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Shared Reading Quality and Brain Activation During Story Listening in Preschool-Age Children

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Abstract

Objective—To explore the relationship between maternal shared reading quality (verbal interactivity and engagement) and brain function during story listening in at-risk, preschool-age children, in the context of behavioral evidence and American Academy of Pediatrics recommendations.

Study design—In this cross-sectional study, 22 healthy, 4-year-old girls from low-socioeconomic status (SES) households completed functional MRI using an established story listening task, followed by videotaped observation of un-coached mother-daughter reading of the same, age-appropriate picture book. Shared reading quality was independently scored applying dialogic reading and other evidence-based criteria reflecting interactivity and engagement, and applied as a predictor of neural activation during the fMRI task, controlling for income and maternal education.

Results—Shared reading quality scores were generally low, and negatively correlated with maternal distraction by smartphones ($P < .05$). Scores were positively correlated with activation in

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left-sided brain areas supporting expressive and complex language, social-emotional integration and working memory ($p < 0.05$, false discovery rate corrected).

Conclusion—Maternal shared reading quality is positively correlated with brain activation supporting complex language, executive function, and social-emotional processing in at-risk, preschool-age children. These findings represent novel neural biomarkers of how this modifiable aspect of home reading environment may influence foundational emergent literacy skills, reinforce behavioral evidence and AAP recommendations, and underscore the potential of dialogic reading interventions to promote healthy brain development, especially in at-risk households.

Keywords

shared reading; dialogic reading; emergent literacy; parent-child engagement; early brain development; functional MRI; language networks; social-emotional processing; home reading environment; story listening

The American Academy of Pediatrics (AAP) recommends shared reading beginning as soon as possible after birth, citing enduring cognitive, social-emotional, and neurobiological benefits.[1] Interventions target home reading environment, a composite of quantitative and qualitative factors.[2] Positive association between quantitative factors (access to books and reading frequency) and brain activation supporting imagery and comprehension in preschool-age children was recently described, complementing behavioral evidence.[3] However, the influence of shared reading quality (verbal interactivity and engagement) on the developing brain has not been investigated.

Originally developed as an intervention to promote language development in low-socioeconomic status (SES) children,[4] dialogic reading is a construct reflecting verbal interactivity and engagement during shared reading.[4] Through the use of specific types of prompts and responses, the caregiver encourages the child to participate in a reciprocal dialogue catalyzed by the story.[4, 5] Behavioral evidence suggests that dialogic reading may confer moderate to large benefits,[6] including expressive language,[7, 8] narrative comprehension,[5] and attention,[9] all foundational emergent literacy skills.[10] Social-emotional benefits are also cited, including increased parent-child bonding and enjoyment of reading.[11, 12] Nurturing behaviors such as child-directed speech and lap sitting can also enhance shared reading quality and improve outcomes.[13] However, although highly variable, shared reading quality “dialogic-ness” tends to be low in low-socioeconomic status (SES) households.[7, 14, 15] Thus, programs such as Reach Out and Read targeted to low-SES, at-risk families encourage providers to model dialogic reading during pediatric well-child visits.[2]

As reading is an evolutionarily new, invented skill, there is no hardwired reading network in the brain. Instead, beginning in infancy, brain areas and networks adapted for other functions such as vision, language, and working memory are gradually integrated in response to reading exposure and practice.[16] This neurobiological process underlies emergent literacy, the skills, Knowledge, and attitudes required to learn to read and write,[10] its foundation laid during the span of rapid brain growth between birth and age 5.[17] It is clear that neurobiological differences during this span predate[18] and can often predict behavioral differences, such as phonological awareness and vocabulary,[19, 20] and long-term outcomes

such as reading ability.[21] Less clear are questions regarding the potential to influence this neurobiological process via home reading practices, specific types of interventions, and dose-response thresholds thereof, during critical developmental stages. Neuroimaging is increasingly applied to provide mechanistic insights into such questions in the context of early home environment and child health outcomes.[3, 22, 23]

The purpose of this study was to apply neuroimaging to explore the association between maternal shared reading quality, which behavioral evidence suggests can convey substantial benefits, and brain function supporting emergent literacy skills in A sample of 4-year-old girls from low-SES households. We hypothesized that children whose mothers exhibited higher-quality shared reading behaviors would show greater activation in brain areas supporting expressive language,[26] social-emotional processing,[12] and attention.[27]

