficacy. However, the correlation between SES and memory performance was moderated by the attention mechanism engaged during encoding. SES predicted memory performance when objects were encoded with basic orienting processes, with infants from low-SES environments showing poorer memory than those from high-SES environments. However, SES did not predict memory performance among infants who engaged selective attention during encoding. Spatial selective attention engagement mitigated the effects of SES on memory and may offer an effective mechanism for promoting learning among infants at risk for poor cognitive outcomes related to SES.

1. Introduction

Growing up in poverty negatively impacts children's brain and cognitive development (e.g., Hackman and Farah, 2009; Lipina and Posner, 2012). Socioeconomic status (SES; McLoyd, 1998) is frequently used as a proxy for children's poverty level. Lower SES adversely impacts language, memory, and cognitive control in childhood and adolescence (Amso et al., 2014; Hackman and Farah, 2009; Noble et al., 2005, 2006a,b, 2007) and leads to parallel differences in brain development (Noble et al., 2012a,b, 2015b; Sheridan et al., 2012, 2013). Growing evidence suggests that SES begins to influence both cognitive development (Clearfield and Jedd, 2013; Clearfield and Niman, 2012; Lipina et al., 2005; Noble et al., 2015a) and structural brain development (Hanson et al., 2013) as early as infancy.

The present study examined links between SES and the development of foundational interactions between spatial selective attention and memory among 9-month-old infants who previously completed a spatial cueing/attention orienting and subsequent memory task (data from Markant and Amso, 2013; Markant et al., 2015a). The effects of SES on attention development vary depending on the specific attention mechanisms considered. For example, low SES has been related to less effective auditory selective attention skills in childhood, as measured by increased attention to distracting auditory stimuli (D'Angiulli et al., 2008; Stevens et al., 2009), but was unrelated to spatial attention orienting in childhood (Mezzacappa, 2004). In contrast, there is strong evidence that lower SES is associated with poorer memory performance and reduced volume of the hippocampus during childhood (Hackman and Farah, 2009; Hanson et al., 2011; Levine et al., 2005; Noble et al., 2012a,b, 2015b). A similar association between SES and recognition memory emerges by 21 months of age among typically developing infants (Noble et al., 2015a).

Previous research has shown that spatial selective attention and memory are mechanistically linked early in life (Markant and Amso, 2013), suggesting that it may be important to consider the interactive effects of selective attention, memory, and SES rather than examine the impact of SES on attention and memory separately. Selective attention involves modulation of visual cortex activity, with enhanced processing of attended stimuli and

* Corresponding author. Tel.: +1 4018623367.
E-mail address: jmarkant@tulane.edu (J. Markant).

http://dx.doi.org/10.1016/j.dcn.2015.10.009

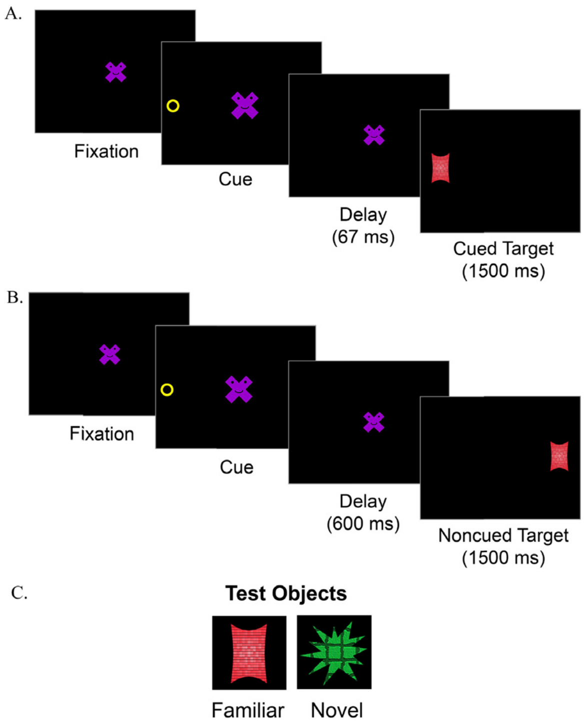

Fig. 1. An example of task trials presented to infants. (A) In the Facilitation spatial cueing condition, target objects were presented in the cued location. (B) In the IOR condition, the cued location is suppressed and the attention bias shifts to the noncued location. (C) Test trials included objects that were familiar to encoding objects along color and texture dimensions as well as completely novel objects for comparison. Object examples taken from Markant and Amso (2013).

concurrent suppression of competing information (Desimone and Duncan, 1995; Gandhi et al., 1999; Kastner et al., 1999). This coupled target enhancement and distractor suppression improves the quality of attended object representations in visual cortical regions and supports enhanced visual processing (Carrasco, 2011, 2013; Zhang et al., 2011). Our work is based on the hypothesis that this reduced noise in the signal for the attended object in visual cortex (Zhang et al., 2011) also improves memory encoding for the target object.

We capitalized on the spatial cueing task (Posner, 1980) to study the role of these spatial selective attention dynamics in early learning and memory. In this task, attention is engaged at a central location while a cue appears in the periphery. After a delay, a target appears in the cued location or in the opposite, noncued location (Fig. 1). When the cue-target delay is short (<250 ms), orienting is facilitated to the previously cued location (Posner and Cohen, 1984; Posner, 1980). However, a longer cue-target delay (>250 ms) elicits suppression at the cued location and biases orienting to the noncued location, an effect known as inhibition of return (IOR; Posner et al., 1985). This task can thus be used to compare orienting mechanisms that differentially engage the suppression component of selective attention. Both facilitation and IOR elicit attention at a target location, but only IOR involves both attention at the target location and suppression at the previously cued location.

We previously asked whether engaging facilitation versus IOR orienting mechanisms during encoding supported differential learning during infancy. Infants viewed objects in the cued or noncued locations during an initial spatial cueing/encoding phase. We assessed infants' subsequent memory for these objects based on looking times to novel objects relative to the familiar target objects. Infants' memory was enhanced in the context of IOR orienting involving distractor suppression relative to basic orienting (facilitation) or a baseline condition with no attention manipulation (Markant and Amso, 2013). An adult fMRI study using a similar IOR design further demonstrated that suppression of visual cortex activity associated with the previously cued location predicted enhanced recognition memory performance (Markant et al., 2015b).

