Supplementary Information

Eye contact marks the rise and fall of shared attention in conversation

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Calculating the fluctuations of synchrony around eye contact at a range of timescales

We chose to look at the fluctuations of pupillary synchrony in the nine seconds surrounding the onsets and offsets of eye contact. This choice was motivated by first plotting the fluctuations of synchrony around eye contact at a range of time series lengths, and noting that regardless of length, a fluctuation of around nine seconds surrounding eye contact emerged. Figure 1 illustrates this effect, depicting synchrony time series surrounding eye contact at three different time series lengths.

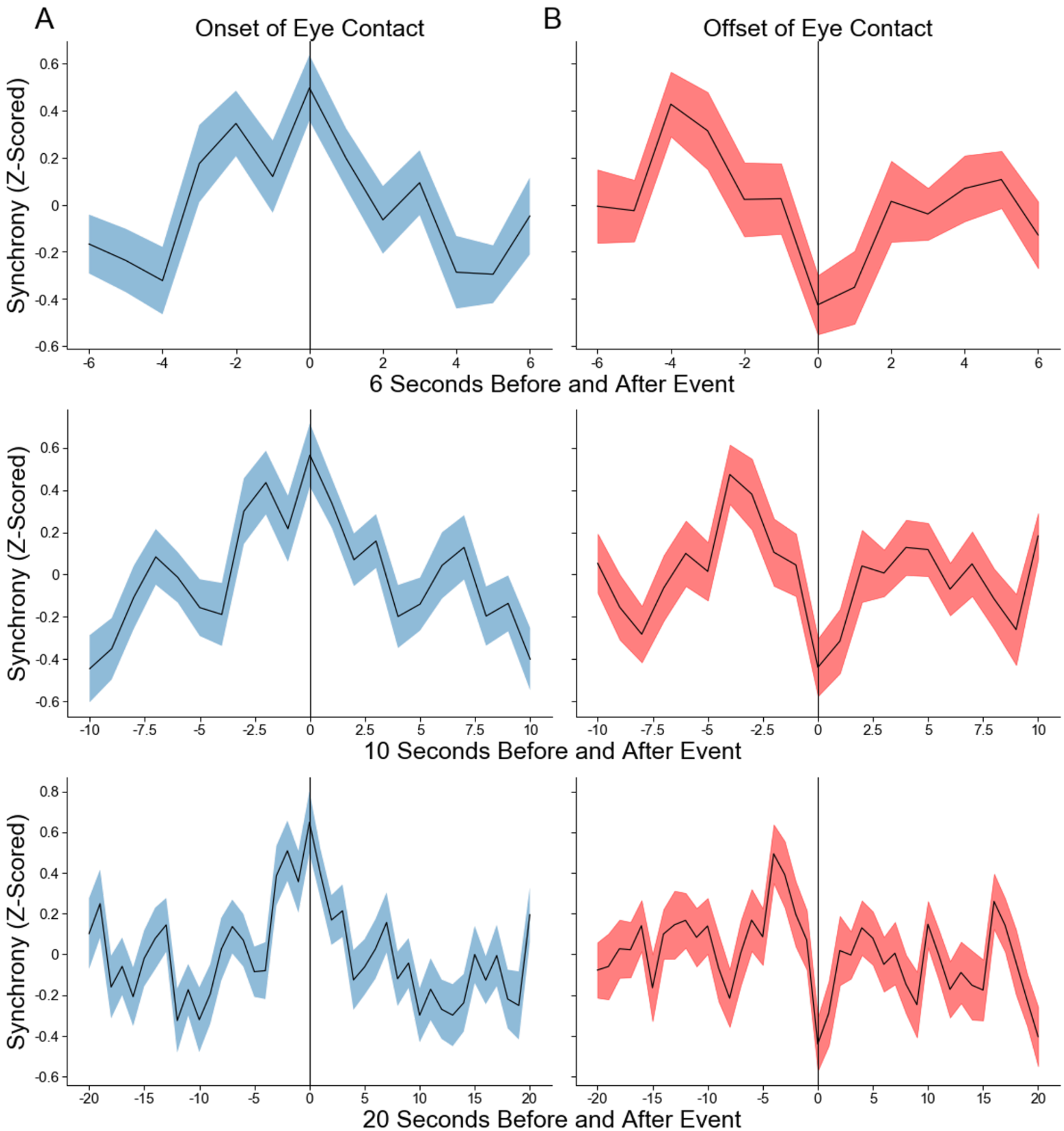

Figure 1. Synchrony curves surrounding the **A)** onset and **B)** offset of eye contact at a range of timescales. Regardless of the length of time used to compute each synchrony curve, we found that a nine-second parabolic fluctuation around the onset and offset of eye contact emerged.