METHODS

All participants in this cross-sectional study were enrolled in a longitudinal home injury prevention trial. That cohort consists of 650 mother-child dyads recruited in infancy from a home visiting program serving low-SES, first-time mothers.[28] Inclusion criteria for the present study were: female sex, approximately 4 years old, full-term gestation, native English speaking household, no history of brain injury or developmental delay, and no contraindications to MRI. Girls were exclusively sampled due to time/budget constraints, higher previous MRI success rates (67% versus 41% for boys),[29] and negligible sex differences in brain activation patterns for our story listening task at this age.[30] We identified 105 girls who would be approximately 4 years old during our study window (oldest in the cohort). Of these, 55 were unable to be contacted, 5 were excluded due to developmental delay, and 4 did not participate because of concerns about MRI. Of the 41 agreeing to participate, 32 arrived for their visit at which informed consent was obtained, including for video observation. Of these, 22 successfully completed the MRI and video tasks (69%). Families were compensated for time and travel, and our study was approved by our medical center Institutional Review Board.

MRI was performed via a 3T Philips scanner equipped with an Avotec audiovisual system. Details of play-based MRI acclimatization techniques are described by Vannest et al,[31] MRI acquisition specifications detailed in Schmithorst et al.[32] For fMRI, BOLD (blood oxygenation level dependent)-weighted scans covering the entire brain with voxel size 3x3x4 mm were acquired at 2-second intervals (TR=2). Data pre-processing was performed using FSL software (fMRI-Brain Software Library, Oxford, UK), as described by Sroka et al.[20] All children were awake and non-sedated during MRI.

Our fMRI story listening task consists of 10 alternating blocks of active and control conditions (5 each) of 32 seconds duration, for a total functional scanning time of 5 minutes 20 seconds. During the active condition, a series of 5 stories of 9–10 sentences each read in a female voice was presented via headphones. The stories were created by a speech pathologist with vocabulary, syntax, and content appropriate for preschool-age children (download: https://www.irc.cchmc.org/software/pedaudio.php).[3, 33] The control condition

consisted of tones in a range of frequencies simulating human speech. No visual stimulus was presented other than a blank screen.

Following MRI, the mother and child were directed to a private waiting room and encouraged to relax. A high-definition webcam was unobtrusively mounted, and arranged on a table were: popular magazines, a sign with a WiFi password, and a children's picture book (*The Little Engine That Could*, Philomel, New York). If the mother or child did not spontaneously choose the book within 3 minutes, a research coordinator advised them that it was theirs to take home and encouraged them to read it together, with no further coaching. After approximately 15 minutes or when finished reading, the research coordinator entered to complete the visit.

Scoring for video reading observations was adapted from a standardized form developed for dialogic reading training.[34] Categories were: 1) introducing the book to build interest (1 point), 2) CROWD prompts (1 point per instance): sentence Completion, Recall of parts of the story, Open-ended questions, "Wh-" questions, and Distancing to relate the story to the child's life, 3) PEER responses to what the child says after the Prompt (1 point per instance): Evaluate, Expand, and/or Repeat, and 4) discussing the book after reading (1 point). Additional evidence-based behaviors[13] were also scored: proximity (0–2 points for distant, side-close, or on lap), child page turning (0–2 points for never, sometimes, often), and use of child-adjusted voice such as sound effects (0–2 points, for never, sometimes, often).

The principal investigator and 2 additional scorers (medical student and research coordinator) independently scored all videos, which were entered into a secure REDCap® database.[35] Scoring training lasted 4 hours, including a dialogic reading online module[34] and interactive role play sessions.[2]

fMRI Group Mean Analysis and Linear Regression with Maternal Reading Quality Scores

A biostatistician uninvolved with video scoring performed all fMRI analyses. Group mean analysis was conducted via the FEAT (fMRI Expert Analysis Tool) modality of FSL software, generating contrast maps reflecting stories>tones activation across all 22 subjects ($p < 0.05$, FDR corrected), as described in Hutton et al.[3] General linear regression was then performed applying z-score maps representing (stories>tones) activation as the dependent variable and reading quality score as the predictor variable, across all subjects. Child age, household income and maternal education were considered as covariates and excluded, given lack of significant correlation with BOLD activation during the story task for these variables (all $p > 0.05$, FDR corrected). Activation maps showing areas of correlation between observed reading quality scores and BOLD activation (stories>tones), along with summary statistics for size, intensity, and location of activation clusters were generated ($p < 0.05$, FDR corrected). Group-level statistical inference was carried out using FSL's *randomise* function,[36] a nonparametric permutation test function providing robust control over false-positive results.[37] The FSLView[38] package was used to identify brain areas corresponding to active clusters in normalized, 3-dimensional, Montreal Neurological Institute (MNI) coordinate space,[39] using the Harvard-Oxford Cortical Structural Atlas. Cluster coordinates were translated into neurological Brodmann Areas via the Talairach Client tool.[40]