This work demonstrated that engaging spatial selective attention supported enhanced memory across development. However, we were unable to examine interactive effects of selective attention, memory, and SES during infancy due to relatively small sample sizes in each study. As such, in the present study we re-analyzed data from these studies with a focus on relating SES and recognition memory in the contexts of facilitation versus IOR orienting mechanisms. In a similar paradigm adapted for children and adolescents (Markant and Amso, 2014), engaging selective attention (IOR) during encoding boosted recognition memory performance and mitigated the effects of lower IQ on recognition memory. When cueing elicited basic orienting (facilitation) during encoding, IQ was the only predictor of recognition memory. In contrast, engaging selection with concurrent suppression (IOR) during encoding improved memory performance among children with lower IQs (Markant and Amso, 2014). These findings raise the possibility that engaging spatial selective attention during encoding may similarly buffer memory from the adverse effects of low SES during infancy. Distractor suppression may support a higher-quality signal in the IOR condition (Markant et al., 2015b; Zhang et al., 2011), which in turn may reduce the load on weaker learning and memory skills among infants from lower SES environments.

To address this question, we re-analyzed our combined samples of 9-month-old attention and memory data to examine main effects of SES on early attention orienting and memory as well as interactions between attention, memory, and SES. We predicted that recognition memory, but not attention orienting, would be adversely affected by lower SES, consistent with previous work in children. However, we also predicted that these adverse effects of low SES on infants' memory performance would not be observed among infants who engaged selective attention mechanisms (IOR) during target encoding.

2. Material and methods

2.1. Participants

The final sample included 136 9-month-old infants (M_{Age} = 276 days, SD = 13 days, 65 Male). According to parental report, 91.9% of participants were Caucasian, 2.9% were Asian, 5.1% were Black, and 0.1% were Pacific Islander. Participants were recruited from the community through advertisements and public birth records. Infants were excluded from the study if they had been born early (<36 weeks), had low birth weight (<5 lbs), or had any history of serious health problems. All families received compensation for participating.

2.2. Eye tracking apparatus

The general procedure was the same for all infants. We recorded eye movements using a remote eye tracker (SMI 60 Hz RED system; SensoMotoric Instruments, Boston, MA). Infants sat on their parent's lap 70 cm from a 22 in. monitor. A digital video camera (Canon ZR960) recorded infants' head movements and allowed for online coding during the test phase. The video output was also recorded as a digital file.

Stimuli were presented using the SMI Experiment Center software. We used a 2-point calibration and 4-point calibration accuracy check as described in Markant and Amso (2013). Average deviation was 2.4° (SD = 1.9°). The digital eye recording was

Please cite this article in press as: Markant, J., et al., Selective attention neutralizes the adverse effects of low socioeconomic status on memory in 9-month-old infants. Dev. Cogn. Neurosci. (2015), http://dx.doi.org/10.1016/j.dcn.2015.10.009

used for offline coding of left/right eye movements if a stable point of gaze (POG) was not obtained. To confirm the accuracy of these data, reliability between coded and POG data was calculated for a subset of videos for infants who had successful eye movement recordings, $r > .90$, $p < .05$.

2.3. Conditions and stimuli

The data were primarily drawn from Markant and Amso (2013), in which abstract objects were used as targets objects during encoding ($n = 95$). In this study, infants participated in a facilitation cueing/encoding condition ($n = 20$), an IOR cueing/encoding condition ($n = 34$), or a baseline encoding condition, where targets were learned in the absence of cues ($n = 41$). An additional 41 infants participated in a second study with an identical IOR cueing paradigm that used faces rather than abstract objects as targets (Markant et al., 2015a). Thus the current study entailed a between-subjects comparison of infants who completed the facilitation condition ($n = 20$), the baseline condition ($n = 41$), or an IOR condition ($n = 75$).

For all infants the task consisted of a spatial cueing/encoding phase followed by a subsequent memory test phase (see Fig. 1). For the spatial cueing/encoding phase, stimuli included a central fixation, a cue, and a set of target objects (abstracts objects or faces). The fixation shape was a purple X that appeared in the center of the screen and loomed in and out (2.5–5.67 cm^2) to engage infants' fixation in the center of the display. The cue was a yellow ring (2.5 cm diameter). Targets were 7.1 cm^2. The cue and targets appeared 16° (19.41 cm) to the left or right of the fixation.

2.4. Procedure

The spatial cueing/encoding phase included 56 trials. Each trial began with presentation of the fixation for 1100 ms, followed by presentation of the cue for 100 ms and a subsequent delay period of either 67 ms or 600 ms in which only the fixation stimulus was visible. A 67 ms cue-target delay elicits a basic orienting response (i.e., facilitation), whereas a 600 ms delay elicits suppression at the cued location and biases attention to targets in the noncued location (i.e., IOR; Markant and Amso, 2013, 2014). After this delay, the fixation disappeared and a target object appeared in the cued or noncued location for 1500 ms. Cued and noncued target trials were randomized and four unique target images were presented across the 56 encoding trials (14 trials for each stimulus). Trials in the Baseline condition were identical in timing and stimulus presentation with the exception that the cue was not presented.

After the spatial cueing/encoding phase, infants saw 4–5 memory test trials[1]. All infants saw one completely novel object and two completely familiar objects seen during encoding (Fig. 1C). All test objects were presented individually in the center of the screen. Order of test trial type (novel, familiar) was counterbalanced. Trials could last up to 20 s. An experimenter (blind to the test displays) viewed the live video feed and advanced to the next trial if the infant looked away for more than 2 s. Look durations at test were validated offline ($r > .90$, $p < .001$). As this is a combined analysis across experiments, we focused our memory measure on infants' responses to the completely novel object presented at test.

[1] The number of test trials depended on the original study in which infants participated. All infants in the facilitation/baseline condition completed four test trials. Some infants in the IOR condition completed four test trials (those drawn from Markant and Amso, 2013, Experiment 1) while others completed five test trials (those drawn from Markant and Amso, 2013, Experiment 2 and Markant et al., 2015a). Infants in all experiments saw two completely familiar test trials and one completely novel test trial.

