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Getting to the root of linguistic alignment: Testing the predictions of Interactive Alignment across developmental and biological variation in language skill

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Abstract

Linguistic alignment—the contingent reuse of our interlocutors' language at all levels of linguistic structure—pervades human dialogue. Here, we design unique measures to capture the degree of linguistic alignment between interlocutors' linguistic representations at three levels of structure: lexical, syntactic, and semantic. We track these measures in a longitudinal dataset of early conversations between caregivers and children with and without perinatal brain injury. Specifically, we test the predictions of the well-known Interactive Alignment Model, taking advantage of the variability within our sample in terms of the strength of interlocutors' linguistic representations, whether owed to age or injury. Ultimately, we find inconsistent support for the (largely untested) predictions of the Interactive Alignment Model, pointing to a need for new quantitative accounts of the mechanisms underlying linguistic alignment. Our results regarding the trajectory of interactive alignment broadly replicate developmental trends documented by other researchers, though analyses linking concurrent vocabulary and child alignment, as well as caregiver alignment and later child vocabulary—defy predictions from previous work. Our goal with these analyses is to start a conversation regarding the mechanisms underlying linguistic alignment, and to inform theories of how interactive linguistic experience supports language development.

Keywords: linguistic alignment, language acquisition, computational linguistics, perinatal brain injury

Verbal interaction is at the heart of linguistic development. Yet despite the presumed centrality of *interactive* language experiences, their contribution to language development is really only close to being understood for instances of *referential* learning: cases where the learner's task is to discover which entities different language units 'map onto.' Extant research has spotlighted how interactive experiences might, for example, increase the child learner's attention to language, or increase the likelihood that the language is relevant to them. Yet we would expect the benefits of interactive linguistic experiences to extend beyond the mere accumulation of clear referential learning instances. What about more enigmatic aspects of language knowledge—things like negation, complex semantics, and syntactic structure—which are evident in adult language use? That is, although effects of contingency on language development pervade the literature (*e.g.,* Goldstein et al., 2003), we remain a long way from understanding the full range of mechanisms by which moment-to-moment interactional behaviors support complex language development. We focus here on *priming* (*e.g.*, Bock, 1986) as a promising mechanism that operates across the linguistic system, from lexical to syntactic to semantic levels of linguistic structure.

Broadly, priming theories suggest there is something automatic and infectious in our processing of incoming linguistic structure, teasing the possibility that linguistic structure can be activated implicitly among interlocutors. Signatures of such implicit transmission represent an ideal place to explore how language structure might develop out of real-time, dynamic interaction (*e.g.*, Savage, Lieven, Theakston, & Tomasello, 2006; Kidd, 2012). Our focus here is on *linguistic alignment*—that is, our conversational tendency to reuse and converge on the same pronunciations, vocabulary, and sentence structures as our interlocutors. Linguistic alignment hints at the ways by which adults' child-directed language might be effortlessly calibrated to children's ever-evolving competence (*e.g.*, Yurovsky, Doyle, & Frank, 2016), as well as how learner's productive knowledge of linguistic structure might be strengthened in the course of verbal engagement.

If the reader knows one account of linguistic alignment in dialogue, it is almost certainly Pickering & Garrod's (2004) Interactive Alignment Model, which sought a single explanatory framework for diverse empirical phenomena in the psycho- and socio-linguistic literatures, and has continued to be highly influential for theorizing today. According to this model, successful communication relies on the alignment of interlocutors' *situation models* (something like their built-up semantic understanding), which is achieved by: (1) alignment between interlocutors' representations at each level of linguistic representation (phonetic, phonological, lexical, and syntactic), via automatic, resource-free priming mechanisms, (2) 'percolation' between levels of linguistic representation within interlocutors, and (3) parity between the representations used in production and comprehension.

Experimental research with adults undergirds these claims. Evidence for (1) comes in part from priming studies: for example, given a depicted event compatible with the description "A sent B the postcard" *or* "A sent the postcard to B," adults are more likely to use the same construction previously used by a confederate, even if the event the confederate had described used a different verb and included different participants (*e.g., X gave Y the kerchief* → "A sent B the postcard" versus *X gave the kerchief to Y* → "A sent the postcard to B;" Bock, 1986). Evidence for (2) comes in part from findings that syntactic priming is even more robust when the primed sentence shares one or more words with the prime (conferring a so-called "lexical boost," as in *X* ***sent*** *Y the kerchief* → "A **sent** B the postcard").

