Journal Club

Editor's Note: These short reviews of recent *JNeurosci* articles, written exclusively by students or postdoctoral fellows, summarize the important findings of the paper and provide additional insight and commentary. If the authors of the highlighted article have written a response to the Journal Club, the response can be found by viewing the Journal Club at www.jneurosci.org. For more information on the format, review process, and purpose of Journal Club articles, please see http://jneurosci.org/content/jneurosci-journal-club.

Language Environment and Infants' Brain Structure

Will Lawton,[1] Ozzy Araujo,[2] and Yousif Kufaishi[2]
[1]Centre for Neuroscience Studies, Queen's University, Kingston, Ontario K7L 3N6, Canada and [2]Undergraduate Life Sciences Program, Queen's University, Kingston, Ontario K7L 3N6, Canada
Review of Huber et al.

The quality and quantity of language experienced during early childhood is a known predictor of brain development, long-term language achievement, and later cognitive and academic ability (Cartmill et al., 2013; Romeo et al., 2018). In early childhood, parental language input is the most frequent and important form of interaction (Barnes et al., 1983; Huttenlocher et al., 1991; Shneidman et al., 2013). In recent years, the quality of parental language input and parent–child interactions rather than word quantity has been put forth as the driving factor behind language achievement (Cartmill et al., 2013; Hirsh-Pasek et al., 2015). Recent work has found that early-childhood intervention of parental language input may be beneficial for long-term language achievement (Ferjan Ramírez et al., 2020). This "parental coaching" is focused on increasing the quality of parental language input through increased use of parentese (speaking with a higher pitch and slower tempo) as well as the number of parent–child conversational turns, in turn increasing overall interaction quality. Ferjan Ramírez et al. (2020) specifically reported that parental language input intervention increased the use of both parentese and conversational turn frequency. These behavioral changes in language were significantly correlated with language growth and overall language achievement at age 18 months. Other work has shown that parental language intervention in early childhood may be able to offset disadvantages that stem from lower familial socioeconomic status (SES), one of the most important determinants of overall health (Jensen et al., 2017; Romeo et al., 2018).

Conversational contingency is a key feature of positive parent–child interactions. Contingency is present when responses within a conversation are on topic and drive the interaction forward while stimulating sustained attention (Masek et al., 2021). Parental engagement is an important factor in conversational contingency and also improves child language ability (Hart and Risley, 1995; Hoff, 2003). Similarly, child engagement is related to higher-quality conversational output and overall language comprehension and production (Masek et al., 2021; Pagmar et al., 2022). Overall, behavioral research shows that in early childhood, language ability is positively correlated with responsive parenting wherein parent–child conversations are topically relevant and reliant on input from both parties (Bornstein et al., 2008; Masek et al., 2021).

Behavioral studies of parental language interventions and the importance of parental input have built a strong literature base in the field. Yet, little research has investigated the effects of parental language input and these interventions on structural and functional brain development in children <3 years of age (Romeo et al., 2018). Although parental language coaching has shown promise as an effective tool to augment childhood language ability, exactly how interventions augment language skills and when during development they could be most beneficial remains unclear. The recent work published by Huber et al. (2023) in *The Journal of Neuroscience* attempted to fill the existing literature gap by describing the effects of parental input on the brain between the ages of 6 and 24 months.

Using participants from an existing intervention study, Huber et al. (2023) used quantitative MRI data to analyze estimates of white matter myelination in children aged 6, 10, 14, 18, and 24 months (Ferjan Ramírez et al., 2020). The study focused on the relationship between measures of conversational quality and myelination in the dorsal language pathways of the brain. This study focused specifically on the arcuate fasciculus (AF) and superior longitudinal fasciculus (SLF)—frontotemporal and frontoparietal white matter tracts, respectively (Janelle et al., 2022). These are key tracts involved in language acquisition and production including connectivity between Broca's and Wernicke's areas (Janelle et al., 2022; Shekari and Nozari, 2023). Conversational data were collected using the home Language Environment Analysis System (LENA), which recorded parent–child conversations during 2 d when children were at the aforementioned ages. The data were separated into 100 30 s intervals of conversation per participant at each age. In total, 22 children took part in the study. Seventeen of the participants were part of the intervention study while 5 were members of a control group.