2.5. Data processing

2.5.1. Spatial cueing encoding

Our primary variable for the spatial cueing phase was eye movement reaction times. Initial processing of the eye movement data utilized the SMI BeGaze analysis software. The screen was divided into three equivalent 14.2 cm^2 areas of interest (AOIs) that corresponded to the central, left, and right stimulus locations. Usable looks were defined as segments of the data in which the POG remained within 7.1 cm^2 (the size of the target) for at least 100 ms. This dispersion criterion was less than a third of the distance between the opposing target locations (24 cm/20°), allowing us to maximize usable data while clearly identifying left/right looks. Reaction times were based on the time at which a look first entered the AOI. Individual trials were discarded for the reaction time analysis if the infant looked at the cue prior to target onset ($M = 4.5$ trials, $SD = 5.3$ trials), looked away from the screen before looking at the target ($M = 13.6$ trials, $SD = 7.1$ trials), or if eye movement data was unavailable ($M = 7.5$ trials, $SD = 7.4$ trials). Trials were further filtered to exclude those with latencies that were less than 200 ms ($M = 0.7$ trials, $SD = 1.8$ trials) or greater than two SD above the infant's mean latency. Reaction times were standardized (z-scored) based on each infant's mean reaction time to account for baseline differences in eye movement response times across infants. A spatial cueing score (RT difference score) was computed for each infant by subtracting his/her standardized reaction time to the noncued location from his/her standardized reaction time to the cued location. Positive difference scores reflect faster responses/an attention bias to the noncued location (i.e., IOR) whereas negative difference scores reflect faster responses/an attention bias to the cued location (i.e., facilitation).

2.5.2. Test

At test infants viewed one completely novel object and two completely familiar objects. Looking times were first averaged across the familiar and novel test trials to generate a mean value per infant. This value was used to standardize (z-score) duration of looking to the novel test object. This standardization ensured that the measure of looking to the novel object was relative to looking times to the familiar object.

2.6. Calculation of variables

2.6.1. SES variable

Parents completed a demographic questionnaire indicating parental education, occupation, income, and family size. We coded education as number of years of school completed and coded occupation on a scale of 1–5 using the O*Net rankings of job zones (Amso et al., 2014). O*Net is a nationally recognized database developed by the US Department of Labor/Employment and Training Administration that contains current occupational information. Job zones reflect occupations requiring similar levels of education and training. Parent 1 and parent 2 education and occupation scores were averaged to yield a single value. Household income was used to generate an income-to-needs ratio (family income divided by the poverty threshold for a family of that size).

Of the 136 families who provided demographic information, $n = 112$ provided all three data points and $n = 24$ provided education and occupation but not income information, consistent with rates of omission of this variable in previous literature (Amso et al., 2014; Bornstein and Bradley, 2003; Noble et al., 2007). We followed the example of previous literature to impute income-to-needs data for these participants. We calculated a regression equation with the parental occupation and education metrics as predictors of income-to-needs. The regression was significant, $R^2 = .392$, $F(2,109) = 35.10$, $p < .001$. Both education and occupation were reliable predictors

Table 1
Sample parental education, occupation, and family income-to-needs ratio statistics.

	SES variable		
	Parent education	Parent occupation	Income-to-needs ratio
Mean	16.02	3.61	4.31
95% confidence interval for mean			
Lower bound	15.66	3.47	3.89
Upper bound	16.39	3.76	4.73
Median	16.00	3.75	3.86
Standard deviation	2.14	0.86	2.46
Minimum	12.00	1.00	0.24
Maximum	21.00	5.00	15.16
Range	9.00	4.00	14.90
Interquartile range	2.50	1.00	2.93
Skewness	0.04	−0.32	1.25

of income-to-needs (all *ps* < .005). The regression equation derived from this analysis was used to impute the income-to-needs ratio of the participants whose parents had reported education and occupation but not household income. Table 1 provides full SES statistics on the sample. Nineteen families were living below an income-to-needs ratio of 2, with a value of 1 being equivalent to living at the national poverty line. All three SES variables were highly correlated (all *ps* < .001) posing a multicollinearity threat to statistical models. The imputation of income-to-needs also raises interpretation concerns of this variable where it was generated from the two others. As such, we extracted a single SES variable. We entered mean parental education, occupation, and income-to-needs into a factor analysis using the principal components method of extraction on a covariance matrix. The extracted factor was used as the SES score and explained 80% of the variance across the three variables. One infant was an outlier on this SES variable, with a score more than 2 *SD* above the group mean. This infant was excluded for all analyses involving SES. There was no significant difference in SES across the facilitation, baseline, and IOR conditions, $M_{\text{Faciliation}} = -0.17$, $SD = 0.75$, range = −1.70–1.77; $M_{\text{Baseline}} = -0.08$, $SD = 0.90$, range = −1.78–1.60; $M_{\text{IOR}} = 0.04$, $SD = 1.03$, range = −1.96–2.57; $F(2,132) = 0.45$, $p = .639$.

2.6.2. Dependent variables

We used separate multiple linear regressions to model predictors of attention orienting and memory. The dependent variable in the attention orienting analysis was the spatial cueing score, computed as each infant's standardized RT to cued–noncued locations during the spatial cueing task (see Section 2.5.1). Positive difference scores reflect IOR whereas negative difference scores reflect facilitation.

The dependent variable for the memory analysis was each infant's standardized duration of looking to novel objects during the memory test phase of the experiment (see Section 2.5.2). Response to novelty is commonly used as an index of learning and memory in infancy. Standardization ensured that the measure of looking to the novel object was relative to looking times to the familiar object.

2.6.3. Predictor variables

Preliminary analyses indicated that sex was not reliably related to attention orienting or memory (*ps* > .60); thus this variable was not included in the regression model. Predictors included age in days, SES, encoding cueing condition, and encoding cueing condition × SES. Refer to Section 2.6.1 above for calculation of the SES variable. The encoding cueing condition variable was a between-subjects variable that reflected the attention orienting mechanism engaged during target encoding (e.g., facilitation vs. IOR). For the attention orienting analysis, the baseline data were not included as there was no attention manipulation. We previously showed that infants had enhanced memory for objects encoded under the spatial selective attention (IOR) conditions whereas memory performance in facilitation and no-cue baseline conditions was equivalent (Markant and Amso, 2013). Thus for the memory analysis, the between-subjects encoding cueing condition variable reflected whether infants participated in an IOR ($n = 75$) or a combined facilitation/baseline ($n = 61$) condition during encoding. We verified that there were no differences in SES across these encoding cueing condition groups, $t(133) = -0.89$, $p = .375$.