Controlling for naturalistic data issues in event-related analysis

Each dyad had a unique time series of eye contact corresponding to their natural behavior during their conversation. Because of this, our eye contact "events" were collected without many controls that are often present in event-related analyses of pupillometry data. Specifically, eye contact events were unevenly spaced and lasted for different lengths of time. Because of this, we also conducted an analysis that restricted which instances of eye contact we accepted in order to mimic the controls generally placed on event-related data.

First, we addressed the fact that eye contact events were unevenly spaced, and that subjects had different numbers of events. Unevenly spaced trials could cause issues when, for example, dyads made eye contact, broke it, and then made it again a second later. In our original analysis, these two instances of eye contact would have corresponding synchrony time series that overlapped with one another, but would both be included in the analysis. Different numbers of events could cause issues if a dyad did not make very much eye contact, leading to a highly variable and therefore potentially unreliable average synchrony time series. For this analysis, we addressed these issues by 1) including only those instances of eye contact that were spaced at least four seconds apart (to avoid overlap), and 2) including only those subjects who had at least 30 of these moments of eye contact. Consistent with the results reported in the main text that used all the data, a quadratic contrast was the best fit for dyads' eye contact onset synchrony curves (β = -0.47, t = -2.88, CI = -0.8 - -0.15, $p = 0.004$) and for dyads' eye contact offset synchrony curves (β = 0.59, t = 3.65, CI = 0.27 - 0.91, $p < 0.001$; figure 2a & 2b).

We chose 30 trials as our minimum because it was the most stringent threshold that still retained at least two-thirds of dyads. However, to ensure our result was not due to an arbitrary threshold choice, we computed synchrony curves at a range of trial minimums (20-45) and found that, regardless of the threshold, the results were consistent (for onset, β ranged from -0.84 to -0.41, t ranged from -3.57 to -2.88, p ranged from 0.0004 to 0.02; for offset, β ranged from 0.42 to 1.3, t ranged from 2.02 to 4.89, p ranged from < 0.0001 to 0.04). Synchrony values for the full range of minimum trial thresholds at the onset and offset of eye contact are plotted in figure 2c & 2d.

Figure 2. Analysis plots limited to data in which eye contact events were spaced >4 seconds. **A)** Time series of synchrony in the four seconds leading up to and following the onset and **B)** offset of mutual gaze. **C)** Line graph depicting average synchrony values at the onset and **D)** offset of eye contact at a range of minimum trial thresholds. All error bars plotted depict standard error. Our original result that eye contact peaks at the onset of eye contact and declines until the offset of eye contact was robust to these additional controls.

Comparing eye-contact effects on synchrony at the end of conversation turns vs. during conversation turns

Turn-taking is a necessary feature of conversation, and one that naturally requires the introduction of new individual contributions. Because past research has found that eye contact often occurs at the end of turns (Kendon, 1967; Rutter et al., 1978), we wondered whether the effects of eye contact observed here were peculiar to the end of turns. We determined that an instance of eye contact occurred between conversation turns if the onset of eye contact began a maximum of one second prior to the start of the turn, or ended at a maximum of one second following the end of the turn. We first compared the number of instances of eye contact during dyads' conversations that occurred at the end of a conversational turn ($M = 63.74$, $SD = 27.76$) vs during a conversational turn ($M = 33.36$, $SD = 14.91$) using a paired samples t-test. Consistent with previous literature, we found that dyads made more eye contact at the end of turns than during turns ($t(46) = 7.82$, $p < 0.001$). Across all dyads, eye contact occurred at the end of a conversation turn 64.8% of the time, and during a conversation turn 35.2% of the time.

To compare pupillary synchrony curves around eye contact occurring during vs between conversation turns, we computed two separate curves for the onsets of eye contact that fell into these two groups (a visualization of these two curves can be found in figure 3). To statistically determine whether these two groups of eye contact differed from one another, we ran paired two-sided t-tests at each of the nine points along the synchrony curves. None of these t-tests were significant ($t(46)$ ranged from -1.8 - 1.52, p ranged from 0.07 to 0.94), suggesting that there is no difference in pupillary synchrony between instances of eye contact occurring within conversation turns versus between conversation turns.