RESULTS

Mean maternal age was 21.4 +/− 3.8 years. Seventy-seven percent reported household income under $15,000/year, 9% between $15,000–$30,000/year, and 14% between $30,000–$50,000/year. Fifty-four percent were high school graduates or less, 41% had some college, and 1 (5%) was a college graduate. All children were girls, mean age 4.1 +/− 0.2 years. Wechsler Preschool and Primary Scale of Intelligence (WPPSI) full-scale IQ for the children was within the normal range (mean 92+/−12; range 74–120), as was verbal IQ (mean 97+/−14; 77–136).

A summary of maternal reading quality scores is shown in the Table and Figure 1.

Six mother-child dyads initiated shared reading spontaneously (27%; 3 prompted via the child and 3 via the mother), 10 prompted by a research coordinator (46%), and 6 did not read despite prompts (27%). Of mothers who read, 12 read the book in its entirety (75%) and 4 partially (25%). Of the 4 that stopped reading, 3 were due to the child losing interest (75%), and 1 due to the mother losing interest. Of the six who did not read, all were due to maternal distraction (5 by smartphone), 3 despite multiple entreaties from the child.

Inter-rater reliability for maternal reading quality scores was high (intra-class correlation coefficient=0.96). Mothers who did not read despite prompts (n=6) received a 0 score. No mothers who read at least some of the book received this score. Mean reading quality score was 6.4 (SD 8.5, range 0 – 35.5). Neither household income nor maternal education was significantly correlated with reading quality scores (all $p > 0.05$). Reading quality scores were positively correlated with child full-scale and verbal IQ, controlled for maternal education and income ($p < 0.05$). Reading quality scores were negatively correlated with maternal smartphone use (R^2=0.25; $p < 0.05$), and marginally positively correlated with scores of child engagement during story sharing (p=0.07), the latter applied as a predictor in a separate MRI-based analysis.[41]

Group mean activation for (stories > tones) involved bilateral, left-lateralized brain regions involved with acoustic, phonological, and semantic processing ($p < 0.05$, FDR correction; Figure 2; available at www.jpeds.com), similar to prior studies applying this task in young children.[3, 33]

Maternal reading quality scores were positively correlated with higher BOLD activation during the story task in exclusively left-sided, anterior brain areas (Figures 3, 4, and 5; Figure 3 available at www.jpeds.com).

Anatomical areas of activation involved: 1) temporal pole, supporting semantic memory[42] and sensory-emotional association for language[43]; 2) anterior insula, a multi-sensory attention hub[44] supporting social-emotional processing[45] and emotional salience; 3) inferior frontal gyrus pars orbitalis, supporting complex language processing[46–49]; 4) inferior frontal gyrus, pars triangularis (Broca's Area), an expressive language hub supporting integration, coordination and semantic processing[50, 51]; and 5) lateral frontal pole, supporting working memory.[52] Smaller areas of activation included anterior middle temporal gyrus, supporting multi-modal (especially audio-visual) semantic processing[53]; inferior temporal gyrus pars

opercularis (Broca's Area), supporting phonological and syntactic processing[54]; parahippocampus, a hub for episodic memory encoding and retrieval[52, 55]; and putamen, supporting instrumental learning[56] and language initiation.[50, 57] Areas of activation are shown in Figure 3 and Figure 4, a 3-dimensional rendering identifying neurological Brodmann Areas (BA) provided in Figure 5.

DISCUSSION

Although 5–17% of reading difficulty has an organic etiology (eg, dyslexia),[58] the majority is environmental, a consequence of inadequate resources, motivation, and/or stimulation required to learn to read.[59] Low-SES populations bear disproportionate risk, fueling cycles of academic failure, poverty and poor health outcomes.[59, 60] Contributing factors include deficient reading role models and routines in the home,[61, 62] especially during the span of rapid brain development from birth through age 5, when children often enter kindergarten.[17] As reading is an evolutionarily new skill requiring the integration of brain networks adapted for language, visual imagery, and executive functions (e.g. attention),[63] the greatest potential to encourage this process is in early childhood, when neuroplasticity is maximal.[17] Similarly, each component network, particularly for language, must be adequately stimulated through constructive experiences such as shared reading, to maximize function.