Table 2A
Regression coefficients – attention model.

Variable	B (*SE*)	Tolerance
Constant	0.56 (*0.61*)	
Age (in days)	−0.003 (*0.002*)	.91
SES	−0.01 (*0.05*)	.42
Encoding cueing condition	0.23* (*0.04*)	.88
Encoding cueing condition × SES	0.05 (*0.05*)	.43
R^2	.32*	
N	94	

* $p < .01$.

3. Results

3.1. Attention orienting

We conducted separate multiple regression models to examine predictors of the dependent variables attention orienting and memory. We first tested the effects of the predictors age, SES, encoding cueing condition, and encoding cueing condition × SES on the dependent variable attention orienting (Table 2). The model explained a significant proportion of the variance in attention orienting, $R^2 = .32$, $F(4,89) = 10.39$, $p < .001$. The only reliable predictor of attention orienting was encoding cueing condition, $B = 0.23$, $SE = 0.04$; $t(89) = 6.24$, $p < .001$. This expected result reflects the success of the cueing manipulation in biasing attention to the non-cued location in the IOR condition ($M = 11.68$ ms, $SD = 53.50$ ms) and to the cued location in the facilitation condition ($M = -67.29$, $SD = 70.80$). Relevant to this investigation, there were no significant effects of SES, $B = -0.01$, $SE = 0.05$; $t(89) = -0.23$, $p = .816$, or encoding cueing condition × SES, $B = 0.05$, $SE = 0.05$; $t(90) = 1.07$, $p = .289$ (Table 2). We further correlated the spatial cueing difference score with SES in the IOR and facilitation groups separately, and found that SES did not correlate with attention orienting in either condition (all *ps* > .22).

3.2. Memory

We next modeled the effects of age, SES, encoding cueing condition, and encoding cueing condition × SES on memory (Table 3). The model explained a statistically significant proportion of variance in memory performance, $R^2 = .09$, $F(4,130) = 3.17$, $p = .016$. Socioeconomic status was a reliable predictor of memory

Table 2B
Correlation coefficients – attention model predictor variables ($N = 95$).

Predictor variable	Age	SES	Encoding cueing condition	Encoding cueing condition × SES
Age	1.00			
SES	.03	1.00		
Encoding cueing condition	.29*	.09	1.00	
SES × Encoding cueing condition	.01	.76*	−.05	1.00

* $p < .01$.

Please cite this article in press as: Markant, J., et al., Selective attention neutralizes the adverse effects of low socioeconomic status on memory in 9-month-old infants. Dev. Cogn. Neurosci. (2015), http://dx.doi.org/10.1016/j.dcn.2015.10.009

Table 3A
Regression coefficients – memory model (Full model).

Variable	B (*SE*)	Tolerance
Constant	2.35 (*1.58*)	
Age	−0.01 (*0.01*)	.90
SES	0.17** (*0.08*)	.92
Encoding cueing condition	0.13* (*0.07*)	.89
Encoding cueing condition × SES	−0.19** (*0.08*)	.92
R^2	.09**	
N	135	

* $p < .10$.
** $p < .05$.

Table 3B
Correlation coefficients – memory model predictor variables ($N = 136$)1.

Predictor Variable	Age	SES	Encoding cueing condition	Encoding cueing condition × SES
Age	1.00			
SES	.03	1.00		
Encoding cueing condition	.31*	.08	1.00	
Encoding cueing condition × SES	−.06	.28*	−.04	1.00

* $p < .01$.

performance, $B = 0.17$, $SE = 0.08$; $t(130) = 2.22$, $p = .028$, with higher SES associated with larger relative responses to novelty (i.e., better recognition memory). Additionally, encoding cueing condition × SES significantly predicted memory performance, $B = -0.19$, $SE = 0.08$; $t(130) = -2.42$, $p = .017$ (Table 3).

We further investigated the encoding cueing condition × SES interaction effect with separate regression models for each encoding cueing condition. The dependent variable was memory performance and the predictors were age and SES. Socioeconomic status was a significant predictor of memory only when objects were encoded in the facilitation/baseline cueing conditions, $B = 0.37$; $SE = 0.12$; $t(58) = 3.09$, $p = .003$ (Fig. 2A). In these conditions, higher SES predicted relatively longer looking times to novel objects, an index of better memory performance at test. However, SES did not predict memory among infants who engaged selective attention during encoding (IOR cueing condition, $B = -.01$; $SE = 0.09$; $t(71) = -0.15$, $p = .885$; Fig. 2B)[2]. Results were similar when we excluded participants where income-to-needs data was imputed; again, SES predicted memory in the facilitation/baseline condition, $B = 0.32$, $SE = 0.16$; $t(44) = 2.01$, $p = .05$, but not in the IOR condition, $B = 0.02$, $SE = 0.10$; $t(61) = 0.19$, $p = .850$. Taken together, these data suggest that spatial attention at encoding moderates the relation between SES and memory in infancy.

3.2.1. Group analyses

The previous results suggest that engaging spatial selective attention (IOR) during encoding boosted recognition memory among infants from low-SES backgrounds. We conducted additional group analyses to further examine this possibility. We dichotomized each attention orienting condition into a group of infants from low-SES homes and a group of infants from high-SES homes (facilitation/baseline condition SES 50th percentile = −.18; IOR condition SES 50th percentile = −.14), yielding four groups of interest (facilitation - low-SES, facilitation - high-SES, IOR - low-SES, IOR - high-SES: Fig. 3). Post-hoc comparisons indicated that memory performance was reliably higher for low-SES infants in the IOR condition ($M = 0.26$, $SD = 0.80$) relative to low-SES infants in the facilitation/baseline condition ($M = -0.16$, $SD = 0.82$; $t(66) = 2.09$, $p = .04$). This further supports the conclusion that engaging spatial selective attention during encoding supported more effective learning for low-SES infants in the IOR the condition; without this added benefit, infants from similar low-SES backgrounds performed reliably worse on the recognition memory task. In contrast, there was no difference in memory performance across the facilitation/baseline and IOR conditions when infants were from high-SES backgrounds ($M_{Facilitation} = 0.23$, $SD = 0.83$; $M_{IOR} = 0.27$, $SD = 0.84$; $t(65) = 0.21$, $p = 0.837$). This suggests that infants in the facilitation/baseline condition who already benefitted from high-SES backgrounds learned effectively without the additional support of spatial selective attention engagement during encoding.