In the current work, we leverage a unique longitudinal dataset of caregiver-child verbal interactions to test some of the basic predictions of the Interactive Alignment Model, including whether alignment is correlated: (1) between conver-

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sational participants and (2) across levels within a given individual. In company with other researchers (Misiek, Favre, & Fourtassi, 2020; Fusaroli, Weed, Fein, & Naigles, 2021), we operationalize linguistic alignment at three levels of linguistic representation (lexical, syntactic, and semantic). In addition, we explore: (3) how caregiver-child alignment relates to and/or reflects children's development and language ability, and (4) the ability of caregiver alignment to *predict* children's linguistic development. Importantly, the corpus contains dialogues between caregivers and typically developing children in the earliest stages of acquiring language, as well as between caregivers and children whose biological predisposition to language acquisition may be impaired — in this case, via perinatal brain injury (Goldin-Meadow et al., 2014). If linguistic alignment depends on overlapping representations between interlocutors, we expect both developmental age and barriers to typical language development, like perinatal brain injury (PBI), to constrain the strength and types of alignment that are possible.

Methods

Participants

The data for this study come from the Language Development Project, which follows 110 monolingual English-speaking children from the Greater Chicagoland Area: 64 typically developing, and 46 with unilateral brain injury (Goldin-Meadow et al., 2014). Children and their primary caregivers were video-recorded engaging in spontaneous interactions in their homes for twelve 90-minute visits ($M = 11.3$, $SD = 1.8$ sessions, range 4—12 sessions), from when the children were 14 months to 58 months old (due to difficulties enrolling children with unilateral brain injuries, the average age of their first visit was 23.9 months; $SD = 11.0$).

Operationalizing Alignment

Data Preprocessing We stripped all utterances of extraneous punctuation and lemmatized lexical tokens (*e.g.,* "dogs"→"dog") using the SpaCy NLP en_core_web_lg library (Honnibal & Montani, 2021). As a proxy for conversational turns, we identified *speaker shifts* where the speaker label in a transcript changed from parent to child ($n = 212,345$ utterances) or child to parent ($n = 212,207$). All alignment measures are computed at speaker shifts, and defined *directionally* in terms of who was responding to whom (we refer to the utterances on either side of a speaker shift as *contingent utterances*; see Figure 1 for illustration).

Lexical Alignment Lexical alignment values reflect the number of lexical tokens shared between contingent utterances as a proportion of the total number of lexical tokens summed across both utterances. For interpretive ease, we multiply this (and the metrics that follow) by 100, producing a score between 0 and 100 (see also Foushee et al., 2021).

Syntactic Alignment In a departure from previous work, we measure syntactic alignment by comparing hierarchical representations of contingent utterances, with the goal of better approximating the structured, productive representations employed by human language users. We use the Berkeley Neural Parser to transform all utterances into their most probable constituency-parsed trees (Kitaev, Cao, & Klein, 2019; Kitaev & Klein, 2018). Sentences with multiple possible parses were analyzed using the most probable parse-tree.

From there, we compute eight descriptive metrics for each parse tree, including *tree depth*, reflecting something like the complexity of the syntactic structure, *node type frequency*, reflecting how recursive the structure is, and number of *identically* and *non-identically traversed nodes*, reflecting the degree of shared sub-structures between the two trees. We quantify semantic alignment by taking the cosine similarity of the vectors for parse-trees of contingent utterances, giving a value between 0 and 1 (which we multiply by 100 for analysis).

By relying on structured tree representations, rather than, say, sequences of part-of-speech tags, our measure of syntactic alignment is both cognitively valid and critically measuring something different from our metric of lexical alignment.

Semantic Alignment To calculate semantic or conceptual alignment, we represent contingent utterances in a high-dimensional vector space, using vectors from SpaCy's en_core_web_lg library (Honnibal & Montani, 2021), trained on the Common Crawl Dataset. Our metric of semantic alignment reflects the similarity between utterance vectors. Scores of zero suggest contingent parent-child utterances are about unrelated topics, while scores near 100 suggest direct repetitions between speakers, and the range between these two poles reflects a range in topical coherence or conceptual relatedness between contingent utterances.