A positive association between quantitative aspects of home reading environment (access to books and shared reading frequency) and brain function supporting semantic processing and visual imagery in preschool-age children was recently described.[3] Our study builds on these findings by providing novel evidence that, despite low levels observed in this low-SES sample, even modest increases in shared reading quality are positively associated with differences in brain function in distinct brain areas supporting other foundational emergent literacy skills. This finding is notable, as it suggests that modifiable aspects of home reading environment influence the developing brain differently, and although targeting one aspect is helpful, combined approaches may be necessary to optimize the integration of brain networks underlying emergent literacy and reading "readiness."

Expressive language is the most well-described benefit of shared reading quality, particularly dialogic reading.[5] Our finding of positive correlation between maternal reading quality scores and child activation in the left inferior frontal gyrus (IFG; Broca's Area) suggests a neural correlate that is remarkably consistent with this evidence. Although counter-intuitive that IFG activation was found during a story listening task where children do not verbally express themselves, recent evidence has refined the role of Broca's Area to that of an expressive language coordination hub,[50] including semantic and syntactic processing, which is later "recycled" into the reading network.[64] Such activation may also reflect the engagement of a putative mirror-neuron system for language (i.e. silent rehearsal),[65, 66] though this notion is controversial. Regardless, our finding suggests that encouraging children to participate actively during shared reading, as advocated by the dialogic approach,[67] may help them develop neural infrastructure to process and verbally express what they hear or read.

Shared reading quality has also been found to enhance narrative comprehension, most likely via greater interactive participation.[68] Although IFG activation is consistent with this effect, increased activation in the left temporal pole during our story task for children whose mothers exhibited higher-quality shared reading suggests an additional biomarker. As a node in the semantic network,[55] the left temporal pole facilitates integration of internal and external, multi-sensory stimuli with language,[43] and plays a key role in semantic memory (concepts and facts).[42] This integrative role is mediated by a major white matter tract[69] connecting the temporal pole and limbic areas[43] including the orbitofrontal cortex and insula, which were also active in our analysis. It is intriguing to speculate that children with more immersive, nurturing shared reading exposure may more efficiently recruit these multi-modal semantic/integrative circuits during story listening, and later reading, facilitating deeper connection and understanding.

Social-emotional benefits of nurturing shared reading routines are intuitive and widely cited.[1, 45, 70] Our finding of positive correlation between maternal reading quality scores and activation in the left anterior insula is consistent with this evidence.[1, 45, 70] Although not generally included in the reading network, the anterior insula is a key node in the "salience network," which helps coordinate attentional shifts based on perceived significance, modulated by input from limbic and episodic memory circuits.[44] During our story listening task, anterior insula activation may reflect determination of the emotional weight of the narrative from the child's perspective, in turn modulating attention. In this context, it is reasonable to speculate that children with greater experience reciprocally engaging in shared reading may be better equipped to form stronger social-emotional connections between stories and their own life, and with caregivers who read with them.[1] Conversely, those with less practice, especially during the critical span of social-emotional development between 2 and 5 years old,[71] may lack such depth of neural processing and reading interest.

A related study involving these dyads found a positive correlation between child engagement during shared reading, which was also positively correlated with maternal reading quality, and activation in cerebellar association cortex, with increased connectivity between this cluster and language and executive function areas.[41] Our finding of positive correlation between maternal shared reading quality and child IQ (full-scale and verbal) is consistent with these MRI results. We feel that this should be interpreted with caution, as our intent for IQ testing was primarily to establish that these children were within a normal range, administered by research coordinators with sub-optimal training. It is also commonly understood that IQ becomes more stable with age, and that the older the child is when tested, the more predictive IQ is of later abilities.[74] Thus, these results may have reduced validity due to insufficient examiner training and the age of the children. However, these results do indicate that such potential associations merit further study. IQ is a multifactorial construct, and although it is reasonable to speculate that shared reading practices may exert substantial benefits via a neurobiological, likely reciprocal process, this complex issue is best addressed via a larger, longitudinal sample.