4. Discussion

This investigation adds several novel insights into the role of SES in attention and memory dynamics in infancy. First, SES had little influence on mechanisms of attention orienting in infancy, consistent with results from a similar investigation in children (Mezzacappa, 2004). Second, SES was related to memory performance such that infants from lower-SES environments performed more poorly than those from higher-SES environments. Third, the impact of SES on memory was diminished when spatial selective attention was engaged at encoding. When lower-SES infants engaged selective attention at encoding their learning and memory was equivalent to that of infants from higher-SES backgrounds (Fig. 3).

There are strong mechanistic reasons for the observed interaction between attention and memory at encoding. Attention enhancement paired with concurrent suppression improves visual processing and the quality of object representations in visual cortical regions (Carrasco, 2011, 2013; Zhang et al., 2011). We previously replicated this effect with adults in the context of the spatial cueing task, as visual cortex regions involved in maintaining object representations (i.e., IT cortex) showed greater activity during the IOR encoding condition relative to the facilitation encoding condition (Markant et al., 2015b). We suggest that this elimination of competing neural interference results in a higher fidelity signal for downstream medial temporal lobe (MTL) memory encoding. In the context of IOR, the competing neural interference derives from residual activation at the previously cued location. In natural settings it may result from data carried over from previously attended locations or from distractors concurrently in the surround while an object is being encoded. In any case, filtering noise from competing distractors improves the visual signal of the target object at encoding. This in turn may reduce the burden on weaker encoding mechanisms and thus override differences in target object encoding and subsequent recognition among infants from lower-SES environments.

Our data also underscored that the influence of SES on developing learning and memory systems begins in infancy. SES is a proxy variable, accounting for both stress and enrichment opportunities in infants' environments. Stress in low-SES homes may arise due to a range of contextual factors, including malnourishment, parental emotional stress, or abuse and neglect (Bradley and Corwyn, 2002; Evans, 2004), that increase risk for atypical developmental profiles (Barajas et al., 2007; Evans and Kim, 2010), whereas

[2] We verified that the grouping of facilitation and baseline did not drive our SES effects. SES correlated similarly with memory performance, controlling for age, in both the facilitation, $r(17) = .53$, $p = .019$, and baseline encoding cueing conditions, $r(38) = .33$, $p = .038$. We also verified that our combination of two different object types across IOR did not swamp any effect of SES on memory in that condition. SES was not correlated with memory performance in the IOR condition when either face, $r(27) = -.19$, $p = .316$, or abstract object, $r(41) = .10$, $p = .541$, stimuli were used. Finally we confirmed that SES did not correlate with memory performance in the IOR condition among infants who saw four test items, $r(19) = .29$, $p = .235$, or among those who saw five test items, $r(55) = -.11$, $p = .444$. These data provide a basic replication of our results when separate samples are used for analyses and justify combining samples drawn from the different studies.

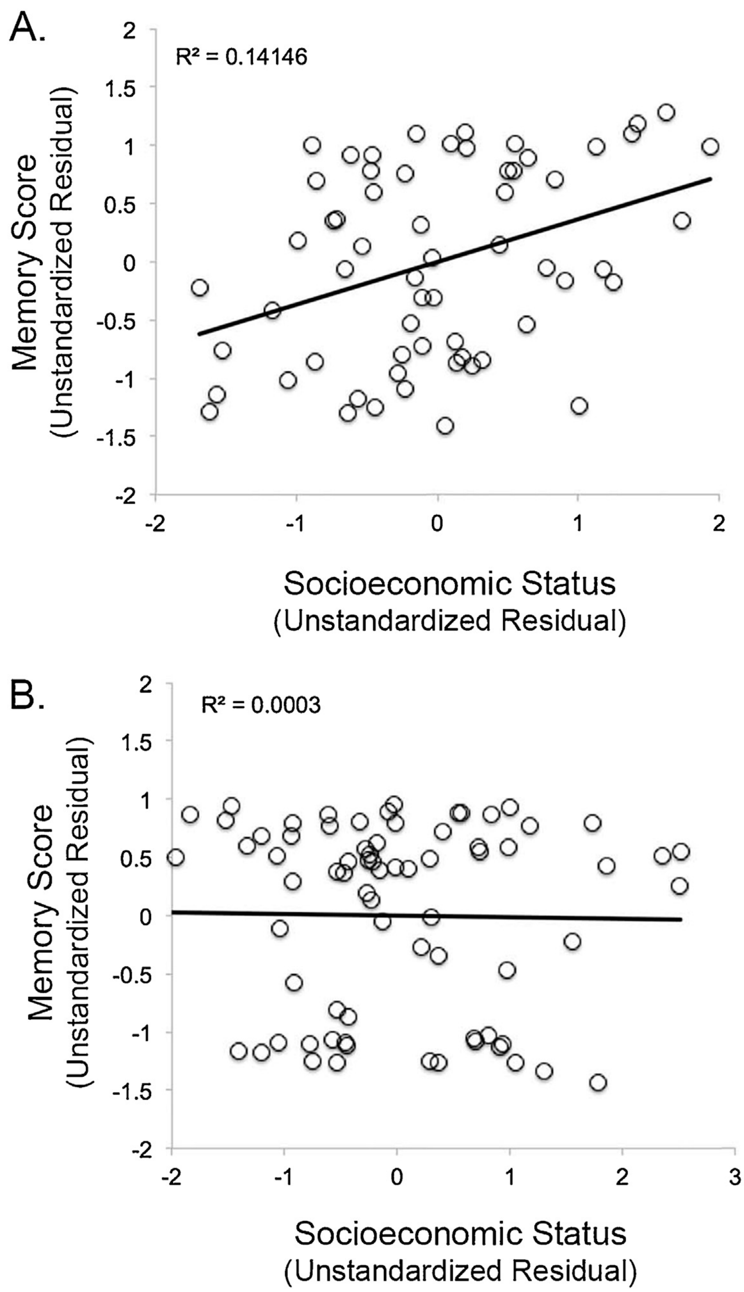

Fig. 2. (A) SES predicted memory among infants who engaged simple orienting mechanisms during encoding (facilitation/baseline). (B) SES was unrelated to memory performance among infants who engaged spatial selective attention (IOR) during encoding.

