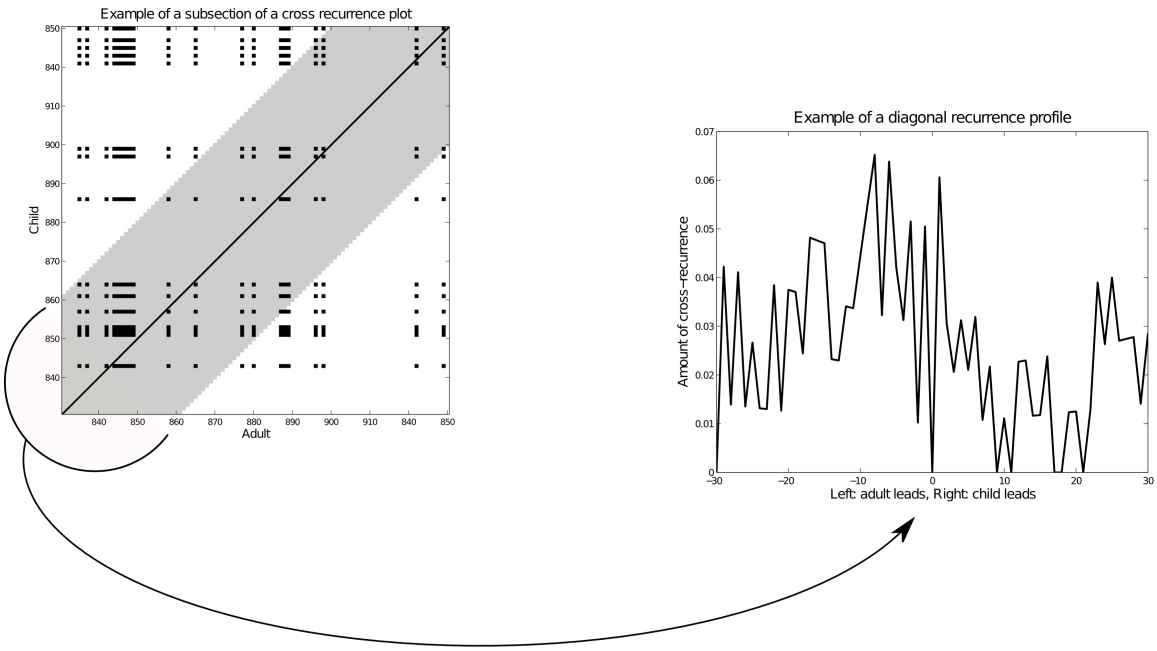
Cross-recurrence Supplemental Material

Cross recurrence analysis starts with the formation of a cross recurrence plot (Marwan, Romano, Thiel, & Kurths, 2007). The plot is essentially a matrix that shows the temporal relationship between all possible combinations of child vocalizations with adult vocalizations occurring anywhere within a recording. Each diagonal of this plot corresponds to a particular temporal relationship between the pair of child and adult vocalizations. By finding the proportion of points along each diagonal that are occupied, a diagonal cross recurrence profile (DCRP) can be created (Dale, Warlaumont, & Richardson, 2011). Note that the DCRPs in the present study included all child vocalizations whether or not they contained speech-related material.

Before performing the cross recurrence analyses, we divided the recording up into segments corresponding to any child or adult speaker segment or into 1 s bins during times when neither the child nor the adult was speaking. This step ensured that interactivity as measured using cross recurrence was not affected by the durations of the vocalizations themselves, only by the timing between child and adult vocalizations.