Results

Testing the Predictions of Interactive Alignment

Correlations *between* Interlocutors We first tested whether degree of alignment is correlated between conversational partners, as would be predicted if within-dialogue alignment at each level of linguistic structure occurred via priming in comprehension and production. To do so, we take the mean of each speaker's alignment scores at each session, and compare the correlation between true parent-child pairs against a baseline distribution of randomly permuted pairs of parents and children.

Interestingly, our results differ by level of linguistic representation. Degrees of lexical alignment were modestly correlated between caregiver and child (*range* = .11, .34, $M = .19$), but significantly (α=.05) so on only two sessions (ages 18 and 22 months, r=.34 and r=.29, respectively; both ps$<$ .05 with Bonferroni correction). For the first four sessions (spanning ages 14–26 months), degree of syntactic alignment showed no significant correlation between caregiver and child (*range* = $-.01$, .31), but an increasingly negative correlation on the remaining eight sessions, ending when children were 58 months (*range*: $-.67$, .01, $M = -.53$; all Bonferroni-corrected ps$<$ .05). Finally, caregiver-child semantic align-

			Lexical	Syntactic	Semantic
1	CHI:	Money please			
2	PAR:	I'm not giving you no money to put in your pockets	0.15	0.14	0.78
3	CHI:	Give me this	0.00	0.93	0.85
4	PAR:	No give your brother that	0.25	0.50	0.87
5	CHI:	Eat this	0.00	0.86	0.68
6	PAR:	No no don't eat that	0.29	0.50	0.78

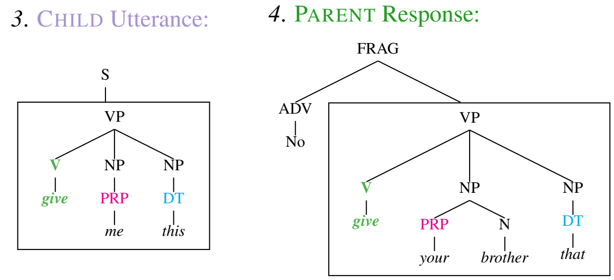

Figure 1: Example Caregiver-Child Conversational Exchange.

Note. Utterances 3–4 in the transcript (left) appear in tree form (right), color-coded to mark aligning linguistic representations.

ment was significantly (and increasingly) positively correlated across all sessions (*range* = .46, .97, $M = .81$, all Bonferroni-corrected $ps < .001$). Such variable (and unstable) between-speaker correlations is unexpected under the Interactive Alignment Model, though we would need a different corpus to determine whether the correlations we observe are typical of casual conversation more generally.

Correlations *within* Interlocutors Next, we asked whether degree of alignment is correlated *within* participants, as would be predicted if there were 'percolation' between levels of linguistic representation, such that alignment at one level led to alignment at others. Rates of lexical, syntactic, and semantic alignment were significantly intercorrelated at 10/12 sessions for children (*range*: .35, .68; $M = .48$), and at all 12 sessions for caregivers (*range*: .56, .89; $M = .72$, all $ps < .05$ with Bonferroni correction). Interestingly, while the internal correlation in children's rates of alignment showed no change across sessions, parents' slowly decreased, consistent with the patterns discussed in the next section.

Returning to our motivation for these analyses: on the Interactive Alignment Model, the variability in adults' degree of alignment across levels of representation is unexpected.

Alignment Across Development

Linguistic alignment relies on shared systems of linguistic representations, implying that patterns of alignment should increase overall as the overlap in interlocutors' linguistic knowledge increases. In this longitudinal dataset we can examine how these changes take place with the same parent-child pairs over the first few years of productive language use, during which both the typically developing and brain injured children displayed rapid growth in linguistic skill, but with a potential barrier to this growth for the latter group. We fit linear mixed effects models to the utterance-by-utterance values for each level of linguistic representation in each sample, with child age, speaker (CHILD or PARENT), and their interaction. In addition, models included utterance length and position within the transcript (scaled to be a value between 0—the first utterance, and 1—the last utterance), maternal education, and child reported sex, along with random intercepts for subjects ($n = 110$) and session ($n = 12$). To evaluate the robustness of the trends we identify, we fit our models for each sample to children's sessions 1–9 (spanning ages 14 to 46 months), and test them on sessions 10–12 (ages 50 to 58 months).