Our study has several important strengths. Our sample of 4-year-old girls is younger than most MRI-based studies of cognitive development, with an adequate sample size[75] drawn from a well-defined cohort, applying an established fMRI paradigm. Our shared reading

assessment involved direct observation, addressing concerns regarding reliability of parental report.[76] Scoring was adapted from a standardized instrument and evidence-based conceptual model,[13, 25] with high inter-rater reliability and independent statistical analysis. Our analyses were hypothesis-driven, and our findings highly consistent with cognitive testing results (notably verbal IQ), behavioral evidence,[5] and in terms of functional brain networks,[44, 77] including the emerging reading network,[63] accounting for potential confounders. Our results build on recent MRI-based evidence of benefits of early home reading environment on brain function,[3, 41] informing an innovative, eco-bio-developmental model[78, 79] that is highly applicable for further research. Intriguingly, these combined results suggest that quantitative factors, such as access to books, may more directly influence posterior, visual-association brain circuits supporting "seeing and understanding,"[3] while qualitative factors may more directly influence anterior executive, language and social-emotional circuits, supporting "attending, relating, and expressing." Although highly simplistic, such a construct is useful to help guide interventions (e.g. book distribution, dialogic reading training) in programs such as home visitation, Imagination Library, and Reach Out and Read,[2] ideally explored via longitudinal studies. Our study also has limitations. Our low-SES sample limits generalizability, though this demographic is most often cited in dialogic reading literature,[5] and low-SES populations stand to benefit most from improved interventions. Our study involved only girls, though this sampling strategy was guided by historical success rates and negligible sex differences in activation during our story listening task,[30] allowing us to collect high-quality data efficiently and cost-effectively in very young children. Our shared reading observation was conducted in a non-natural setting. However, the room was comfortably arranged via a scripted protocol with prompts provided, highly conducive compared with oft-chaotic home environments experienced by low-SES families.[80] Our reading score reflected a single snapshot, and may not be representative of longer-term behavior, though household reading behaviors tend to be stable during the preschool period[81] and discrete observations are reliably used in assessment of the home environment,[82] including reading.[83, 84] Applying dialogic scoring criteria to mothers showing low mastery may be unrealistic. However, although developed for intervention,[85] the dialogic construct is a well-defined means to assess nurturing behaviors during shared reading – questioning, responding, closeness - that do not require explicit teaching, and other basic, evidence-based items were included.[13] Our finding of generally low scores is concerning, highlighting the difficulty of remediating shared reading quality compared with book distribution, given limited resources[86, 87] and provider training.[7] That said, our findings suggest that even modest improvement in shared reading quality may provide meaningful benefits for brain development supporting emergent skills in at-risk children. Determining the relative impact of qualitative behaviors - from lap sitting, to dialogic prompts, to reducing maternal distraction by smartphones, a major observed barrier worthy of emphasis - warrants further study. Finally, whereas our results show compelling correlation between maternal shared reading quality and brain function during a foundational developmental stage, our cross-sectional design cannot establish causation. Longitudinal studies are needed to better understand how a child's developing brain responds to various modifiable aspects of home reading environment, to optimize literacy and health outcomes.

Our work provides novel preliminary evidence of positive association between maternal shared reading quality and brain function in preschool-age children listening to stories. These findings are highly consistent with behavioral evidence, reinforce AAP recommendations, expand recent MRI-based work exploring home reading environment, and underscore the potential of interventions such as dialogic reading to promote healthy brain development, especially in low-SES households. We hope that this early study reinforces the perspective of shared reading as a critical health issue for parents, pediatricians and policymakers.

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Abbreviations

AAP	American Academy of Pediatrics
BOLD	blood oxygen level dependent
CHIP	Cincinnati Home Injury Prevention (study)
CROWD (prompts)	Completion, Recall, Open-ended questions, Wh-questions, Distancing
FDR	false discovery rate
fMRI	functional magnetic resonance imaging
IFG	inferior frontal gyrus
MNI	Montreal Neurological Institute
PEER	Prompt, Evaluation, Expansion, Repetition
SES	socioeconomic status