enrichment varies as a function of both financial resources and the availability of stimulation in the home (Dahl and Lochner, 2012; Duncan et al., 2011; Hart and Risley, 1995). Stress during development impacts the hypothalamic-pituitary-adrenal (HPA) axis and MTL memory operations (e.g., Gunnar and Quevedo, 2007). Lack of enrichment may also provide fewer opportunities for memory systems to engage and strengthen. There is a great deal of focus on alleviating achievement gaps in SES by providing more resources to low-SES children in the preschool period. The present data highlight the need for more focus and resources as early as infancy.

The critical finding here is that this early link between SES and learning and memory was further modulated by spatial selective attention engagement. Our data suggest that SES was specifically related to memory encoding processes. The negative correlation between SES and memory was moderated by the engagement of spatial selective attention orienting mechanisms *at encoding*. This is the second demonstration of this type of interaction. In previous work, we showed that the same mechanism counteracted the effects of individual differences in IQ on memory in children and adolescents (Markant and Amso, 2014). In both Markant and Amso (2014) and the present study, attention orienting in the facilitation condition did not add any benefit in recognition memory performance beyond individual differences in IQ or SES (Reber et al., 1991). In contrast, engaging selective attention during encoding boosted memory performance among participants with low IQ/SES. In other words, the association between memory performance and risk variables (low IQ, low SES) became more malleable when spatial selective attention was engaged, suggesting that this engagement of selective attention during encoding may be effective in promoting enhanced learning and memory among at-risk groups. In both studies spatial selective attention was engaged during encoding via the spatial cueing task. Future work can examine

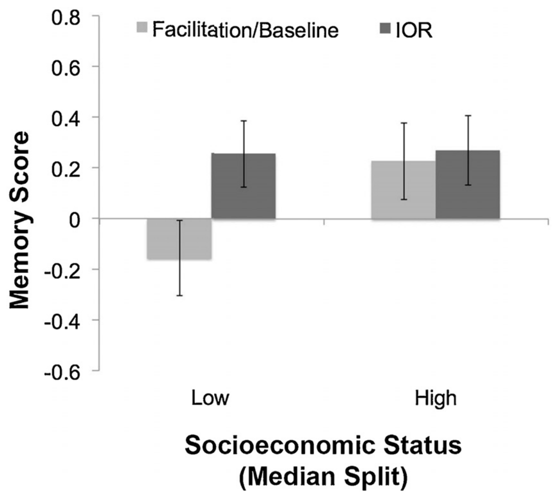

Fig. 3. Infants from low-SES homes who engaged selective attention (IOR) during encoding had reliably higher memory scores relative to infants from similarly low-SES homes who encoded targets in the facilitation/baseline conditions.

whether providing other learning contexts that promote engagement of selective attention during encoding can similarly boost learning and memory.

The multidimensional nature of SES measures can make it difficult to identify the specific mechanisms linking SES to developmental outcomes. In this study, SES may index infants' early mental abilities/IQs, which in turn contribute to learning and memory efficacy. In this case, the current findings would mirror those seen among children and adolescents in Markant and Amso (2014). IQ predicted memory performance among children in the facilitation condition but not among participants who engaged spatial selective attention during encoding. However, while there is substantial research documenting a link between SES and older children's IQ scores (Brooks-Gunn and Duncan, 1997; Gottfried et al., 2003; Smith et al., 1997), the link between SES and early mental abilities during infancy is less clear (Tucker-Drob et al., 2011; von Stumm and Plomin, 2015). Thus it is also possible that the current results reflect an early link between SES and basic learning and memory functions in infancy, which then contributes to the emergence of a consolidated mental ability/IQ as development proceeds. The present study did not use standardized measures of infants' mental abilities, making it difficult to distinguish between these potential mechanisms. Incorporating these measures into future studies will clarify the mechanisms linking SES to specific cognitive processes in infancy.

In the present study, attention orienting was manipulated in a between-subjects manner, such that one group of infants engaged basic orienting processes during encoding and a separate group of infants engaged spatial selective attention (i.e., IOR) during the encoding phase. Our group analyses (see Section 3.2.1) showed that memory scores were reliably higher for low-SES infants who engaged spatial selective attention in the IOR condition relative to infants from similar low-SES homes who engaged basic orienting mechanisms in the facilitation/baseline condition. In contrast, there was no difference in memory performance across the facilitation/baseline and IOR conditions among infants from high-SES homes. These data provide further support for the idea that engaging spatial selective attention during encoding specifically benefitted infants from low-SES homes. However, this between-subjects design is limited by potential unobserved group differences. Future work can more powerfully examine the role of selective attention engagement in boosting learning and memory efficacy among low-SES/at-risk populations by manipulating attention orienting in a within-subject design.

5. Conclusions

The present findings further underscore that attention and memory are functionally integrated beginning early in life, as the nature of the orienting mechanism engaged during encoding moderated the association between SES and recognition memory performance. This mirrors the pattern observed with IQ and recognition memory among children and adolescents, but at the remarkably early age of 9 months. These data additionally speak to the plasticity of interactive systems in the human brain. Hackman and Farah (2009) argued that SES impacts neurocognitive systems in a graded fashion. We argue here that it is imperative to understand which cognitive systems are shaped by SES, which systems are resilient, and how these systems interact with each other. This understanding will guide the formulation of learning strategies and educational environments that are designed to counteract and ultimately reverse poorer cognitive outcomes in individuals from lower SES communities as early as in infancy.