Received Apr. 27, 2023; revised June 5, 2023; accepted June 8, 2023.
We thank Dr. Amanda Bongers, Queen's University, for insight and support during the writing of this article.
Correspondence should be addressed to Will Lawton at 22wjl@queensu.ca.
https://doi.org/10.1523/JNEUROSCI.0787-23.2023

MRI acquisition included both diffusion-weighted imaging (DWI) and macromolecular proton fraction (MPF) mapping. In addition to the well established techniques and uses associated with DWI, MPF mapping offers added sensitivity to changes in myelin density (Kisel et al., 2022). MRI scans were performed after the completion of the intervention study at age 24 months (mean age, 26.30 months; SD, 1.62). Previous work in children 4–6 years of age has shown that myelination of the dorsal language pathway, namely white matter connectivity in the left AF and SLF, specifically adjacent to Broca's area are related to language ability independent of adult word count (Romeo et al., 2018). The current study attempted to build on these findings by identifying the relationship between the AF and SLF and language development and ability in younger children.

The MRI scan MPF and DWI data were compared with behavioral data from ages 6 to 24 months. All participants (intervention and control) were treated as a single group during analysis. Conversational turns were found to be correlated with MPF (left anterior AF) from 6 to 18 months and with MPF (left posterior SLF) from 6 to 14 months, but only the correlation between MPF (left anterior AF) and CT results at 18 months remained significant after multiple-comparison correction. In addition, MPF (left anterior AF) was predicted by individual growth in conversational turns from 6 to 24 months. Although no significant correlation was observed for the left arcuate or SLF, vocabulary was correlated with MPF percentage in the right inferior longitudinal fasciculus (ILF) and right inferior fronto-occipital longitudinal fasciculus (IFOF) at 24 months.

The right inferior frontal cortex has been implicated in word learning and early literacy (Bosseler et al., 2021; Shekari and Nozari, 2023). Specifically, the ILF is involved in the processing of complex visual information tied to word and emotion perception, and the IFOF has been noted as a key factor in reading, facial recognition, and spatial awareness (Catani, 2022). The exploratory findings of Huber et al. (2023) indicate early that markers of top-down control and visual/emotional processing are related to language ability, namely vocabulary size.

These findings alongside those of Fibla et al. (2023) suggest that fostering contingent conversations throughout infancy, particularly those with quality language, may enhance the development of myelinated circuits (Fibla et al., 2023; Huber et al., 2023). These increases in myelin density during early development may optimize or facilitate language-related cognitive abilities and learning in childhood development (Corrigan et al., 2022). This may be in part because of myelin growth being shaped as a result of neuronal function and vice versa, whereby refinement in circuitry because of white matter-induced neuroplasticity improves synchrony and speed of synaptic transmission (Wake et al., 2011; Pajevic et al., 2014; Noori et al., 2020). Myelin density may also determine individual differences in propensity for future language growth (Zuk et al., 2021). Notably, increases in myelin density observed in language-effective pathways during early development relative to other association white matter tracts are potentially enhanced by the social aspect of communication (Makinodan et al., 2012). This simultaneous maturation in the arcuate fasciculus and the IFOF may be a result of the receptive and productive language skills encompassing the learning experience throughout infancy (Tierney and Nelson, 2009).

The findings by Huber et al. (2023) support the notion that myelination increases are coupled to cognitive development. These myelination increases are not exclusive to the neonatal and infancy period, but may also shape adulthood learning (Chang et al., 2015). The current paradigm of myelination holds that the third trimester to the end of infancy (2 years) is the most sensitive period for alterations in myelin development; particularly of importance is how disruption of this critical period may lead to cognitive and learning issues in adulthood as seen in preterm births (Kennedy et al., 2021). A study by O'Muircheartaigh et al. (2014) noted that individual differences in cognitive abilities, particularly those of expressive and receptive language skills, showed a significant relationship to myelin volume fraction. This coupling may be facilitated by the seemingly programmed course of myelination of particular sensory regions from birth. Specifically, it has been suggested that the maturation of language comprehension and production regions shows parallel maturation rates along the temporofrontal language network throughout infancy (Pujol et al., 2006). This is in accordance with the evidence seen with regard to the theories of myelination, gradients from anterior to posterior regions (Grotheer et al., 2022). Myelination of the brain is nonuniform and dynamic; developmentally, it occurs in the posterior to anterior direction, whereby changes in functionally related white matter tracts are synchronized (Buyanova and Arsalidou, 2021).