Table 1: Linear Models Predicting Alignment in Typically Developing Sample

	Alignment Type		
	Lexical	Syntactic	Semantic
Intercept	9.29^{***}	45.79^{***}	68.38^{***}
	(6.96, 11.62)	(44.10, 47.49)	(66.77, 69.99)
Age	-0.14^{***}	-0.04	0.10^{***}
	(−0.25, −0.04)	(−0.11, 0.02)	(0.04, 0.15)
PARENT	6.69^{***}	12.97^{***}	1.33^{***}
	(6.51, 6.87)	(12.81, 13.12)	(1.24, 1.43)
Age:PARENT	-0.26^{***}	-0.44^{***}	-0.05^{***}
	(−0.27, −0.24)	(−0.46, −0.43)	(−0.06, −0.04)
$R2_{CV}$[†]	0.004	0.043	0.062

[†]Evaluated on held-out test set $^{***}p<.001$

In Typically Developing Children

Lexical Alignment Caregivers do more lexical alignment than their children do. Lexical alignment in both caregivers and children decreases with age, consistent with caregivers and children producing longer, less repetitious utterances with more varied words over the course of development. Caregivers' rates of alignment fell more quickly than children's ($\chi^2(1) = 1120$, $p < .001$; see Figure 2 for illustration, and Table 1 for relevant coefficients).

Syntactic Alignment Caregivers also aligned more than their children at the syntactic level. While children's syntactic alignment did not change across development, caregivers' significantly decreased. Longer utterances were associated with greater syntactic alignment in both children and caregivers, consistent with longer utterances providing greater opportunities for shared structure. Notably, these trends hold even when excluding all single-word utterances from the data.

Semantic Alignment Caregivers semantically aligned more than children did, and both groups showed greater align-

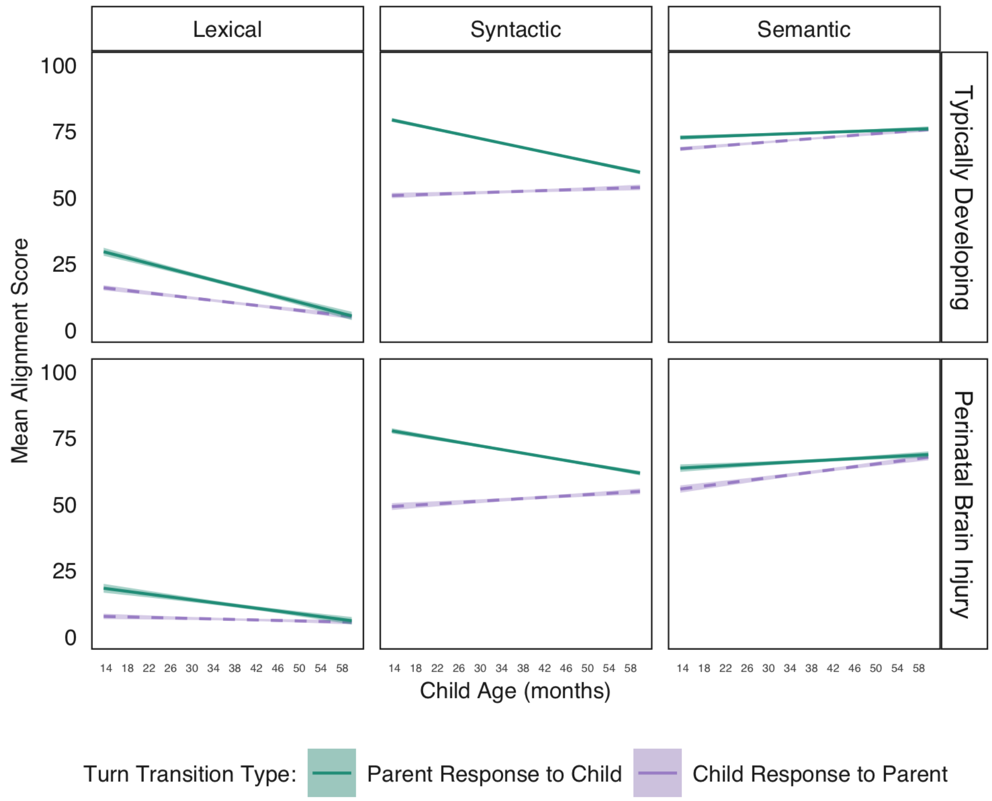

Figure 2: Developmental Trajectory of Alignment Across Dyads and Populations.