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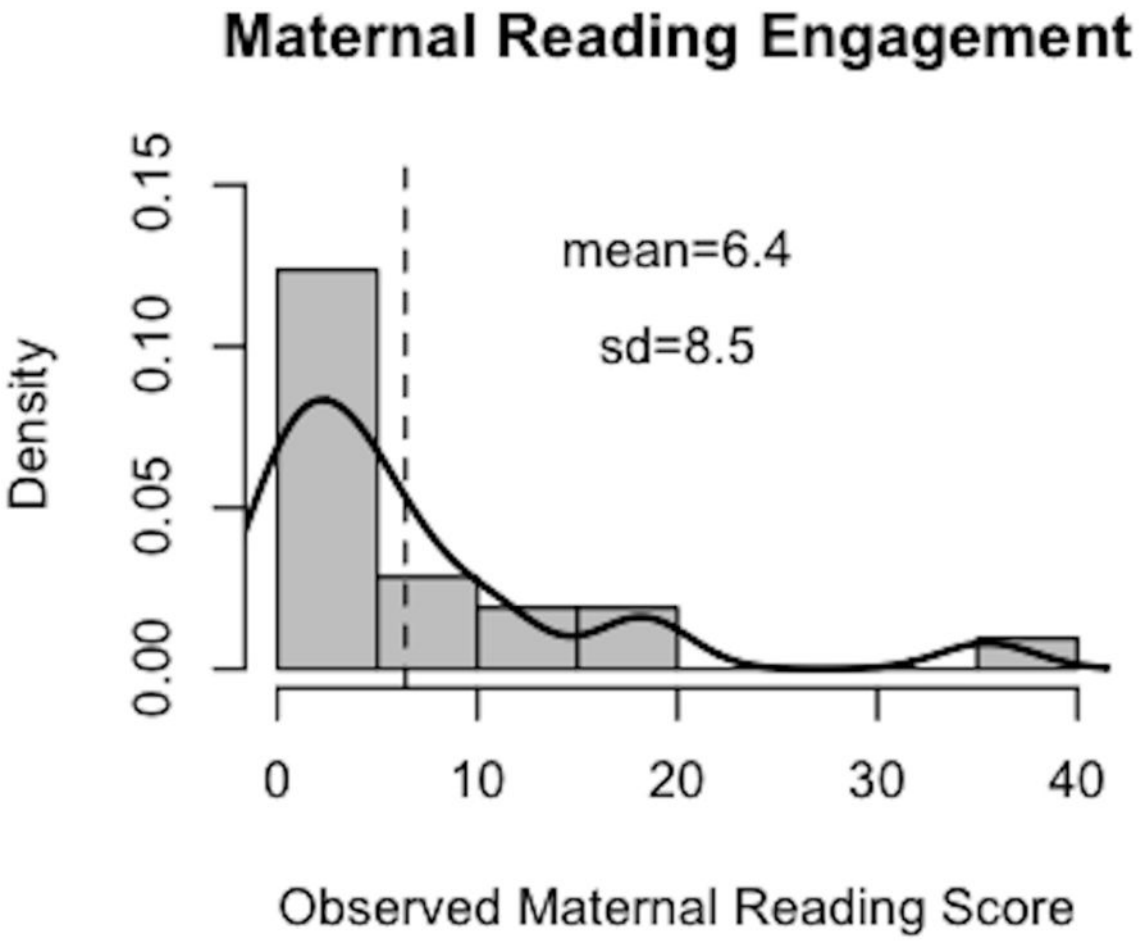

Figure 1. Observed maternal reading quality scores

Histogram and density curve for observed maternal reading quality scores, including mean (dashed line) and standard deviation (SD). Mothers who did not read despite encouragement received a score of 0. Points were awarded for CROWD prompts, PEER expansions, opening/closing questions, spontaneous book sharing, proximity, child page turning and use of child-adjusted language.