The study by Huber et al. (2023) is also consistent with previous studies that have linked fractional anisotropy of SLF and AF with home language and literacy environment (HLLE) in infancy. HLLE is found to be a predictor of white matter tract organization specific to prereading and linguistic development; as well as a predictor of preliteracy skill development (Turesky et al., 2022). Interestingly, Turesky et al. (2022) measured SES using maternal education level in contrast to Huber et al. (2023), who measured SES using the Hollingshead index. Although measures of SES can vary in the accuracy and factors considered, the Hollingshead index used by Huber et al. (2023) is considered to be a more complete measure as it considers several additional factors, including occupation (Conway et al., 2019). Nevertheless, the two studies showed similar results underscoring the importance of the home language environment in infancy.

To conclude, this work by Huber et al. (2023) investigates the role of parental language input on cortical myelination at 24 months of age. The study found compelling evidence that the quality of conversation and, specifically, the number of conversational turns, are predictors of myelin levels in the dorsal language stream before 2 years of age. This study brings the field one step closer to elucidating whether there is a sensitive period for intervention to facilitate white matter development; implications may include early interventions for reducing speech impediments or to counter disadvantages because of SES (Jensen et al., 2017; Stephens et al., 2020). Future work that examines time frames and cortical structures that are particularly sensitive to the social–interactional variables of conversation are thus an important avenue to explore. Moreover, larger and more diverse samples (including language disorders; e.g., autism) should be considered as well as the use of participants from outside of parental input interventions to expand current findings. Finally, these findings provide compelling information for all parents and early childhood caregivers. Increased conversational turn-taking, child-directed speech, and use of parentese are documented predictors of later cognitive and academic achievement, and should be implemented as early as possible in both home and educational settings.

References

Barnes S, Gutfreund M, Satterly D, Wells G (1983) Characteristics of adult speech which predict children's language development. J Child Lang 10:65–84.

Bornstein MH, Tamis-LeMonda CS, Hahn C-S, Haynes OM (2008) Maternal responsiveness to young children at three ages: longitudinal analysis of a multidimensional, modular, and specific parenting construct. Dev Psychol 44:867–874.

Bosseler AN, Clarke M, Tavabi K, Larson ED, Hippe DS, Taulu S, Kuhl PK (2021) Using magnetoencephalography to examine word recognition, lateralization, and future language skills in 14-month-old infants. Dev Cogn Neurosci 47:100901.

Buyanova IS, Arsalidou M (2021) Cerebral white matter myelination and relations to age, gender, and cognition: a selective review. Front Hum Neurosci 15:662031.

Cartmill EA, Armstrong BF, Gleitman LR, Goldin-Meadow S, Medina TN, Trueswell JC (2013) Quality of early parent input predicts child vocabulary 3 years later. Proc Natl Acad Sci U S A 110:11278–11283.

Catani M (2022) The connectional anatomy of the temporal lobe. In: Handbook of clinical neurology (Miceli G, Bartolomeo P, Navarro V, eds), pp 3–16. Amsterdam: Elsevier.

Chang YS, Owen JP, Pojman NJ, Thieu T, Bukshpun P, Wakahiro MLJ, Berman JI, Roberts TPL, Nagarajan SS, Sherr EH, Mukherjee P (2015) White matter changes of neurite density and fiber orientation dispersion during human brain maturation. PLoS One 10:e0123656.

Conway DI, McMahon AD, Brown D, Leyland AH (2019) Measuring socioeconomic status and inequalities. In: Reducing social inequalities in cancer: evidence and priorities for research (Vaccarella S, Lortet-Tieulent J, Saracci R, Conway DI, Straif K, Wild CP, eds), Chap 4. Lyon, France: International Agency for Research on Cancer.

Corrigan NM, Yarnykh VL, Huber E, Zhao TC, Kuhl PK (2022) Brain myelination at 7 months of age predicts later language development. Neuroimage 263:119641.

Ferjan Ramírez N, Lytle SR, Kuhl PK (2020) Parent coaching increases conversational turns and advances infant language development. Proc Natl Acad Sci U S A 117:3484–3491.

Fibla L, Forbes SH, McCarthy J, Mee K, Magnotta V, Deoni S, Cameron D, Spencer JP (2023) Language exposure and brain myelination in early development. J Neurosci 43:4279–4290.

Grotheer M, Rosenke M, Wu H, Kular H, Querdasi FR, Natu VS, Yeatman JD, Grill-Spector K (2022) White matter myelination during early infancy is linked to spatial gradients and myelin content at birth. Nat Commun 13:997.

Hart B, Risley TR (1995) Meaningful differences: everyday parenting and intellectual development in young American children. Baltimore: Paul H. Brookes.

Hirsh-Pasek K, Adamson LB, Bakeman R, Owen MT, Golinkoff RM, Pace A, Yust PK, Suma K (2015) The contribution of early communication quality to low-income children's language success. Psychol Sci 26:1071–1083.