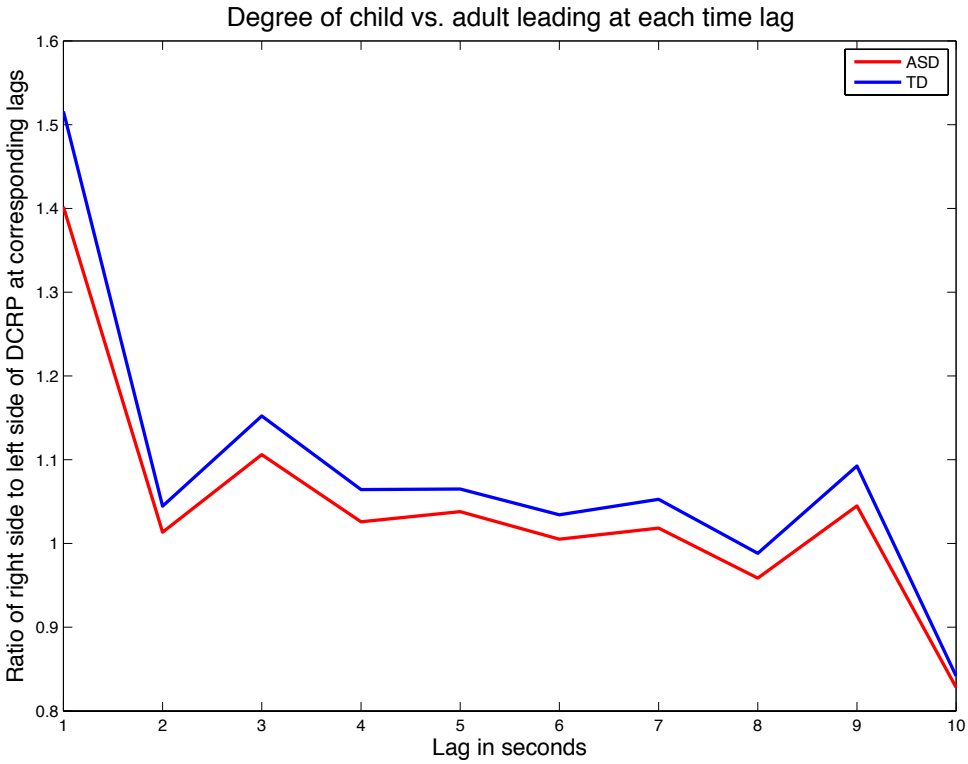
The figure below gives an example of a cross-recurrence plot and illustrates how the diagonal cross recurrence profile (DCRP) is computed. A cell in the cross recurrence plot is considered occupied (marked black in the example shown in the figure) if there is a child segment at the time corresponding to the cell's y-coordinate and an adult segment at the time corresponding to the cell's x-coordinate. Otherwise the cell is considered unoccupied (marked white in the figure).



Recurrence plot for a 200 s section of a recording (left) and the associated diagonal cross recurrence profile (DCRP) (right).

Filled cells on the diagonal that runs from the origin to the final event represent pairs of child and adult vocalizations that occurred at the same time. Since the speaker labels in the present study are mutually exclusive, there were never any points on this central diagonal. Filled cells above and left of the central diagonal represent pairs of child and adult vocalizations where the child's vocalization followed the adult's, whereas filled cells in the bottom right represent pairings where the child led the adult. Each diagonal running from the bottom left to the top right represents pairings with the same lag relationship. Adding up the filled points along each diagonal and dividing by that diagonal's length gives the height (the y-axis value) for the lag (the x-axis value) in the diagonal cross recurrence profile (DCRP) (Dale et al., 2011). In the physical sciences,

diagonal recurrence profiles have been referred to as recurrence probabilities or recurrence spectra (Marwan et al., 2007). The overall height of this profile indicates the level of interactivity within the maximum and minimum lags on the plot. The height of the right side of the plot indicates the amount of child leading and the height of the left side indicates the amount of adult leading. Thus, the ratio of the right side to the left side provides a measure of the degree to which there was child leading vs. adult leading.



The ratio of child leading vs. adult leading at each time lag for the TD and ASD groups in the matched subsample. See Figure 5 in the main text to view the DCRPs on which this figure is based. Note that our statistical analyses to test for significant differences across groups did not analyze right side to left side ratio individually for each lag but instead analyzed the overall right side vs. overall left side.

It can be observed that the average DCRPs in Figure 5 of the main text have a "zig-zag" structure to them. We hypothesize that this pattern reflects conversational or proto-conversational turn-taking between the child and adults. Confirming this explanation would require further, more in-depth analyses.

References

Dale, R., Warlaumont. A. S., & Richardson, D. C. (2011). Nominal cross recurrence as a generalized lag sequential analysis for behavioral streams. *International Journal of Bifurcation and Chaos*, *21*(4), 1153–1161. doi:10.1142/S0218127411028970

Marwan, N., Romano, M. C., Thiel, M., & Kurths, J. (2007). Recurrence plots for the analysis of complex systems. *Physics Reports*, *438*(5–6), 237–329. doi:10.1016/j.physrep.2006.11.001