ment in longer utterances. However, in stark contrast to the preceding two levels, both caregivers and children showed *increasing* semantic alignment with child age, with children showing a steeper slope than their caregivers.

Table 2: Linear Models Predicting Alignment in Sample with Perinatal Brain Injury

	Alignment Type		
	Lexical	Syntactic	Semantic
Intercept	8.05***	44.36***	46.62***
	(6.81, 9.28)	(42.59, 46.12)	(41.91, 51.34)
Age	−0.04***	−0.01	0.32***
	(−0.05, −0.03)	(−0.05, 0.02)	(0.20, 0.44)
Parent	11.03***	29.06***	6.48***
	(10.39, 11.66)	(28.41, 29.71)	(5.86, 7.10)
Age:Parent	−0.16***	−0.38***	−0.09***
	(−0.17, −0.14)	(−0.39, −0.36)	(−0.10, −0.07)
$R2_{CV}$ †	0.003	0.146	0.014

†Evaluated on held-out test set ***p<.001

In Children with Brain Injury

Lexical Alignment Caregivers aligned more than their children. Both groups lexically aligned less and less across developmental time, with parents' rates of lexical alignment falling more steeply than children's (Table 2).

Syntactic Alignment As at the lexical level, caregivers aligned syntactically more than their children, with parents' rates of syntactic alignment falling more steeply than children's.

Semantic Alignment As with lexical and syntactic alignment, children aligned less than their caregivers. However, unlike previous levels, semantic alignment *increased* over time, and at a slightly steeper rate for children than for adults.

Child Alignment and Concurrent Language Skill

If alignment depends on the mutual availability of linguistic representations in speaker and listener, we should expect to see a correlation between measures of children's language ability or linguistic maturity, and rates of alignment. The last analysis investigated this prediction by tracking alignment over child age as a proxy for language development. Here, we take a finer-grained approach, making predictions of linguistic alignment on the basis of actual measures of linguistic maturity. To do so, we fit linear mixed effects models to children's utterance-by-utterance alignment scores for each level, this time including concurrent administrations of the Peabody

Picture Vocabulary Test (Dunn & Dunn, 2007) as a fixed effect (along with the covariates described above, and random intercepts for subject and session).

Table 3: Linear Models Predicting Alignment from Child Vocabulary Size in Typically Developing Sample

	Alignment Level		
	Lexical	Syntactic	Semantic
Intercept	11.73	38.99^{***}	68.84^{***}
	(−2.67, 26.13)	(36.57, 41.41)	(67.20, 70.48)
PPVT	0.005	0.04^{**}	0.05^{***}
	(−0.02, 0.03)	(0.01, 0.06)	(0.04, 0.07)
Age	-1.15^{***}	-0.17^{***}	-0.10^{***}
	(−1.72, −0.59)	(−0.23, −0.10)	(−0.14, −0.06)

*p<0.05; **p<0.01; ***p<0.001

In Typically Developing Children Contrary to our expectations, there was no relation between typically developing children's concurrent PPVT scores and their rates of lexical alignment ($\beta = 0.005$ [−0.02, 0.03], $\chi^2(1) = 0.22, p = .64$). However, both a model fit to children's syntactic alignment values and a model fit to their semantic alignment scores showed a small but reliable positive effect of PPVT score (on syntactic alignment: $\beta = 0.038$ [0.01, 0.06], $\chi^2(1) = 8.11, p = .004$; on semantic alignment: $\beta = 0.05$, [0.04, 0.07]; $\chi^2(1) = 48.6, p < .001$). This is consistent with the positive developmental trends for children in the previous section, and with a theory of linguistic alignment that relies on some degree of shared linguistic representations. The null result regarding lexical alignment might reflect the interacting forces of conversation (constraining the space of relevant vocabulary) and maturity (where direct repetitions are more common at smaller vocabulary sizes, but the child's potential to re-use greater numbers of the caregivers' words increases in line with vocabulary).