Hoff E (2003) The specificity of environmental influence: socioeconomic status affects early vocabulary development via maternal speech. Child Dev 74:1368–1378.

Huber E, Corrigan NM, Yarnykh VL, Ferjan Ramírez N, Kuhl PK (2023) Language experience during infancy predicts white matter myelination at age 2 years. J Neurosci 43:1590–1599.

Huttenlocher J, Haight W, Bryk A, Seltzer M, Lyons T (1991) Early vocabulary growth: relation to language input and gender. Dev Psychol 27:236–248.

Janelle F, Iorio-Morin C, D'amour S, Fortin D (2022) Superior longitudinal fasciculus: a review of the anatomical descriptions with functional correlates. Front Neurol 13:794618.

Jensen SK, Berens AE, Nelson CA 3rd (2017) Effects of poverty on interacting biological systems underlying child development. Lancet Child Adolesc Health 1:225–239.

Kennedy E, Poppe T, Tottman A, Harding J (2021) Neurodevelopmental impairment is associated with altered white matter development in a cohort of school-aged children born very preterm. Neuroimage Clin 31:102730.

Kisel AA, Naumova AV, Yarnykh VL (2022) Macromolecular proton fraction as a myelin biomarker: principles, validation, and applications. Front Neurosci 16:819912.

Makinodan M, Rosen KM, Ito S, Corfas G (2012) A critical period for social experience–dependent oligodendrocyte maturation and myelination. Science 337:1357–1360.

Masek LR, McMillan BTM, Paterson SJ, Tamis-LeMonda CS, Golinkoff RM, Hirsh-Pasek K (2021) Where language meets attention: how contingent interactions promote learning. Dev Rev 60:100961.

Noori R, Park D, Griffiths JD, Bells S, Frankland PW, Mabbott D, Lefebvre J (2020) Activity-dependent myelination: a glial mechanism of oscillatory self-organization in large-scale brain networks. Proc Natl Acad Sci U S A 117:13227–13237.

O'Muircheartaigh J, Dean DC 3rd, Ginestet CE, Walker L, Waskiewicz N, Lehman K, Dirks H, Piryatinsky I, Deoni SC (2014) White matter development and early cognition in babies and toddlers. Hum Brain Mapp 35:4475–4487.

Pagmar D, Abbot-Smith K, Matthews D (2022) Predictors of children's conversational contingency. Lang Dev Res 2:139–179.

Pajevic S, Basser PJ, Fields RD (2014) Role of myelin plasticity in oscillations and synchrony of neuronal activity. Neuroscience 276:135–147.

Pujol J, Soriano-Mas C, Ortiz H, Sebastián-Gallés N, Losilla JM, Deus J (2006) Myelination of language-related areas in the developing brain. Neurology 66:339–343.

Romeo RR, Segaran J, Leonard JA, Robinson ST, West MR, Mackey AP, Yendiki A, Rowe ML, Gabrieli JDE (2018) Language exposure relates to structural neural connectivity in childhood. J Neurosci 38:7870–7877.

Shekari E, Nozari N (2023) A narrative review of the anatomy and function of the white matter tracts in language production and comprehension. Front Hum Neurosci 17:1139292.

Shneidman LA, Arroyo ME, Levine SC, Goldin-Meadow S (2013) What counts as effective input for word learning? J Child Lang 40:672–686.

Stephens RL, Langworthy BW, Short SJ, Girault JB, Styner MA, Gilmore JH (2020) White matter development from birth to 6 years of age: a longitudinal study. Cereb Cortex 30:6152–6168.

Tierney AL, Nelson CA (2009) Brain development and the role of experience in the early years. Zero Three 30:9–13.

Turesky TK, Sanfilippo J, Zuk J, Ahtam B, Gagoski B, Lee A, Garrisi K, Dunstan J, Carruthers C, Vanderauwera J, Yu X, Gaab N (2022) Home language and literacy environment and its relationship to socioeconomic status and white matter structure in infancy. Brain Struct Funct 227:2633–2645.

Wake H, Lee PR, Fields RD (2011) Control of local protein synthesis and initial events in myelination by action potentials. Science 333:1647–1651.

Zuk J, Yu X, Sanfilippo J, Figuccio MJ, Dunstan J, Carruthers C, Sideridis G, Turesky TK, Gagoski B, Grant PE, Gaab N (2021) White matter in infancy is prospectively associated with language outcomes in kindergarten. Developmental Cognitive Neuroscience 50:100973.