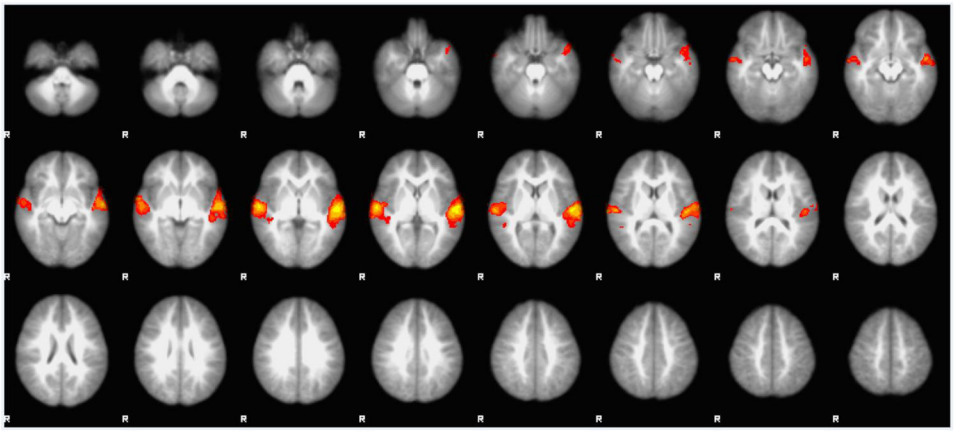

Figure 2. Group mean activation map for the story listening task

Group mean BOLD fMRI activation map for our story listening task (stories>tones) in 4-year-old girls (n=22). All voxels significant at $P < .05$ (FDR corrected), slice thickness 5 mm for contiguous slices. Slices range from $z=-28$ to $z=74$ in MNI coordinate space. Color scale from $t=1.25$ (cooler) to 4 (hotter). Radiological orientation, left=right, right=left.

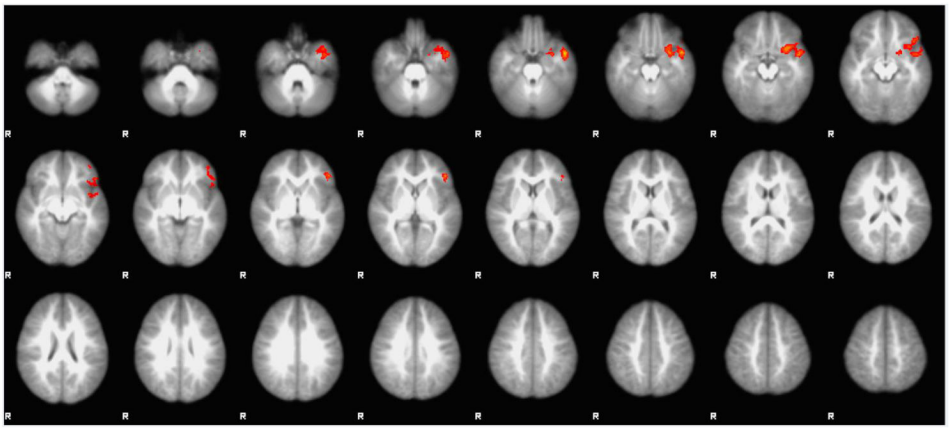

Figure 3. Regression map for the story listening task (stories>tones activation) applying maternal reading quality score as a predictor variable

Regression map for the story listening task (stories>tones; n=22), applying maternal reading quality score as the predictor variable. Total cluster size 1374 voxels ($P < .05$, FDR corrected), with center of gravity at (x=−41, y=12, z=−17; left temporal pole) in MNI coordinate space and z-score local maxima 3.11–4.24. Shown as 5 mm axial slices from z=−28 to z=74 in MNI coordinate space. Color scale t=1.25 (cooler) to 4 (hotter). Radiological orientation, left=right, right=left.

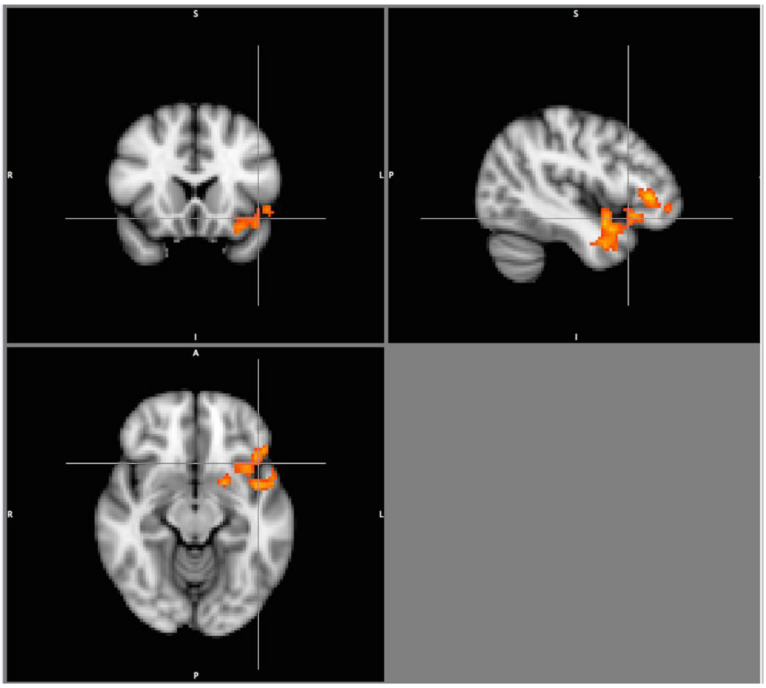

Figure 4. Tri-planar view of neural activation (stories>tones) for the story listening task applying maternal reading quality score as a predictor variable