Table 4: Linear Models Predicting Alignment from Vocabulary Size in Children with Perinatal Brain Injury

	Alignment Level:		
	Lexical	Syntactic	Semantic
Intercept	6.17^{***}	39.64^{***}	51.89^{***}
	(3.97, 8.37)	(37.10, 42.19)	(49.95, 53.84)
Age	-0.06^{***}	-0.04^{***}	0.15^{***}
	(−0.08, −0.04)	(−0.05, −0.03)	(0.14, 0.16)
PPVT	0.002	−0.02	−0.01
	(−0.03, 0.04)	(−0.06, 0.02)	(−0.04, 0.02)

*p<0.05; **p<0.01; ***p<0.001

In Children with Brain Injury Surprisingly, parallel models fit to the alignment data for the children with perinatal brain injury showed no relation between children's scores on the PPVT (*range*: 0–120; $M = 53.52$, $SD = 25.87$) and lexical alignment ($\beta = 0.002$ [−0.03, 0.03], $\chi^2(1) = 0.01, p = .92$), syntactic alignment ($\beta = -0.02$ [−0.06, 0.02], $\chi^2(1) = 0.81, p = .37$), or semantic alignment ($\beta = -0.01$ [−0.04, 0.02], $\chi^2(1) = .17, p = .68$). This observation challenges the notion that the *link* between language development and alignment should be stable across populations, pointing the way to future research.

Caregiver Alignment and Future Child Language

Finally, we used these data to test the prediction that caregivers' alignment to their children might itself promote children's language development, as investigated and shown in previous work (Denby & Yurovsky, 2019; Foushee, Byrne, Casillas, & Goldin-Meadow, 2021; Fusaroli et al., 2021). To do so, we used linear models to predict children's 50-month PPVT score from caregivers' mean alignment at the 46-month session.

In Typically Developing Children To our surprise, of these models, only mean rates of caregiver *semantic* alignment predicted children's PPVT scores ($\beta = 198.20$ [64.19, 332.20]), rather than lexical ($\beta = 54.24$ [−96.16, 204.64]) or syntactic ($\beta = -7.01$ [−161.36, 147.34]).

In Children with Brain Injury For caregivers of children with perinatal brain injury, neither lexical ($\beta = 9.90$ [−202.08, 221.88]), syntactic ($\beta = -79.79$ [−285.04, 125.45]), nor semantic alignment ($\beta = 146.74$ [−94.19, 387.68]) predicted children's later vocabulary scores.

General Discussion

The current study sought to test a set of interrelated predictions of priming models generally, and of the Interactive Alignment Model in particular, with the potential to inform future mechanistic accounts of language development. By testing these predictions in two longitudinal samples of caregiver-child dyads, we explored alignment among language users whose linguistic representations we might expect to be more or less fragile — whether because of age or an early insult to the brain.

With respect to the basic premises of the Interactive Alignment Model, we found inconsistent support. The model—and related priming accounts—predicts that levels of linguistic alignment should be correlated both *between* interlocutors, and *within* individuals. There is no reason to expect these predictions to differ for children versus for caregivers, and indeed, we see high intercorrelations among levels of linguistic alignment within individuals in both children and caregivers, albeit at slightly different magnitudes. That correlations among *caregivers'* levels of linguistic alignment were higher than children's is consistent with the idea that the strength of an interlocutor's linguistic representations will affect the degree to which activation at one level 'percolates' to others.

Interestingly, alignment between interlocutors showed distinct patterns of correlation based on level of linguistic structure and developmental time. Lexical alignment—the amount that caregivers and children tended to re-used each other's words, relative to other dyads—was inconsistently (positively) correlated between interlocutors, while semantic alignment was robustly so. Contrary to the model's and our own predictions, degree of syntactic alignment was *negatively* correlated between caregivers and their children. Exploring whether this finding generalizes from caregiver-child interaction to adult dialogues will be critical to understanding whether it is a consequence of children and adults' differential representations, or an observation about conversation generally that merits investigation.