References

Amso, D., Haas, S., McShane, L., Badre, D., 2014. Working memory updating and the development of rule-guided behavior. Cognition 133, 201–210, http://dx.doi.org/10.1016/j.cognition.2014.06.012.

Barajas, R.J., Philipsen, N., Brooks-Gunn, J., 2007. Cognitive and emotional outcomes for children in poverty. In: Crane, D.R., Heaton, T.B. (Eds.), Handbook of Families and Poverty, 5. Sage, Newbury Park, CA, pp. 311–333.

Bornstein, M.H., Bradley, R.H., 2003. Socioeconomic Status, Parenting, and Child Development. Lawrence Erlbaum Associates, Mahwah, NJ.

Bradley, R.H., Corwyn, R.F., 2002. Socioeconomic status and child development. Ann. Rev. Psychol. 53, 371–399, http://dx.doi.org/10.1146/annurev.psych.53.100901.135233.

Brooks-Gunn, J., Duncan, G.T., 1997. The effects of poverty on children. Future Child. 7 (2), 55–71.

Carrasco, M., 2011. Visual attention: the past 25 years. Vision Res. 51, 1484–1525, http://dx.doi.org/10.1016/j.visres.2011.04.012.

Carrasco, M., 2013. Spatial covert attention: perceptual modulation. In: Nobre, A.C., Kastner, S. (Eds.), The Oxford Handbook of Attention. Oxford University Press, Oxford, UK, p. 183.

Clearfield, M.W., Jedd, K., 2013. The effects of socio-economic status on infant attention. Infant Child Dev. 22, 53–67, http://dx.doi.org/10.1002/icd.1770.

Clearfield, M.W., Niman, L.C., 2012. SES affects infant cognitive flexibility. Infant Behav. Dev. 35, 29–35, http://dx.doi.org/10.1016/j.infbeh.2011.09.007.

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, http://dx.doi.org/10.1037/0894-4105.22.3.293.

Dahl, G.B., Lochner, L., 2012. The impact of family income on child achievement: evidence from the earned income tax credit. Am. Econ. Rev. 102 (5), 1927–1956, http://dx.doi.org/10.2307/41724610.

Desimone, R., Duncan, J., 1995. Neural mechanisms of selective visual attention. Ann. Rev. Neurosci. 18, 193–222, http://dx.doi.org/10.1146/annurev.ne.18.030195.001205.

Duncan, G.J., Morris, P.A., Rodrigues, C., 2011. Does money really matter? Estimating impacts of family income on young children's achievement with data from random-assignment experiments. Dev. Psychol. 47 (5), 1263–1279, http://dx.doi.org/10.1037/a0023875.

Evans, G.W., 2004. The environment of childhood poverty. Am. Psychol. 59 (2), 77–92, http://dx.doi.org/10.1037/0003-066X.59.2.77.

Evans, G.W., Kim, P., 2010. Multiple risk exposure as a potential explanatory mechanism for the socioeconomic status-health gradient. Ann. N. Y. Acad. Sci. 1186, 174–189, http://dx.doi.org/10.1111/j.1749-6632.2009.05336.x.

Gandhi, S.P., Heeger, D.J., Boynton, G.M., 1999. Spatial attention affects brain activity in human primary visual cortex. Proc. Natl. Acad. Sci. 96 (6), 3314–3319.

Gottfried, A.W., Gottfried, A.E., Bathurst, K., Guerin, D.W., Parramore, M.M., 2003. Socioeconomic status in children's development and family environment: infancy through adolescence. In: Bornstein, M.H., Bradley, R.H. (Eds.), Socioeconomic Status, Parenting and Child Development. Lawrence Erlbaum, Mahwah, NJ, pp. 189–207.

Gunnar, M., Quevedo, K., 2007. The neurobiology of stress and development. Ann. Rev. Psychol. 58, 145–173, http://dx.doi.org/10.1146/annurev.psych.58.110405.085605.

Hackman, D.a., Farah, M.J., 2009. Socioeconomic status and the developing brain. Trends Cognit. Sci. 13 (2), 65–73, http://dx.doi.org/10.1016/j.tics.2008.11.003.

Hanson, J.L., Chandra, A., Wolfe, B.L., Pollak, S.D., 2011. Association between income and the hippocampus. PLoS One 6 (5), 1–8, http://dx.doi.org/10.1371/journal.pone.0018712.

Hanson, J.L., Hair, N., Shen, D.G., Shi, F., Gilmore, J.H., Wolfe, B.L., Pollak, S.D., 2013. Family poverty affects the rate of human infant brain growth. PLoS ONE 8 (12), e80954, http://dx.doi.org/10.1371/journal.pone.0080954.

Hart, B., Risley, T.R., 1995. Meaningful Differences in the Everyday Experience of Young American Children. Paul H Brookes Publishing, Baltimore, MD.

Kastner, S., Pinsk, M.A., De Weerd, P., Desimone, R., Ungerleider, L.G., 1999. Increased activity in human visual cortex during directed attention in the absence of visual stimulation. Neuron 22, 751–761.

Levine, S.C., Vasilyeva, M., Lourenco, S.F., Newcombe, N.S., Huttenlocher, J., 2005. Socioeconomic status modifies the sex difference in spatial skill. Psychol. Sci. 16 (11), 841–845, http://dx.doi.org/10.1111/j.1467-9280.2005.01623.x.

Lipina, S.J., Martelli, M.I., Vuelta, B., Colombo, J.A., 2005. Performance on the A-not-B task of argentinean infants from unsatisfied and satisfied basic needs homes. Interam. J. Psychol. 39 (1), 49–60.

Lipina, S.J., Posner, M.I., 2012. The impact of poverty on the development of brain networks. Front. Human Neurosci. 6 (238), 1–12, http://dx.doi.org/10.1111/j.1467-9280.2005.01623.x.

Markant, J., Amso, D., 2013. Selective memories: infants' encoding is enhanced in selection via suppression. Dev. Sci. 16, 926–940, http://dx.doi.org/10.1111/desc.12084.

Markant, J., Amso, D., 2014. Leveling the playing field: attention mitigates the effects of intelligence on memory. Cognition 131, 195–204, http://dx.doi.org/10.1016/j.cognition.2014.01.006.