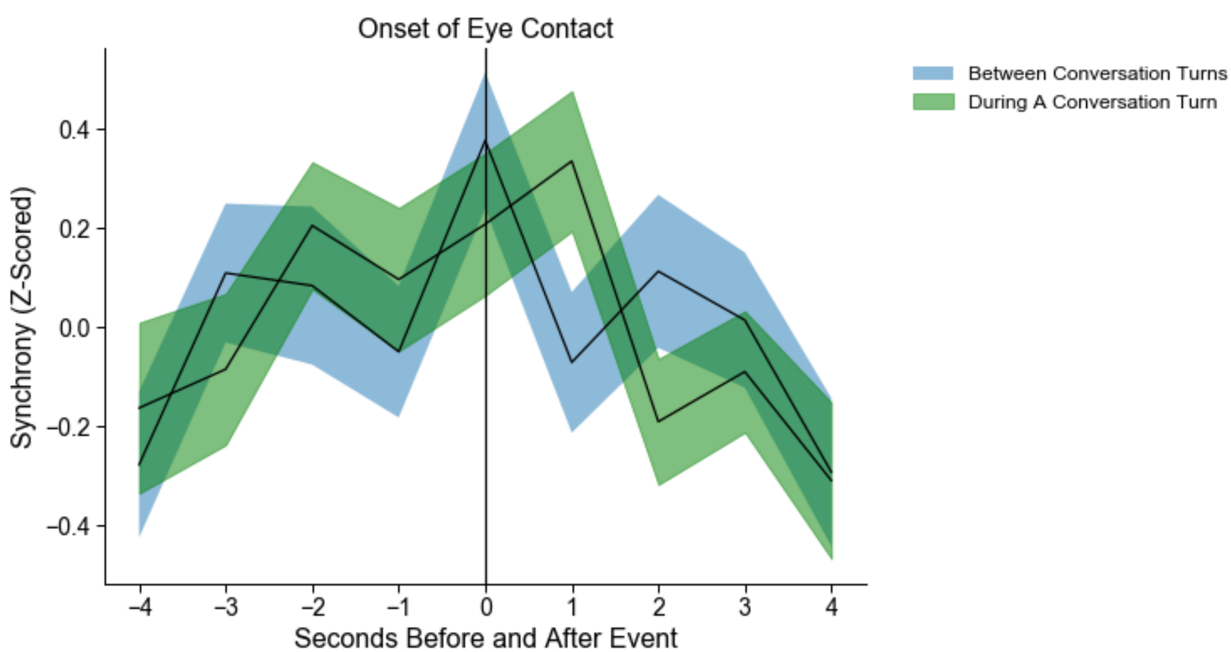

Figure 3. Visualization of synchrony at the onset of eye contact occurring within a conversation turn (standard error plotted in green) and between conversation turns (standard error plotted in blue). These two synchrony curves did not significantly differ from one another.

Permutation testing to verify the relationship between eye contact, synchrony, and conversational engagement

We found that eye contact and synchrony were significantly and positively linked to dyads' mean reported conversational engagement throughout the conversation. Further, we found that eye contact marginally moderated these effects such that, when dyads *were not* making eye contact, synchrony and engagement were positively related, but when dyads *were* making eye contact, this positive relationship was reversed. Because these effects were computed on continuous data sampled at 1Hz, our effect sizes for these main effects and interactions were small (eye contact main effect $\beta = 0.028$; synchrony main effect $\beta = 0.012$; interaction effect $\beta = -0.017$). To further test these relationships against chance, we permuted our data within and between subjects 5000 times and compared our true effects to null distributions created by those permutations. For these tests, within-subjects permutations consisted of shuffling the eye contact and synchrony time series for each dyad and computing the relationship between these shuffled time series and dyads' mean engagement. Between-subjects permutations consisted of shuffling fully intact eye contact and synchrony time series between different dyads (e.g. synchrony from dyad A and eye contact from dyad B is assigned to dyad C) and computing the relationship with engagement for these pseudo-dyads.