Orthogonal tri-planar view (origin x=−44, y=18, z=−12, MNI coordinate space; left inferior frontal gyrus) of BOLD activation for the story listening task (stories>tones; n=22), applying maternal reading quality score as the predictor variable. Total cluster size 1374 voxels ($P < .05$, FDR corrected). Color scale t=1.25 (cooler) to 4 (hotter). Radiological orientation, left=right, right=left, sagittal plane viewed from the right.

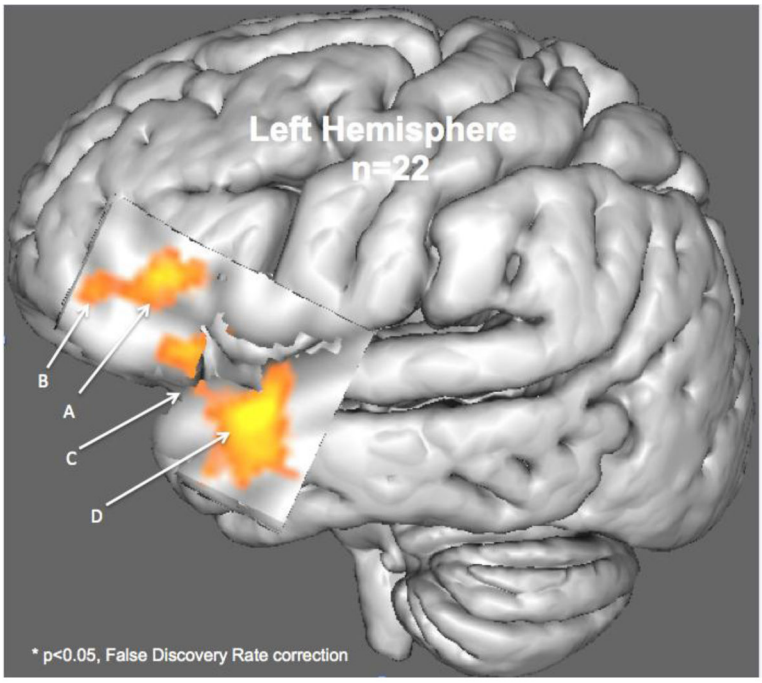

Figure 5. Three-dimensional rendering of neural activation (stories>tones) for the story listening task applying maternal reading quality score as a predictor variable

Three-dimensional rendering of BOLD activation for the story listening task (stories>tones; n=22), applying maternal reading quality score as the predictor variable. Major areas of activation ($p < 0.05$, FDR corrected) include: A) inferior frontal gyrus (BA 44, 45; Broca's Area), B) frontal pole (BA 10), C) anterior insula, and D) temporal pole (BA 38). Cutout is in the left hemisphere, with anterior=left, posterior=right. Color scale t=1.25 (cooler) to 4 (hotter).

Table 1

Maternal reading observation scores and frequencies

Summary of maternal reading quality scores (n=22) and frequencies of behaviors. Total score includes mean, standard deviation (SD), minimum and maximum. Frequencies of behaviors reflect use at least once in mothers who read (n=16). For total score, 1 point was awarded for each CROWD/PEER instance, and 0–2 points for additional items.

Item	n	%	Mean	SD	Min	Max
Total observed score	22	100	6.4	8.5	0	35.5
0 (did not read)	6	27				
1–3	4	18				
4–11	9	41				
12–19	2	9				
20 or more	1	5				
Number of mothers (n=16) using CROWD Prompts						
Completion	1	6				
Recall	2	13				
Open-ended questions	6	38				
Wh- questions	9	56				
Distancing	5	31				
PEER sequence						
Evaluation	5	31				
Expansion	4	25				
Repetition	2	13				
Additional items						
Spontaneous reading	6	27				
Discussion before reading	2	13				
Discussion after reading	7	44				
Proximity - lap	2	13				
Proximity – side close	6	38				
Proximity – distant	8	50				
Page turning - never	9	56				
Page turning - sometimes	4	25				

Item	n	%	Mean	SD	Min	Max
Page turning - often	3	19				
Child-adjusted voice - never	5	31				
Child-adjusted voice - sometimes	11	69				
Child-adjusted voice - often	0	0				