Markant, J., Oakes, L.M., Amso, D., 2015a. Visual selective attention biases contribute to the other-race effect among 9-month-old infants. Dev. Psychobiol., http://dx.doi.org/10.1002/dev.21375.

Markant, J., Worden, M.S., Amso, D., 2015b. Not all attention orienting is created equal: recognition memory is enhanced when attention involves distractor suppression. Neurobiol. Learn. Mem., http://dx.doi.org/10.1016/j.nlm.2015.02.006.

McLoyd, V.C., 1998. Socioeconomic disadvantage and child development. Am. Psychol. 53 (2), 185–204, http://dx.doi.org/10.1037/0003-066X.53.2.185.

Mezzacappa, E., 2004. Alerting, orienting, and executive attention: developmental properties and sociodemographic correlates in an epidemiological sample of young, urban children. Child Dev. 75 (5), 1373–1386, http://dx.doi.org/10.1111/j.1467-8624.2004.00746.x.

Noble, K.G., Engelhardt, L.E., Brito, N.H., Mack, L.J., Nail, E.J., Angal, J., Elliott, A.J., 2015a. Socioeconomic disparities in neurocognitive development in the first two years of life. Dev. Psychobiol. 57, 535–551, http://dx.doi.org/10.1002/dev.21303.

Noble, K.G., Houston, S.M., Brito, N.H., Bartsch, H., Kan, E., Kuperman, J.M., Sowell, E.R., 2015b. Family income, parental education and brain structure in children and adolescents. Nat. Neurosci. 18 (5), http://dx.doi.org/10.1038/nn.3983.

Noble, K.G., Farah, M.J., McCandliss, B.D., 2006a. Socioeconomic background modulates cognition-achievement relationships in reading. Cognit. Dev. 21, 349–368, http://dx.doi.org/10.1016/j.cogdev.2006.01.007.

Noble, K.G., Wolmetz, M.E., Ochs, L.G., Farah, M.J., McCandliss, B.D., 2006b. Brain-behavior relationships in reading acquisition are modulated by socioeconomic factors. Dev. Sci. 9 (6), 642–654, http://dx.doi.org/10.1111/j.1467-7687.2006.00542.x.

Noble, K.G., Grieve, S.M., Korgaonkar, M.S., Engelhardt, L.E., Griffith, E.Y., Williams, L.M., Brickman, A.M., 2012a. Hippocampal volume varies with educational attainment across the life-span. Front. Hum. Neurosci. 6 (November), 307, http://dx.doi.org/10.3389/fnhum.2012.00307.

Noble, K.G., Houston, S.M., Kan, E., Sowell, E.R., 2012b. Neural correlates of socioeconomic status in the developing human brain. Dev. Sci. 15, 516–527, http://dx.doi.org/10.1111/j.1467-7687.2012.01147.x.

Noble, K.G., McCandliss, B.D., Farah, M.J., 2007. Socioeconomic gradients predict individual differences in neurocognitive abilities. Dev. Sci. 10 (4), 464–480, http://dx.doi.org/10.1111/j.1467-7687.2007.00600.x.

Noble, K.G., Norman, M.F., Farah, M.J., 2005. Neurocognitive correlates of socioeconomic status in kindergarten children. Dev. Sci. 8 (1), 74–87, http://dx.doi.org/10.1111/j.1467-7687.2005.00394.x.

Posner, M.I., 1980. Orienting of attention. Q. J. Exp. Psychol. 32, 3–25, http://dx.doi.org/10.1080/00335558008248231.

Posner, M.I., Cohen, Y., 1984. Components of visual orienting. In: Bouma, H., Bouwhuis, D. (Eds.), Attention and Performance, X. Erlbaum Lawrence Associates, Hillsdale, NJ, pp. 531–556.

Posner, M.I., Rafal, R.D., Choate, L.S., 1985. Inhibition of return: neural basis and function. Cognit. Neuropsychol. 2, 211–228, http://dx.doi.org/10.1080/02643298508252866.

Reber, A.S., Walkenfeld, F.F., Hernstadt, R., 1991. Implicit and explicit learning: individual differences and IQ. J. Exp. Psychol: Learn. Mem. Cognit. 17 (5), 888–896, http://dx.doi.org/10.1037/0278-7393.17.5.888.

Sheridan, M.A., How, J., Araujo, M., Schamberg, M.A., Nelson, C.A., 2013. What are the links between maternal social status, hippocampal function, and HPA axis function in children? Dev. Sci. 16 (5), 665–675, http://dx.doi.org/10.1111/desc.12087.

Sheridan, M.A., Sarsour, K., Jutte, D., D'Esposito, M., Boyce, W.T., 2012. The impact of social disparity on prefrontal function in childhood. PLoS One 7 (4), e35744, http://dx.doi.org/10.1371/journal.pone.0035744.

Smith, J.R., Brooks-Gunn, J., Klebanov, P., 1997. The consequences of living in poverty for young children's cognitive and verbal ability and early school achievement. In: Duncan, G.J., Brooks-Gunn, J. (Eds.), Consequences of Growing Up Poor. Russell Sage Foundation, New York, NY, pp. 132–189.

Stevens, C., Lauinger, B., Neville, H., 2009. Differences in the neural mechanisms of selective attention in children from different socioeconomic backgrounds: An event-related brain potential study. Dev. Sci. 12 (4), 634–646, http://dx.doi.org/10.1111/j.1467-7687.2009.00807.x.

Tucker-Drob, E.M., Rhemtulla, M., Harden, K.P., Turkheimer, E., Fask, D., 2011. Emergence of a gene-by-socioeconomic status interaction on infant mental ability from 10 months to 2 years. Psychol. Sci. 22 (1), 125–133, http://dx.doi.org/10.1177/0956797610392926.

von Stumm, S., Plomin, R., 2015. Socioeconomic status and the growth of intelligence from infancy through adolescence. Intelligence 48, 30–36, http://dx.doi.org/10.1016/j.intell.2014.10.002.

Zhang, Y., Meyers, E.M., Bichot, N., Serre, T., Poggio, T.A., Desimone, R., 2011. Object decoding with attention in inferior temporal cortex. Proc. Natl. Acad. Sci. 108 (21), 8850–8855, http://dx.doi.org/10.1073/pnas.1100999108.