Our ability to explore these questions was made possible by a new approach to quantifying syntactic alignment, which compares features of hierarchically structured representations of utterances, rather than 'flat' representations of the words that comprise them. We view this as an innovation in the cognitive validity of our measurement of linguistic alignment, and note that it boasts the additional benefit of dissociating our measures of alignment across different levels of linguistic representation, making comparisons between levels more meaningful.

Conclusion

Ultimately, despite ourselves finding inconsistent evidence for the connection between linguistic alignment and formal metrics of linguistic maturity (*i.e.,* PPVT), our hope with this work is to pave the way for future research into the mechanisms by which verbal interaction makes the learning of complex linguistic structure possible.

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References

Bock, J. K. (1986). Syntactic persistence in language production. *Cognitive psychology*, *18*(3), 355–387.

Denby, J., & Yurovsky, D. (2019). Parents' linguistic alignment predicts children's language development. In *Cogsci* (pp. 1627–1632).

Dunn, L. M., & Dunn, D. M. (2007). *PPVT–4: Peabody picture vocabulary test*. Minneapolis, MN: Pearson Assessments.

Foushee, R., Byrne, D., Casillas, M., & Goldin-Meadow, S. (2021). *Differential impacts of linguistic alignment across caregiver-child dyads and levels of linguistic structure.* CUNY.

Fusaroli, R., Weed, E., Fein, D., & Naigles, L. (2021). Caregiver linguistic alignment to autistic and typically developing children.

Goldin-Meadow, S., Levine, S. C., Hedges, L. V., Huttenlocher, J., Raudenbush, S. W., & Small, S. L. (2014). New evidence about language and cognitive development based on a longitudinal study: hypotheses for intervention. *American Psychologist*, *69*(6), 588.

Goldstein, M. H., King, A. P., & West, M. J. (2003). Social interaction shapes babbling: Testing parallels between birdsong and speech. *Proceedings of the National Academy of Sciences*, *100*(13), 8030–8035.

Honnibal, M., & Montani, I. (2021). *SpaCy 3: Natural language understanding with bloom embeddings, convolutional neural networks and incremental parsing.* (To appear)

Kidd, E. (2012). Individual differences in syntactic priming in language acquisition. *Applied Psycholinguistics*, *33*(2), 393–418. doi: 10.1017/S0142716411000415

Kitaev, N., Cao, S., & Klein, D. (2019, July). Multilingual constituency parsing with self-attention and pre-training. In *Proceedings of the 57th annual meeting of the association for computational linguistics* (pp. 3499–3505). Florence, Italy: Association for Computational Linguistics. Retrieved from `https://www.aclweb.org/anthology/P19-1340` doi: 10.18653/v1/P19-1340

Kitaev, N., & Klein, D. (2018, July). Constituency parsing with a self-attentive encoder. In *Proceedings of the 56th annual meeting of the association for computational linguistics (volume 1: Long papers)* (pp. 2676–2686). Melbourne, Australia: Association for Computational Linguistics. Retrieved from `https://www.aclweb.org/anthology/P18-1249` doi: 10.18653/v1/P18-1249

Misiek, T., Favre, B., & Fourtassi, A. (2020). Development of multi-level linguistic alignment in child-adult conversations. In *Proceedings of the workshop on cognitive modeling and computational linguistics* (pp. 54–58).

Pickering, M. J., & Garrod, S. (2004). Toward a mechanistic psychology of dialogue. *Behavioral and Brain Sciences*, *27*(02), 169–190. doi: 10.1017/s0140525x04000056

Savage, C., Lieven, E., Theakston, A., & Tomasello, M. (2006). Structural priming as implicit learning in language acquisition: The persistence of lexical and structural priming in 4-year-olds. *Language Learning and Development*, *2:1*, 27-49.

Yurovsky, D., Doyle, G., & Frank, M. C. (2016). Linguistic input is tuned to children's developmental level. In A. Papafragou, D. Grodner, D. Mirman, & J. C. Trueswell (Eds.), *Proceedings of the 38th annual meeting of the cognitive science society* (pp. 2093–2098). Austin, TX: Cognitive Science Society.