Eye Contact Main Effect

The relationship between eye contact and reported engagement (true $\beta = 0.028$, $p = 0.006$) was robust to both within-subjects ($p = 0.002$) and between-subjects ($p = 0.02$) permutation tests (figure 4A). This suggests that eye contact is a robust predictor of conversational engagement, above and beyond random variation in the eye contact time series and in a way that is specific to the individual structure of dyads' conversations. That we found this effect to be robust to a between-subjects permutation test suggests that dyads are not merely adhering to global conversation norms when employing eye contact, but making it at moments that served to increase engagement in their unique conversations.

Pupillary Synchrony Main Effect

The relationship between pupillary synchrony and reported engagement (true $\beta = 0.012$, $p = 0.05$) was robust to a within-subjects permutation test ($p = 0.02$), suggesting that pupillary synchrony is a robust predictor of conversational engagement above and beyond random variation in the synchrony time series. However, this effect was not robust to a between-subjects permutation test ($p = 0.56$; figure 4B). The lack of a between-subjects effect was due, at least in part, to a linear trend across dyads to become both more engaged and more synchronous over the course of the conversation. This suggests that, as dyads conversed, they increased shared attention which corresponded to a similar increase in reported engagement.

Interaction between Eye Contact and Pupillary Synchrony on Engagement

The marginal interaction between pupillary synchrony and eye contact on reported engagement (true $\beta = -0.017$, $p = 0.08$) was robust to a within-subjects permutation test ($p = 0.04$), suggesting that this interaction, while marginal, predicted conversational engagement above and beyond random variation in synchrony and eye contact time series. However, this effect was not robust to a between-subjects permutation test ($p = 0.12$; figure 4C) due, at least in part, to pupillary synchrony and reported engagement being correlated across all dyads. Thus, although pupillary synchrony and engagement are inversely correlated *during* eye contact, outside of these moments, pupillary synchrony and reported engagement increase together over the course of the conversation.

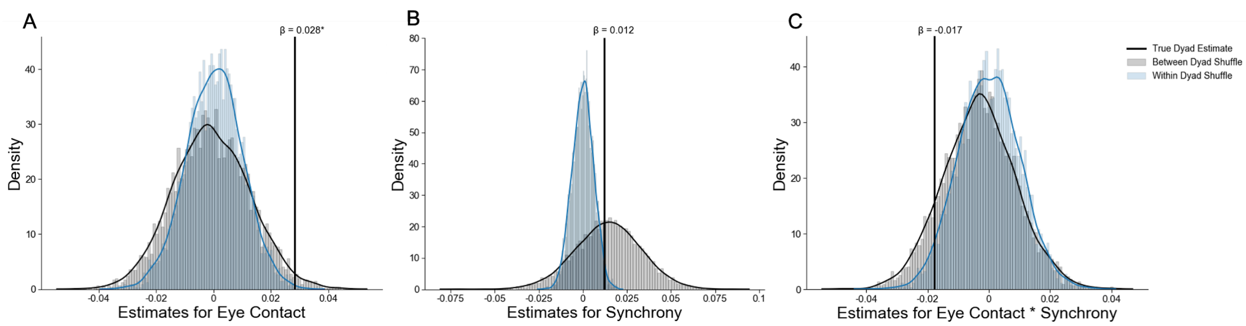

Figure 4. Results of both within- and between-subjects permutation tests testing **A)** the positive relationship between eye contact and reported engagement, **B)** the positive relationship between pupillary synchrony and reported engagement, and **C)** the interaction between eye contact and synchrony on reported engagement against null-distributions created by shuffling eye contact and synchrony time series 5000 times both within- and between- dyads. The relationship between eye contact and engagement was robust to both within- and between- subjects permutation tests. The relationship between pupillary synchrony and engagement and the interaction between eye contact and pupillary synchrony on engagement were robust to within-subjects permutation tests. However, we found that global increases in both shared attention and mean reported engagement over the course of dyads' conversations produced non-significant between-subjects permutation tests for both the relationship between pupillary synchrony and engagement and the interaction between synchrony and eye contact on engagement.

References

Kendon, A. (1967). Some functions of gaze-direction in social interaction. In *Acta Psychologica* (Vol. 26, pp. 22–63). https://doi.org/10.1016/0001-6918(67)90005-4

Rutter, D. R., Stephenson, G. M., Ayling, K., & White, P. A. (1978). The timing of Looks in dyadic conversation. *The British Journal of Social and Clinical Psychology*, *17*(1), 17–21.